

Enhancing climate change mitigation in protected areas

Risa B. Smith, Anouska Kinahan, Toni Lyn Morelli, Clarissa Samson, Shane Orchard, Megan Critchley, Ben Lucas, Zhilang Zhu, Neal Pastick, Aminur Rahman, Olga Laiza Kupika, Jon Day, Tim Healy, Sara Weiskopf, Maria Isabel Arce-Plata, Jaime Burbano-Girón, Kadambari Devarajan, Shannon Dickey, Elizabeth A. Fulton, Hamed Gholizadeh, Tobi A. Oke, Gretta Pecl, Darren J. Ranco, Annika Keely, Madeleine Ankenman, Thomas P. Mommsen.



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asiaprotectedareaspartnership.org

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Foreword

The World Commission on Protected Areas (WPCA) has long recognised the importance of biodiversity and climate change as dual crises that can only be effectively addressed by managing for both. It is this nexus that creates the imperative to include climate change mitigation into PCA management and policy – the subject of this technical report.

Many of the ecosystems most critical to address the biodiversity/climate change nexus are being degraded to the extent that they already, or in the near future, will not be able to provide the ecosystem services of capturing and storing greenhouse gases. This is true for forests, as a result of deforestation and degradation; wetlands, including lakes and peatlands, as a result of drainage, afforestation and fires; grasslands and savannas, as a result of fires, land-use change and overgrazing; and oceans and coasts, as a result of development, land-use change, climate change (including ocean-acidification) and loss of biodiversity.

Protected and conserved areas are the most effective solution to addressing the biodiversity/ climate change nexus and ensuring that natural ecosystems can continue their critical role of capturing and storing carbon. Second to protection is restoration, including ensuring the permanence of restored areas through PCA establishment and management. This technical report has been developed to facilitate the incorporation of climate change mitigation into PCA management.

I am pleased to present this new document, which will stand as an important addition to several recently released WCPA Technical Reports. It will also serve as background information for the Technical Note, *Enhancing climate change mitigation in protected and conserved areas:* A practical guide for managers and policy-makers.

Signed by Madhu Rao, Chair, IUCN WCPA



Coastal blue carbon ecosystem: mangrove forest on Siargao Island, Philippines. © Alexpunker / iStock.com

Executive summary

The importance of protected and conserved areas (PCAs) in biodiversity conservation is well-established; their importance for climate change mitigation and adaptation is becoming increasingly recognised. There is strong evidence that PCAs are the most effective Natural Climate Solution to leverage nature for climate change mitigation. Although specific numbers on the GHG emissions that PCAs can mitigate vary, there is general agreement that the role of PCAs is significant. For example, it has been estimated that:

- protecting 30% of land in strategic locations could safeguard 500 billion tonnes (Gt) of the carbon stored in vegetation and soils, and reduce the extinction risk of nearly 9 out of 10 threatened terrestrial species by 2030 (de Lamo et al., 2020);
- ii. 20% of the carbon emission reductions needed to achieve the Paris Agreement target could be delivered by protection of 30% of the oceans (Lubchenco, Haugan, & Pangestu, 2020; Stuchtey et al., 2023).

This report covers both terrestrial and marine PCAs. The audience is practitioners and policymakers who seek background information on the role of PCAs in climate change mitigation to:

- develop policies that enhance biodiversity and climate change simultaneously;
- · quantify the importance of PCAs as a mechanism to reduce GHG emissions in Nationally Determined Contributions (NDC) to the Paris Agreement;
- include the role of PCAs in climate change mitigation in National Biodiversity Strategies and Action Plans (NBSAPs) required by the Convention on Biological Diversity (CBD);
- quantify the climate change mitigation role of PCAs in funding applications.

This report contains nine chapters.

Chapter 1 provides the context for development of this report and the general framework used. Some of the particularities of coastal marine ecosystems versus terrestrial ecosystems that are important to keep in mind when measuring carbon fluxes also appear in Chapter I.

Chapter 2 identifies the underlying policy needed to incorporate climate change mitigation into PCA management and creation, including enabling international policy, regional and national frameworks and opportunities created by required updates to the Convention on Biological Diversity's National Biodiversity Strategies and Actions Plans (NBSAPs) and the Paris Agreement's Nationally Determined Contributions (NDCs).

Chapter 3 identifies the most promising ecosystems, both coastal marine and terrestrial, for enhancing carbon sequestration and protecting carbon reservoirs or stores. It provides the evidence that a focus on some ecosystems, such as primary forests, peatlands, coastal blue carbon (i.e. mangroves, salt marshes, seagrass meadows), grasslands and savannas, is more effective than focusing on all ecosystems.

Chapter 4 outlines the methodologies used to quantify carbon sequestration and carbon stores. It considers both the similarities and differences in measuring carbon in terrestrial PCAs and coastal MPAs and provides links to standardised methodologies, where they exist. The role of destructive sampling, spatial mapping products, satellite imagery, field measurements and models are also explained.

Chapter 5 outlines the common practices for measuring biodiversity, including field methods, remote sensing and ecological modelling. The chapter explains the strengths and weaknesses of different approaches in the context of the climate change/biodiversity nexus.

Chapter 6 brings to the forefront the tools that have been developed, in recent years, to overlay carbon-density and biodiversity. The chapter presents mapping tools for both terrestrial and coastal marine ecosystems and decision-support tools.

Chapter 7 provides the tools for planning restoration projects intended to enhance climate change mitigation. The authors provide some important considerations to enhance the usefulness of restoration, from the perspective of greenhouse gas emissions.

Chapter 8 identifies the available mechanisms for funding PCAs for both climate change and biodiversity. The chapter presents the pros and cons of market-based programmes and other methods for using climate funds to finance PCAs.

Chapter 9 provides a brief summary of future work that will facilitate the incorporation of climate change mitigation into PCA management and policy.

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Glossary of terms used

Biome. A biome "denotes a biotic community finding its expression at large geographic scales, shaped by climate factors" (Mucina, 2019).

Carbon (C). A chemical element which is present in many gases and compounds. The mass of a carbon atom is 12 and oxygen is 16, so the atomic mass of CO₂ is 44 (12+(16*2)=44); 1 kg of CO₂ can be expressed as 0.27 kg of C (12/44).

Carbon accounting. Carbon accounting comprises the recognition, the non-monetary and monetary evaluation and the monitoring of greenhouse gas emissions at all levels of the value chain and the recognition, evaluation and monitoring of the effects of these emissions on the carbon cycle of ecosystems (Stechemesser & Guenther, 2012).

Carbon density. The amount of carbon stored in an ecosystem measured as tC ha⁻¹ (or tonnes of carbon per hectare).

Carbon dioxide (CO₂). The most common GHG emitted by human activities, in terms of its total impact on global warming (Brander, 2012).

Carbon dioxide equivalent (CO,e). Describes GHGs in a common unit. For all GHGs it signifies the amount of CO_a which would have the equivalent global warming potential (Brander, 2012).

Carbon sequestration. The uptake of carbon containing substances, in particular carbon dioxide (CO₂), in terrestrial or marine reservoirs. Biological sequestration includes direct removal of CO₂ from the atmosphere through land-use change, afforestation, reforestation, revegetation, carbon storage in landfills, and practices that enhance soil carbon in agriculture (IPCC, 2014).

Carbon sink. A component of an ecosystem that absorbs more carbon from the atmosphere than it releases, for example, plants, soil, the ocean.

Carbon store. The carbon that is stored in ecosystems, as a result of sequestration, is referred to as a carbon reservoir or store.

Climate change mitigation. An anthropogenic intervention that reduces the sources or enhances the sinks of greenhouse gases (IPCC, 2021).

Coastal blue carbon (CBC). "CBC occupies the intertidal margins of shorelines worldwide, extending from the freshwater tidal rivers downstream to shallow coastal water that support emergent or submerged vascular plants. The presence of vascular plants distinguishes these coastal ecosystems from ocean blue carbon" (p.107, Section 3.4.1.1 Laffoley & Baxter, 2016).

Ecosystem. "An ecosystem is a region where a bubble of life is created by plants, animals and other organisms interacting with the weather, landscape, and other factors. Abiotic and biotic factors both exist in ecosystems" (Jain et al., 2025). The concept of an ecosystem can exist at different scales and always involves interactions (Jax, 2007).

Ecosystem-based management. "An environmental management approach that recognises the full array of interactions within an ecosystem, including humans, rather than considering single issues, species or ecosystem services in isolation" (Christensen et al., 1996).

Ecosystem integrity. The United Nations System of Environmental-Economic Accounting (SEEA-EA) defines ecosystem integrity as "...the ecosystem's capacity to maintain its characteristic composition, structure, functioning and self-organisation over time within a natural range of variability". Ecosystems with high integrity are typically more resilient (i.e. they are able to recover from perturbations such as natural disturbances or environmental change) (UN Statistical Commission, 2021). Ecological integrity is sometimes referred to as "ecosystem health", which is perhaps a more accessible term.

Ecosystem or ecological resilience. The capacity of ecosystems to cope with a hazardous event or trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure, while also maintaining the capacity for adaptation, learning and transformation (Pörtner et al., 2022).

Gender mainstreaming. Gender mainstreaming is a strategy towards realising gender equality, involving integration of a gender perspective into all aspects of policy development and evaluation (EIGQ, 2025).

Greenhouse gases (GHG). Any gas in the atmosphere that absorbs and re-emits heat. The main GHGs are water vapour, CO₂, methane (CH₄), nitrous oxide (N₂O) and ozone (Brander, 2012).

Natural Climate Solutions (NCS). NCS are deliberate human actions that protect, restore and improve management of forests, wetlands, grasslands, oceans and agricultural lands to mitigate climate change. NCS are synonymous with what the IPCC calls Agriculture, Forestry and Other Land Use (AFOLU) mitigation. Ellis and colleagues have articulated a set of principles that define NCS (Ellis et al., 2024). In some cases, NCS are used interchangeably with Nature-based Climate Solutions, although they are not exactly the same. NCS are a subset of NbCS (Beasley et al., 2019).

Nature-based Solutions (NbS). Defined by IUCN as "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (Cohen-Shacham et al., 2016). NbS Incorporates a broad set of actions that address a range of societal challenges beyond climate mitigation. They can have multiple outcomes with multiple metrics (Ellis et al., 2024).

Nature-based Climate Solutions (NbCS) embrace the power of nature to reduce the effects of and adapt to climate change all while supporting biodiversity. NbCS are broader than NCS as they include some activities in engineered ecosystems (e.g. macroalgae farming) that have moved away from their natural state (Ellis et al., 2024).

Negative emission. Net removal of CO₂ equivalents of GHG from the atmosphere (Don et al., 2024).

Novel ecosystem. An ecosystem in which the biological and/ or abiotic characteristics are outside historical ranges. Novel ecosystems are believed to have crossed a threshold in which restoration to an historical state is unlikely (Higgs et al., 2018; Hobbs et al., 2014).

Other Effective Area-based Conservation Measures (OECMs). Defined by the CBD as "other effective area-based conservation measures" (OECMs). An OECM is "a geographically defined area other than a protected area, which is governed and managed in

ways that achieve and sustain positive and sustained long-term outcomes for the in situ conservation of biodiversity" (CBD, 2018). Protected area. A clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature

with associated ecosystem services and cultural values. This IUCN definition includes six management categories and four governance types (Dudley, 2008).

Protected and conserved area (PCA). Refers to all forms of area-based protection, including Protected Areas as defined by IUCN categories I-VI, Other Effective Area-based Conservation Measures (OECMs) and different forms of governance such as Indigenous Protected and Conserved Areas (IPCAs), and Indigenous and Community Conserved Areas (ICCAs). It also refers to terrestrial protected areas and marine protected areas.

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Carbon-dense salt marsh on the coast of Virginia, USA.

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Herd of wildebeests and antelopes migrating on the savanna in Tanzania. © Janina Delissen / iStock.com



Chapter 1 Introduction

Risa B. Smith and Jon Day

1.1 Context

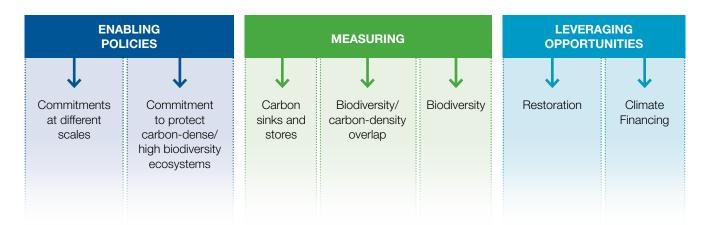
Climate change mitigation refers to an intervention, by people, that reduces the sources or enhances the sinks of greenhouse gases (GHGs) (IPCC, 2021). Mitigating climate change has become increasingly urgent: 2024 was 1.55° C $\pm 0.13^{\circ}$ C above the 1850–1900 average, the warmest year in the 175-year observational record. Other indicators of climate change continued to increase, such as sea surface temperature, sea ice loss, sea level rise and glacier loss, while greenhouse gasses emissions also rose (Copernicus Climate Change Service (C3S) & World Meteorological Organization (WMO), 2025; World Meteorological Organization (WMO), 2025). There is strong scientific consensus that attaining the Paris Agreement target to hold the rise in global average temperature to 2°C and strive for less than 1.5°C will require rapid and significant reductions in GHG emissions, supplemented by other climate change mitigation tools (IPCC, 2023). The creation and effective management of Protected and Conserved Areas (PCAs)1 are increasingly recognised as one of these tools. PCAs protect the ability of ecosystems to sequester carbon dioxide (CO₂) from the atmosphere, prevent the release of stored carbon, and over time may be important for the large-scale permanent removal of carbon CO_a from the atmosphere, depending on the composition of the PCA (Brunner, Hausfather, & Knutti, 2024; Cannizzo et al., 2024; Ellis, 2019; IPCC, 2022; Kapos et al., 2022; Wolf et al., 2021). In addition, PCAs contribute to the resilience of the natural world, essential to long-term maintenance of ecosystem function and services, including climate regulation (Dinerstein et al., 2019; Nabuurs et al., 2022; Pörtner et al., 2022; Rockström et al., 2017). A recent study estimated that global protected areas store 61.43 billion tonnes (Gt) of above-ground carbon – 9.65 Gt of which is attributed to their protected areas status. This additional carbon stored above ground in protected areas is roughly equivalent to one year of annual anthropogenic global fossil fuel emissions (Duncanson et al., 2023) and does not even include below-ground carbon storage, which often contains more stored carbon than above ground (see Chapter 4).

PCA managers and planners consistently identify the lack of specific tools as a barrier to incorporating climate change mitigation into their decision-making (Ankenman & Smith, 2025). This report is intended to fill that gap. It provides a resource for incorporating climate change mitigation into PCA management and planning. It supplements the volume on *Adapting to climate change: Guidance for protected areas managers and planners*, which provides a tool for incorporating Ecosystem-based Management, including climate change adaptation, in PCA management and planning (Gross et al., 2016).

Protected areas are generally created and managed for multiple values, including biodiversity conservation, cultural heritage, recreation, sustainable use of resources and other ecosystem services such as climate regulation and water regulation. Managing for multiple values is at the heart of effective protected areas management. Jung and colleagues (Jung et al., 2021) showed that protecting 30% of the Earth's land base would result in protection of most species, carbon and water. Nevertheless, this report is focused on how to incorporate one of these values – climate change mitigation – into protected areas creation and management. The focus on one value is not intended to diminish the importance of managing for multiple values. Rather, this report is intended to fill a gap on how climate change mitigation can be incorporated into PCA management, as one of many values.

Figure 1.1 Organisational framework for this report. The report is organised around the elements required to incorporate climate change mitigation into PCA management and policy. Enabling policies are discussed in chapters 2 and 3; methodologies for measurement are discussed in chapters 4, 5 and 6; opportunities to obtain co-benefits for biodiversity and climate change mitigation are discussed in chapters 7 and 8.

1.2 Framework



^{1.} In this report we use the term Protected and Conserved Areas (PCAs) to refer to all types of area-based protected areas, whether they be protected as defined by IUCN categories I–VI, Other Effective Area-based Conservation Measures (OECMs), Indigenous Protected and Conserved Areas (IPCAs) or Indigenous and Community Conserved Areas (ICCAs).

1.3 Report highlights

✓ An underlying policy framework that recognises the climate change mitigation potential of PCAs and makes commitments to create, enhance and/or manage PCAs with this potential in mind is necessary (see Chapter 2).

A policy framework can enable and help finance climate change mitigation measures in PCAs, support policies that enhance the longevity of carbon sinks and stores and recognise the rights, sovereignty and title of Indigenous peoples.

✓ Ecosystems with the most potential for carbon sequestration and long-term storage need to be identified so that the management of existing PCAs, and the creation of new ones, can focus on these ecosystems (see Chapter 3).

In general, oceans, forests, grasslands/savannas, peatlands and coastal vegetated areas (coastal blue carbon) are the most important natural ecosystems for GHG emissions reduction, although other ecosystems can be locally important. PCAs are managed for multiple values. Not all PCAs will be candidates for the incorporation of climate change mitigation.

Methodologies for measuring carbon in natural ecosystems are already well established (see Chapter 4).

Two types of carbon measurement are required to support the recognition and incorporation of natural ecosystems in policy and financing for climate change mitigation: i) the quantity of carbon that an ecosystem or a PCA can sequester from the atmosphere; ii) the ability of the ecosystem or PCA to store the carbon sequestered for long periods (i.e. hundreds or even thousands of years).

✓ Publicly available datasets, validation techniques, models and high-resolution imagery for many ecosystems are generally available. In some cases, increasing accessibility to carbon-related information would facilitate assessing the climate change mitigation potential of PCAs, especially if it is available at a relevant scale for individual PCAs (see Chapters 4 and 6).

Global data that is compiled from local, sub-national or national data is useful for analysis of carbon in PCAs, especially if it can be disaggregated. The type of data required to demonstrate or document the climate mitigation contributions of natural ecosystems and PCAs depends on the scale and purpose of the analysis. If the purpose is to obtain carbon credits or support reductions in GHG emissions in Nationally Determined Contributions (NDCs) to the Paris Agreement, internationally agreed on methodologies have to be followed. More fundamentally, there is a need to develop reliable and robust methods for a range of different ecosystem types in their various local contexts, and it is desirable that such methods are also comparable, cost-effective and affordable for stakeholders. The aggregation of data from finer scales (e.g. sub-national ecosystem types or individual PCAs) will also become increasingly important for more accurate climate change mitigation analyses, including the contributions of PCAs to GHG emissions reduction.

✔ Build capacity amongst protected areas managers and policymakers to use available tools and models (see Chapter 2 and 3).

A survey conducted prior to developing this report identified that most protected areas managers did not feel competent to incorporate climate change mitigation into their management plans (Ankenman & Smith, 2025). The development of training modules geared at the level of PCA manager is foundational to expanding assessments of the carbon content and GHG emissions reduction potential of PCAs.

✓ Terrestrial PCAs and coastal MPAs are both important contributors to reductions in GHG emissions (see Chapters 1, 3 and 4).

Often methods to account for climate change mitigation in coastal marine and terrestrial ecosystems are provided in different documents, inhibiting comparisons. In this report the similarities and differences of terrestrial and marine PCAs are discussed with the aim of improving understanding of the respective roles of terrestrial and marine protected areas.

✓ Although biodiversity is always measured in PCAs, incorporating carbon measurements should be done in a way that ensures climate change mitigation actions benefit biodiversity conservation and do not cause unintended negative consequences (see Chapter 5, 7 and 8).

Employing Natural Climate Solutions ¹ to reduce GHG emissions is generally positive for biodiversity, although some climate change mitigation actions can negatively impact biodiversity. For example, forest management practices that increase the diversity of plant species have been shown to also increase sequestration of atmospheric CO₂. On the other hand, forest management practices that result in afforestation where forests were not previously present can result in an increase in sequestration of atmospheric CO₂, but have negative impact on biodiversity (i.e. reducing the composition, structure and function of the ecosystem that has been forested). Careful consideration has to be given to impacts on both GHG emissions reduction and biodiversity.

Restoration of damaged ecosystems in PCAs has a role to play in climate change mitigation. Realising the full climate mitigation benefits of restoration outside PCAs may require protecting restored ecosystems to ensure the longevity of restored carbon (see Chapter 7).

Although protection of healthy but at-risk high carbon ecosystems has the most immediate benefits for the global climate and biodiversity, restoring degraded ecosystems makes a significant contribution to climate change mitigation over the longer term. The most important aspects of restoration, from the viewpoint of climate change mitigation, are: i) the restoration of degraded ecosystems within PCAs; and ii) the restoration of degraded ecosystems outside PCAs, including protecting restored ecosystems to ensure long-term carbon sequestration and storage.

Incorporating climate change mitigation into PCA management and/or creation provides opportunities to leverage climate financing for biodiversity. This can help bridge the gap between biodiversity financing and climate change financing (see Chapter 8).

The climate financing sector has many tools that are appropriate for funding new PCAs and managing existing PCAs for climate change mitigation. However, serious pitfalls related to the credibility of carbon measurements have been identified in the literature. Avoiding these pitfalls is critical to the return on investments in climate change mitigation. Conversely, there are also many opportunities to align the business case for climate finance with PCA establishment or management improvements using either existing or new tools and approaches. Identifying and facilitating these alignments through climate finance is a key strategy for implementing Natural Climate Solutions.

Carbon-dense rainforest in Queensland, Australia. © AustralianCamera / Shutterstock.com



1. In this report the term 'Natural Climate Solutions' (NCSs) is used to refer to human actions that make use of the properties of natural ecosystems to protect, restore and improve management of forests, wetlands, grasslands, oceans and agricultural land to mitigate and adapt to climate change. NCSs are often used interchangeably with the more general term 'Nature-based Climate Solutions' (NbCSs). NbCSs are similar, but they can make use of engineered ecosystems in addition to natural ecosystems. See also glossary of terms used.

1.4 Comparing coastal marine and terrestrial realms

This report addresses both terrestrial protected areas and coastal marine protected areas (MPAs). It does not address open ocean MPAs. There is strong evidence supporting the importance of coastal marine protected areas as a climate change mitigation tool, while the role of open ocean MPAs is less clear (Howard et al., 2023). Chapter 4 provides a comparison for measuring carbon stores and sequestration in terrestrial and coastal blue carbon ecosystems. While there are many similarities, important differences need to be taken into account.

1.4.1 Absorption of atmospheric CO,

Terrestrial plants take up atmospheric CO_2 directly and turn it into organic carbon, through the process of photosynthesis. In marine systems, the uptake of atmospheric CO_2 is more complex and involves three pathways: i) the biological carbon pump, in which marine phytoplankton and algae absorb and transform CO_2 through photosynthesis and deposit it on the seabed, much like in terrestrial systems; ii) the physically dissolved carbon pump, in which atmospheric CO_2 is dissolved directly into seawater; iii) the marine carbonate pump, in which carbon is absorbed, transformed and released by shellfish, coral reefs and other marine organisms (McLeod et al., 2011; Tang et al., 2018). In coastal blue carbon ecosystems most atmospheric CO_2 is processed through the biological carbon pump, similar to terrestrial ecosystems. That is, plants, phytoplankton, macrophytes, algae and calciferous organisms, in salt marshes, mangroves and seagrass ecosystems, directly take up atmospheric CO_2 .

However, it is important to note that absorption and release of CO_2 by seawater is controlled by the partial pressure of atmospheric CO_2 and the partial pressure of CO_2 dissolved in sea water: "When the partial pressure in the atmosphere is greater than (less than) the partial pressure of dissolved seawater, there is a net influx (efflux) of CO_2 from the atmosphere" (Hori, Bayne, & Kuwae, 2019). This mechanism creates uncertainty in the role of marine ecosystems in atmospheric CO_2 concentrations because if atmospheric CO_2 concentrations decline, it could create a feedback loop in which oceanic CO_2 is released back into the atmosphere.

1.4.2 Spatial extent

While the spatial extent of the oceans is far greater than all land masses combined, the spatial extent of coastal blue carbon ecosystems is significantly less than land masses. Even though coastal blue carbon has a carbon density equivalent or more than some of the important terrestrial ecosystems, the sheer extent of terrestrial ecosystems like forests makes them a more important carbon sink than coastal blue carbon. Although this report does not address the open ocean, it is equally true that the sheer extent of the open ocean magnifies its global importance for climate change mitigation.

Mangrove forests, like this one in Cambodia, are important for the vast amounts of carbon they store and their high biodiversity value. © f9photos / iStock.com



1.4.3 Ownership

The ownership of terrestrial systems varies widely, including government, private, and Indigenous ownership. In the coastal marine realm, ownership is less clear. Often governments are responsible, recently some sea claims by Indigenous peoples have been recognised, and private ownership is rare. This influences management approaches for terrestrial PCAs and coastal MPAs.

1.4.4 Ecological considerations

Ecosystem boundaries on land can be distinct and identifiable, although even on land ecosystem boundaries can change as a result of many factors including those accelerated by climate change and the spatial scale under consideration. In coastal marine areas, ecosystem boundaries are more transitional, as some ecosystems can disappear and appear again from year to year. As well, climate change effects, such as sealevel rise, deoxygenation and acidification, can have profound effects on coastal MPAs. It is important to note that climate change effects on terrestrial ecosystems are also profound (i.e. warming, drought, floods, climate-exacerbated wildfires).

1.4.5 Longevity

If undisturbed, the carbon stored in coastal marine ecosystems can be maintained for millennia, as the rate of decomposition is hindered by the anaerobic conditions. In some terrestrial ecosystems, the longevity of stored carbon can be comparable to coastal marine ecosystems, especially if below-ground conditions tend to be anaerobic, as in peatlands. However, in most terrestrial ecosystems processes of decomposition release carbon at a faster rate than in the marine environment.

1.4.6 Abiotic influences

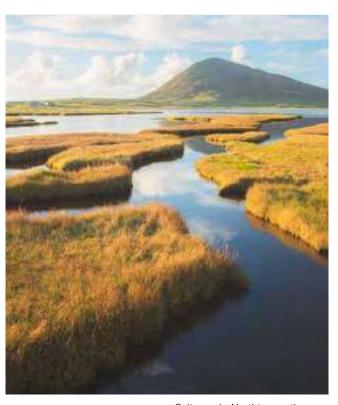
Although a variety of abiotic influences affect both terrestrial and marine ecosystems, in the marine realm underwater light penetration, salinity and the effects of tides are additional influences (Serrano et al., 2019).

1.4.7 Coastal squeeze

A combination of sea-level rise and physical barriers, such as infrastructure, can prevent the landward migration of ecosystems as the coastline moves inland. This exposes coastal blue carbon ecosystems to further degradation, including the loss of primary producers that sequester carbon and potential indirect disturbance of the substrate where most of the carbon is stored (Martínez et al., 2014; Serrano et al., 2019).

1.4.8 Carbon source

In terrestrial systems, carbon is usually produced and deposited in the same location (i.e. the carbon is autochthonous). In coastal blue carbon ecosystems, the carbon can be produced and deposited in the same location – which is usually the case for mangroves and salt marshes – or it can be produced in one location and deposited in another (i.e. allochthonous) – which is the case for about 50% of the carbon stored in seagrass meadows. This makes it difficult to accurately estimate the carbon sequestration potential of coastal blue carbon ecosystems when the fate of the sequestered carbon is unknown (Fest, Swearer, & Arndt, 2022; Howard et al., 2014).



Salt marsh, Northton on the Isle of Lewis and Harris, Outer Hebrides, Scotland.

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Sediments in seagrass beds, like this one, store carbon for long periods if undisturbed. © divedog / Shutterstock.com

Chapter 2

Policy to support climate change mitigation in protected areas

Anouska Kinahan, Olga Laiza Kupika, Toni, L. Morelli, Tim Healy and Annika Keeley

2.1 Chapter highlights

Ensuring the right policies to support the role of Protected and Conserved Areas (PCAs) as a climate change mitigation tool is a foundational step. This requires:

- ✓ Identifying policy entry points at different scales (regional, national, sub-national);
- ✓ Strengthening multisectoral collaboration and stakeholder engagement;
- ✓ Incorporating Natural Climate Solutions and/or Ecosystem-based Management into national targets for both National Biodiversity Strategies and Action Plans (NBSAPs) to the UN Convention on Biological Diversity and Nationally Determined Contributions (NDCs) to the Paris Agreement;
- ✓ Identifying and prioritising carbon-dense/high-biodiversity areas for protection;
- ✓ Having mechanisms to ensure the longevity of all types of PCAs, but particularly if they are to have a meaningful role in climate change mitigation;
- ✓ Increasing PCA connectivity;
- ✓ Increasing ecosystem integrity and resilience of PCAs;
- Recognising the rights and title of Indigenous peoples and the reality that most of the world's remaining intact terrestrial areas have been under the stewardship of Indigenous peoples around the world.

2.2 Introduction

Biodiversity loss and climate change are linked global crises requiring rapid policy responses and significant financial investments (also see Chapter 6: Integrating hotspots for carbondensity and biodiversity and Chapter 8: Financing protected areas for climate change mitigation). The scientific evidence supports policy initiatives that link biodiversity targets, agreed through the Kunming-Montreal Global Biodiversity Framework (CBD, 2022), and climate change targets, agreed to through the Paris Agreement to the United Nations Framework Convention on Climate Change (UNFCCC, 2015). It is the integration of these two global policies that provides the context for incorporating climate change mitigation into PCA management (Mori et al., 2024). Supporting policies at regional, national and sub-national levels stem from these two global frameworks and call for the integration of biodiversity and climate change policies in a more holistic manner (CBD, 2020; IPBES, 2019; Pettorelli et al., 2021; Turney, Ausseil, & Broadhurst, 2020; UNFCCC, 2019, 2023b).

2.3 Enabling international policy

2.3.1 The Paris Agreement

The Paris Agreement (2015) is a legally binding international treaty to limit global warming, negotiated under the United Nations Framework Convention on Climate Change (UNFCCC) (UNFCCC, 2015). It came into force in November 2015. The Paris Agreement highlights the importance of protecting, conserving and restoring terrestrial and marine nature and ecosystems as sinks and reservoirs of greenhouse gases in order to achieve the long-term global goal of the UNFCCC. It also recognises the role of PCAs in climate change mitigation. During the 26th Conference of the Parties to the UNFCCC (COP26), in Glasgow, Scotland, for the first time, oceans were integrated into the areas of work (Lennan & Morgera, 2022; UNFCCC, 2023a). The need for a greater integration of nature protection into climate solutions was further solidified with the Sharm el-Sheikh Implementation Plan from COP 27 in Egypt (UNFCCC, 2022) and at COP28, in Dubai, UAE, where Parties emphasised "the importance of conserving, protecting and restoring nature and ecosystems towards achieving the Paris Agreement temperature goal" by protecting "terrestrial and marine ecosystems acting as sinks and reservoirs of greenhouse gases and by conserving biodiversity" (UNFCCC, 2023c). At COP29, in 2024 in Baku Azerbaijan, further recognition of the Kunming-Montreal Global Biodiversity Framework (GBF) was not included in the text. A coalition of organisations produced a guide to incorporating Natural Climate Solutions, including protected areas, into NDCs (Nature4Climate Coalition, 2024).

Case Study 2.1

Climate mitigation benefits of PCAs in Tanzania



Submitted by

Mengyu Liang, Stanford University and University of Maryland, USA

Location of PA

All PCAs in Tanzania as documented in the World Database on Protected Areas

IUCN governance type

More than 98% of Tanzania's PAs¹ are nationally designated, including national parks, forest reserves, game reserves, game-controlled areas, and forest plantations, representing approximately 55% of the total protected land area in the country. The remaining 2% of Tanzania PAs are internationally designated, meaning they are protected under global conventions, such as World Heritage Sites and the UNESCO-MAB Biosphere Reserve, accounting for approximately 45% of the total Tanzanian protected areas.

Governance is often shared by government and Indigenous peoples and local communities.

The project

This case study conducts a retroactive assessment of the climate mitigation benefits resulting from protected areas designations in Tanzania by comparing the carbon stocks to similar but unprotected areas. A total of 830 PAs are documented in the World Database on Protected Areas (WDPA) for Tanzania. These PAs vary in size and collectively cover 38.2% of Tanzania's terrestrial land area. Ecosystems represented are:

- Tropical and Subtropical Grasslands Savannas, and Shrublands (TSGSS) (84.6%);
- Tropical and Subtropical Moist Broadleaf Forests (TSMBF) (7.6%);
- Flooded Grasslands and Savannas (FGS) (6.8%);
- Montane Grasslands and Shrublands (MGS) (0.5%);
- Mangroves (0.5%).

Results

The authors of this study estimated the carbon stocks in Tanzania's PAs utilising the climate change data from the Global Ecosystem Dynamics Investigation (GEDI), a NASA mission designed to provide near-global satellite LiDAR data (Dubayah et al., 2020). GEDI is a fullwaveform spaceborne LiDAR instrument that measures vegetation's 3-dimensional structure through systematic sampling at 25 m spatial resolution (or footprint) within a latitudinal range of 52.6° N and 52.6° S (Dubayah et al., 2020). GEDI produces a suite of forest structure products, including canopy heights, cover and foliage metrics, and biomass. At each footprint, precise structural measurements of canopy relative height (RH) can be obtained from GEDI's Level 2A (L2A) products. GEDI is open-source data, which allows knowledge gaps to be filled in countries where traditional methods are not available.

In this study, GEDI data from 2019-2020 were used to compare the ecological structure of PAs with controls that have comparable environmental and socioeconomic characteristics in the baseline year of 2000. To account for potential confounding factors that could influence the ecological outcomes of PAs, the authors employed statistical matching to find unprotected counterfactuals. Statistical matching can account for the potential influence of PA placement in remote areas with less human disturbance, for example. The matching process involved pairing 1 km² protected sites with unprotected control sites based on a suite of 12 environmental and socio-economic variables from approximately the year 2000. The matching algorithm was then evaluated to ensure confidence in its ability to select reliable unprotected counterfactual data and reduce confounding effects.

1. In the case studies the use of the terms PA and PCA depend on the term used by the author(s).

The authors subsequently extracted GEDI's forest structure metrics and above-ground biomass estimates for both protected and control sites, comparing how the forest structure and carbon stocks differed between the two. A total of 2,400,502 quality-filtered GEDI observations over Tanzania were analysed. Of these, 1,618,454 GEDI samples were taken from PAs, while 782,048 were taken from control sites across a 1 km raster surface of the matched sites.

Successes

The results revealed that forests in PAs are 20.7% taller, have 23.0% larger canopy cover, and have a 37.2% higher plant area index (PAI) per unit area than controls. These findings indicate that PAs store 24.4% more biomass per unit area, suggesting that the

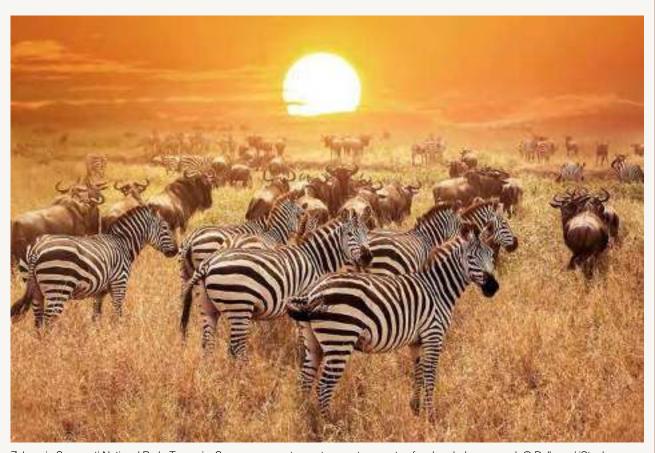
355,799 km² (35,579,900 ha) of PAs analysed in Tanzania could have the potential to store approximately 0.39 Gt (390 Mt) carbon. This highlights area-based conservation's potential in preserving carbon stocks for climate mitigation.

Challenges

Some PAs have missing attributes as documented in the WDPA, such as the types of PA governance. This presented challenges to the stratified analyses where we aimed to understand how governance types are related to PA's effectiveness in preserving forest carbon.

Additional resources

(Liang et al., 2023)



Zebras in Serengeti National Park, Tanzania. Savanna ecosystems store vast amounts of carbon below-ground. © Delbars / iStock.com

2.3.2 Kunming-Montreal Global Biodiversity Framework

In December 2022 at COP 15, the CBD adopted the Kunming-Montreal Global Biodiversity Framework (GBF), in which Parties to the Convention agreed, through Target 3, to "Ensure and enable that by 2030 at least 30 per cent of terrestrial, inland water, and coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem functions and services, are effectively conserved and managed through ecologically representative, well-connected and equitably governed systems of protected areas and other effective area-based conservation measures, recognizing indigenous and traditional territories, where applicable, and integrated into wider landscapes, seascapes and the ocean, while ensuring that any sustainable use, where appropriate in such areas, is fully consistent with conservation outcomes, recognizing and respecting the rights of Indigenous peoples and local communities, including over their traditional territories" (CBD, 2022). Analyses suggests that:

- Protecting 30% of land in strategic locations could safeguard 500 gigatonnes (Gt) of the carbon stored in vegetation and soils, and reduce the extinction risk of nearly 9 out of 10 threatened terrestrial species, by 2030 (de Lamo et al., 2020).
- Twenty percent of the carbon emission reductions needed to achieve the Paris Agreement target could be delivered by protection of 30% of the oceans (Lubchenco, Haugan, & Pangestu, 2020; Stuchtey et al., 2023).

Target 8 of the GBF also incorporates climate change and aims to "Minimise the impact of climate change and ocean acidification on biodiversity and increase its resilience through mitigation, adaptation and disaster risk reduction actions, including through nature-based solutions and/or ecosystem-based approaches while minimizing negative and fostering positive impacts of climate action on biodiversity" (Archer et al., 2022; CBD, 2022).

2.3.3 Cooperation between UNFCCC and CBD

As explained in a recent review by Boran and Pettorelli (Boran & Pettorelli, 2024), successful implementation of the Paris Agreement and the GBF requires establishment of a joint programme of work between the UNFCCC and the CBD. Although there has long been recognition of the need for joint work between these Rio Conventions, efforts to create mutually supportive implementation frameworks have so far failed. For example, intentions to initiate joint work began with the 2001 creation of a Joint Liaison Group of the three Rio Conventions – UNFCCC, CBD, UN Convention to Combat Desertification (UNCCD). Due to lack of meaningful progress, the group has not met since 2016.

Recent signals of the intent for cooperation are found in the Joint Statement on Climate, Nature and People led by the UNFCCC and CBD presidencies at UNFCCC COP28, and the subsequent statement of intent, January 2024. The presidents of the two conventions committed, among other things, to increases in finance and investments for climate and nature, interoperability across data sources and data collection and voluntary reporting frameworks. However, a much needed joint work programme remains elusive (Boran & Pettorelli, 2024).



Cooperation is essential to manage large carbon-dense ecosystems, like the Amazon Rainforest, that crosses nine national borders. © mariusz_prusaczyk / iStock.com

2.3.4 Other global cooperation

During COP 27 of the UNFCCC, a collaborative initiative between the COP27 presidency and IUCN was established "Enhancing Nature-based Solutions (NbS) for and Accelerated Climate Transformation (ENACT)" (IUCN, 2022). This initiative aims to increase collective action, bringing global coherence to activities and to close the finance gaps across climate, biodiversity and desertification. As of 2024 the biodiversity finance gap was estimated to be USD 700 billion per year to 2030 (Pettinotti et al., 2024). ENACT aims to do this by facilitating collaboration and policy dialogue between government and non-state actors. Additional cooperation commitments were also made by Ministers and other heads of delegations under the Kunming Declaration (CBD, 2021) during COP15, where they agreed to "enhance collaboration and coordinate actions with ongoing multilateral environmental agreements, such as the United Nations Framework Convention on Climate Change".

Although several commitments are already being taken at the global level to integrate each other's agendas, these have yet to be fully and effectively translated on the ground. There is a need therefore to scale up this cooperation even further and jointly support the translation and integration of global biodiversity protection and climate change mitigation commitments at local, regional and national levels. Figure 2.1 shows a summary of potential pathways - not necessarily mutually exclusive – for climate change mitigation and PCA policy integration.

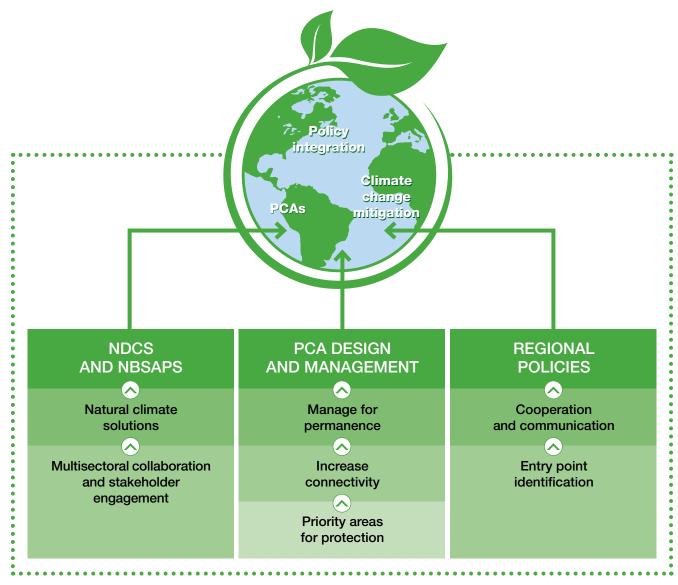


Figure 2.1 Potential pathways for protected areas and climate change mitigation policy integration. Regional policies related to the identification of new protected areas and expansion and/or management of existing ones, can provide insights into the role of PCAs for climate change mitigation.

2.3.5 Building capacity

Capacity building for climate change and sustainable development are the subjects of many UN decisions and philosophical discussions that cannot be addressed in this technical document. A helpful review on the subject can be found in a 2022 special issue of the journal Climate Policy (Klinsky & Sagar, 2022). Guidance on how PCA managers can adapt to the impacts of climate change has been addressed by several initiatives (Gross et al., 2016; Melbourne-Thomas et al., 2024; van Kerkhoff et al., 2019). On the other hand, guidance on incorporating climate change mitigation in PCA management and policy is rarely addressed. For example, the IUCN publication on governance for PA management discusses cultural and operational capacity building, the importance of building an understanding of the impacts of climate change and managing PCAs for uncertainties and risk. It does not address the need to build knowledge on the potential for PCAs to provide climate change mitigation (Worboys et al., 2015).

Intergovernmental communities, multi-stakeholder networks, NGOs and projects can play a large role in building capacity for protected area managers to be better equipped to incorporate climate change mitigation actions into protected area strategies (see Box 2.1 for examples from Africa).

Box 2.1

Building capacity on the ground in Africa

The Southern African Development Community (SADC) Secretariat provided training to participants from across 18 Trans-frontier Conservation Areas (TFCAs) in the region to address climate change, including integrating climate change adaptation and mitigation into the TFCA management plans and engaging with local communities about climate change (SADC, 2020). A Climate Change and Protected Areas Project (2016–2018) supported experts and professionals in politics and practice to strengthen protected areas as effective instruments of climate change mitigation and adaptation.

2.4 Integrating climate change mitigation and protected and conserved areas policies at the regional level

Regional policies enable landscapes and seascapes to be governed and managed as an ecosystem unit, which allows for a more holistic and effective approach for addressing multiple transboundary threats and their impacts. Regional or transboundary conservation also promotes the protection of migratory and other important mobile species. Climate change can be considered a transboundary threat for humans and biodiversity. For example, extreme events such as fires and floods often transcend geographic and political boundaries and require a transboundary or regional management approach. Competing interests and priorities may confound individual efforts with actions in one territory potentially having negative implications in others. Individual territories rarely have sufficient power or authority to address transboundary problems adequately on their own (McKinney, 2015; McKinney & Johnson, 2009).

Both biodiversity protection and climate change mitigation require multi-jurisdictional and multinational governance approaches (Malhi et al., 2020) to meet global targets, making regional initiatives and policies highly important for promoting climate action in protected areas, in particular.

Case Study 2.2

Is climate-smart conservation feasible in Europe? Spatial relations of protected areas, soil carbon and land values



Submitted by

Kerstin Jantke, Center for Earth System Research and Sustainability, University of Hamburg, Germany

Name of protected or conserved area and location

The Terrestrial Natura 2000 network consists of over 27,000 PCAs of 26 EU member states, namely Austria, Belgium, Bulgaria, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom. The EU member states Croatia and Cyprus were excluded due to data deficiencies.

IUCN governance type

Natura 2000 is a network of protected areas established under the European Union's Birds Directive and Habitats Directive. Most of the areas are privately owned, although a number are managed by government entities. The network covers 18% of Europe, in 26 of 28 member states. Additionally, there are PCAs that actively involve Indigenous peoples and local communities. These protected areas aim to conserve Europe's most valuable and threatened species and habitats. While these protected areas were originally created to protect biodiversity, the need to incorporate climate change mitigation priorities to achieve conservation goals has more recently been identified.

The project

The objective of this study was to investigate the overlap between existing Natura 2000 sites, land value, and soil organic carbon stocks. To conduct the spatial analyses, the research team compiled three key datasets: the boundaries of Natura 2000 PCAs (Directorate-General for Environment (DG ENV), 2014), the soil organic carbon content of top-soils across Europe (Jones et al., 2004) and agricultural land values, derived from author calculations based on data from the European Commission's Farm Accountancy Data Network (FADN). Jantke and colleagues (2016) provide details of the methodology (Jantke et al., 2016). Agricultural land

values were chosen as an estimate for overall land values because of the prevalence of agricultural land within the protected area network. The researchers categorised both the land value and carbon datasets into 'low', 'medium' and 'high' classifications, subsequently overlaying these map layers onto the Natura 2000 sites to obtain the results.

Successes

Most Natura 2000 sites (1,573,052 km²) are in areas with medium carbon content and medium agricultural land value. This is followed by areas with low agricultural land value and high soil carbon content (~100,000 km²), and then those with high agricultural land value and high soil carbon content (23,456 km²). The fewest sites were in areas with low soil carbon and high agricultural land value.

These findings indicate that there is a significant overlap between Natura 2000 sites and regions with high carbon content across Europe. Further, these carbon-rich sites have statistically significantly lower land values than carbon-poor sites. The results suggest that both biodiversity conservation and climate change mitigation can be simultaneously achieved in Europe's protected areas by prioritising protecting areas with high soil carbon. The researchers concluded that there is a notable potential for climate-smart conservation in Europe that requires further research.

Associated resources

(Jantke et al., 2016) (Neigenfind, 2015)



Salt marsh at Ebro Delta Natural Park, Catalonia, Spain. © Gerold Grotelueschen / iStock.com

2.4.1 Identifying potential regional policy entry points

The first step for incorporation of climate change mitigation into protected areas management is to link approaches to relevant regional networks. A few examples of regional networks already integrating biodiversity and climate change mitigation into regional policies are:

- The EU's Biodiversity Strategy for 2030, which aims to put Europe's biodiversity on the path to recovery by 2030 for the benefit of people, climate and the planet. It explicitly mentions the need for policy coherence in particular to reduce biodiversity loss world-wide. The strategy identifies the protection and restoration of biodiverse areas with high ecosystem services and climate mitigation potential as one area requiring particular attention (European Commission, 2020) (see case study 2.2).
- The Economic Community of West African States (ECOWAS) has developed a Regional Climate Strategy (2022–2030) that identifies protected forests as a crucial measure to mitigate climate change (ECOWAS, 2022).
- The Intergovernmental Authority on Development (IGAD) in Eastern Africa has developed the IGAD Regional Climate Change Strategy and Action Plan (2023–2030), which identifies mainstreaming natural resource protection into mitigation actions and mitigation actions into nature conservation and land management, as key strategies (IGAD, 2023).
- The Southern African Development Community (SADC) has developed a Regional Indicative Strategic Development Plan (RISDP) 2020–2030 which includes cross-cutting issues such as the environment and climate change as well as gender, youth, and Disaster Risk Management (SADC, 2020).
- Latin American Technical Cooperation Network on National Parks, other Protected Areas, Wild Flora and Fauna (Panorama Solutions for a Healthy Planet, 2025) is a unique network of protected area agencies that seeks to improve the management of national parks and other protected areas through technical cooperation and the exchange of knowledge and experience among its 19 member countries. One of the unique elements of REDPARQUES is that it has expanded recognition of the importance of protected areas in mitigation of and adaptation to climate change (Smith et al., 2019).
- The Caribbean Community Climate Change Centre (CCCC) coordinates the Caribbean region's response to climate change and works on effective solutions. It provides climate change-related policy advice and guidelines to the Caribbean Community (CARICOM) Member States (Rosenberg, 2020).
- The Asian Pacific Region has several collaborative regional initiatives for protecting biodiversity across national borders, such as the Greater Mekong Sub-Region (Greater Mekong Subregion Secretariat, 2021), the Terai Arc Landscape in India and Nepal (WWF Nepal, 2021), the Heart of Borneo Initiative (WWF, 2007), the Sulu-Sulawesi Marine Areas and the Coral Triangle (Marine Conservation Institute, 2024).
- North America has several regional initiatives including Canada, United States and Mexico that address technical and policy integration on biodiversity and climate change, among other issues (e.g. CEC, 2021). These include the Commission for Environmental Cooperation (CEC) and the Trilateral Committee for Wildlife and Ecosystem Conservation and Management (Stoett & Temby, 2015).
- The Arctic Council is an intergovernmental forum that promotes cooperation in the Arctic. Through three of its working groups Arctic Monitoring and Assessment Programme, Conservation of Arctic Flora and Fauna, and Protection of the Arctic Marine Environment circumpolar assessments of climate change, pollution, biodiversity and the marine environment have successfully addressed policy across all eight Arctic States, although since its invasion of Ukraine in 2022, the Russian Federation has been excluded from this forum (Arctic Council, 2023).



Arctic tundra in Tombstone National Park, Yukon, Canada. © Jef Wodniack / iStock.com

2.5 Integrating Nationally **Determined Contributions (NDCs)** and National Biodiversity Strategies and Action Plans (NBSAPs)



The Paris Agreement calls on Parties to submit Nationally Determined Contributions (NDCs) which outline their actions to reduce their GHG emissions. Although under no legal obligation to achieve their NDCs, Parties are required to update their NDCs every five years, ratcheting up their ambitions. National Biodiversity Strategy and Actions Plans (NBSAPs) are the principal instruments for implementing the Convention on Biological Diversity at a national level. Parties are encouraged to revise or update their NBSAPs in alignment with the Kunming-Montreal Global Biodiversity Framework and its goals and targets (Convention on Biological Diversity, 2022, December 18).

Revising NBSAPs presents a significant opportunity to incorporate climate mitigation in national biodiversity targets related to PCAs. Strengthening coordination between countries' NDCs and NBSAPs to include PCA and climate change mitigation targets respectively, will reinforce the importance and benefits of integrated national measures that favour climate and biodiversity ambitions. For example, through the Paris Agreement's recognition of the role of protecting and conserving ecosystems in mitigating climate change and the inclusion of Nature-based Solutions in the Sharm el-Sheikh Implementation Plan (COP 27), a significant opportunity exists for PCAs and OECMs, including Indigenous lands, to be included as viable national measures for countries to help meet their mitigation targets. COP 28 presented further opportunities for integration by calling on governments to consider ecosystems, biodiversity and carbon stores when developing their NDCs due in 2025.

Barren-ground caribou in the Arctic tundra, Canada. The Arctic tundra is a carbon-dense ecosystem with most of its carbon reservoirs belowground. © Cowtown_Scribe / iStock.com

Similarly, the inclusion of Target 3 (related to protected areas) and Target 8 (related to climate change) in the GBF, provides additional opportunities for integration. This could be achieved by the identification of concrete actions in NBSAPs that recognise PCAs and OECMs as climate change mitigation measures and the identification of climate mitigation measures that enhance biodiversity conservation. Technical and financial support for the revision of NBSAPs can be provided through enhanced cooperation measures. In South Africa, for example, the Department of Forestry, Fisheries and the Environment (DFFE) developed and implements effective, knowledge-based climate and biodiversity measures that help deliver their Nationally Determined Contributions (NDCs) in the biodiversity sector through the Climate Support Programme (2022–2026) (GIZ, 2022). Integration of the biodiversity and climate change agendas, however, requires full consideration of the synergies and trade-offs between climate and biodiversity goals (Deprez et al., 2021). Trade-offs including conflicts between climate change mitigation and prioritised areas for biodiversity conservation have been summarised by Neugarten and colleagues (Neugarten et al., 2024) and Smith and colleagues (Smith et al., 2022). Most trade-offs can be addressed by careful attention to how projects are implemented and intentional reductions in impacts on biodiversity. Examples include:

- Preferred locations for large renewable energy and critical minerals development conflicting with high-biodiversity/carbon-dense natural areas;
- Suitable areas for economic development conflicting with habitats of special concern such as mangroves, forests, grasslands and savannas;
- Afforestation in ecologically sensitive areas that did not previously have forests;
- Areas identified for agricultural expansion conflicting with existing land uses that support grazing, access to nature and sediment and nitrogen retention;
- Replacement of biologically diverse forests with monoculture plantations in the interest of carbon sequestration;
- Large-scale use of bioenergy crops which would require exploiting vast areas of land for energy at the expense of biodiversity, ecosystem services and food production.

Climate mitigation actions that also have benefits for biodiversity have been summarised by Smith and colleagues (Smith et al., 2022) and include:

- protected areas and other biodiversity conservation measures;
- improved agriculture management for croplands, grazing, livestock;
- improved forest management including reduced deforestation, reforestation;
- restoration and reduced conversion of coastal wetlands and peatlands.

Trade-offs and co-benefits can be maximised and understood at multiple scales, from local to international (Picourt et al., 2021).

2.5.1 Strengthening multisectoral collaboration and stakeholder engagement

Strengthening multisectoral collaboration and stakeholder engagement will be essential for integrating NDCs' and NBSAPs' agendas. Multisectoral national development plans already exist in many countries, and many have integrated policies that include Natural Climate Solutions or Ecosystem-based Management to some degree. In most countries, the national development planning framework and decision-making cycles such as appropriation, budgeting and other economic planning activities are potential entry-points for mainstreaming climate change issues into protected areas and vice versa. Experience can be shared and numerous lessons can be learnt from the implementation of these policies to improve and enhance greater cooperation and joint policy implementation. Some examples of multi-stakeholder collaboration for integrating agendas are:

- In Central Asia the mainstreaming of Ecosystem-based Approaches (EbA) has been used as a cross-cutting approach into national, regional and local policies, with relevant targets built into the country's Nationally Determined Contributions (NDC), Green Economy, National Adaptation Plan (NAP) and Regional Adaptation Plans (RAP) (Schumacher, P. et al. 2018).
- Peru has further strengthened the EbA case at basin and landscape (regional) levels through
 existing regional climate change planning processes, aligned with development planning.
 Here, the government is mandated through the Regional Strategies for Climate Change along
 with Regional Development Plans and their guidelines, for the consideration of sub-national
 land use planning and the management of protected areas in the articulation of policies
 (Pramova, E., Di Gregorio, M., Locatelli, B., 2015).

At a national level, there is a need for improved coordination and information sharing among the relevant actors within the country (Pham & Le Thi, 2019) and for a 'whole of society' and 'whole of government' approach to be taken for policy integration. Collaboration among government stakeholders to review existing and anticipated policy commitments and plans on biodiversity conservation and climate change mitigation is key (Kapos et al., 2022).

Gender mainstreaming is an often-forgotten, but important element to achieving climate action targets for protected areas. Women, Indigenous people and other marginalised stakeholders are among the most vulnerable to climate change impacts and restricted from land use for areas under protection (Pörtner et al., 2021). Therefore, it is always good practice to have an inclusive planning process, ensuring that women, vulnerable communities, stakeholders and representatives of different levels of government, including Indigenous governments, are involved in the integration of climate change mitigation and protected areas policies (UNFCCC, 2018). Ethical considerations and the perspectives of Indigenous and local communities are essential. It is necessary to engage other international groups including financial institutions, multilateral agencies and NGOs, in order to ensure their work programmes and agendas are aligned with integrated global policies and can therefore provide support to the relevant bodies for concrete on-the-ground action and policy integration at a national level.

2.5.2 Incorporating Natural Climate Solutions and **Ecosystem-based Management into national targets** for biodiversity and climate change

Natural Climate Solutions (NCS) are now considered an important pathway for climate action and in achieving the Paris Agreement. They are also identified as a measure that can increase biodiversity resilience (e.g. Target 8 GBF). As such, they provide a critical and relevant entry point for the inclusion of PCAs and OECMs into climate mitigation policies (e.g. NDCs) and for climate mitigation action to be incorporated into the biodiversity agenda (e.g. NBSAPs) at all levels. NCS refer to actions that protect, manage or restore natural and modified ecosystems for reductions in GHG emissions and increased carbon storage and sequestration. NCS are an important avenue to climate change mitigation and have been estimated to provide around a quarter of the cost-effective CO₂ mitigation needed by 2030 for a >66% chance of holding warming below the 2°C level set by the Paris Agreement (Griscom et al., 2017). Considered a simpler and more cost-effective strategy for climate mitigation than other potential solutions (Cheng et al., 2022), these may be a more appealing approach for resource limited countries (Griscom et al., 2017). In Madagascar for example, Natural Climate Solutions could potentially meet 90% of the country's mitigation potential (USAID, 2021) and Kenya has already included NCS components within its Low Emissions Climate Resilient Development (LECRD) project (Murphy et al., 2012).

More often than not, however, restoration, afforestation or reforestation are often prioritised over protection and improved management in climate mitigation strategies (Cook-Patton et al., 2021). A proposed Natural Climate Solutions hierarchy (Cook-Patton et al., 2021) suggests that protection, followed by improved management of PCAs for permanence, offers a cost-effective mitigation solution that typically provides many co-benefits and aligns with other global commitments to reduce land degradation and biodiversity loss. Restoring damaged ecosystems has an important role to play after undamaged ecosystems are protected (Cook-Patton et al., 2021).



Proboscis monkeys in the Borneo rainforest, a carbondense rainforest extending into Brunei Darussalam, Indonesia and Malaysia. © Dave Primov / iStock.com

Case Study 2.3

China's national blue carbon accounting system



The results of baseline accounting for the period from 1 January 2021 to 31 December 2021 show that China's coastal blue carbon ecosystems are a net carbon source of 4.7 Tera-gram (Tg) $\rm CO_2e$ (= 0.0047 Gt), with the greatest $\rm CO_2e$ releases coming from salt marshes, mangroves and seagrass meadows, in that order. The release of $\rm CO_2e$ from blue carbon is a result of reductions (=reclamations), disturbance and degradation of blue carbon ecosystems and can possibly be reversed through restoration and protection.

Summarised from

(Liu, Failler, & Ramrattan, 2024)

China intends to use NbS as a tool towards meeting its NDC to the Paris Agreement. To support inclusion of carbon sequestered and stored as a result of protecting and restoring blue carbon ecosystems, China has been developing a national-scale systematic blue carbon accounting system for mangroves, salt marshes and seagrasses. The accounting system will be used to: i) support decision-makers in monitoring the nationwide blue carbon inventory; ii) support an analysis of investment availability and cost comparison of the three coastal blue carbon ecosystems; and iii) to compare carbon sequestration costs of mangroves and terrestrial forests.

China is using the UN System of Ecosystem Accounting (SEEA) to formulate its blue carbon accounting mechanism. Detailed tables on the extent, annual carbon burial and sequestration rates, existing and lost carbon stocks, and other critical measurements are based on a National Blue Carbon Sink Research Report (2020), which is not publicly available.

China's work on accounting for blue carbon follows several policy commitments articulated in its updated NDC, including:

- Peaking CO₂ emissions around 2030 or earlier;
- Lowering CO₂ emissions per unit of GDP by 60–65% from the 2005 level;
- Increasing the share of non-fossil fuels in primary energy consumption to around 20%;
- Increasing forest stock volume by ~6 billion m³ from 2005 levels;
- Increasing the total installed capacity of wind power and solar power generation to more than 1.2 billion kilowatts.



Figure 2.2 The spatial distribution of blue carbon in the coastal wetlands of China. Source: (Meng et al., 2019). Reproduced with permission from Elsevier.

2.6 National protected area network design and management

Protected areas are important natural instruments for climate change mitigation and can be recognised as key parts of any strategy developed by national and local governments to promote climate action (Mori et al., 2024). In order to include PCAs into climate mitigation policies, there is a need for a greater spatial understanding of priority areas for carbon storage and sequestration as well as biodiversity conservation benefits (Soto-Navarro et al., 2020) (see Chapter 6: Integrating hotspots for carbon density and biodiversity). For marine protected areas (MPAs) in particular, building on IPCC Guidelines for Coastal Marine Areas (Kennedy et al., 2014), which includes mangroves, salt marshes and seagrass meadows, it is important to include MPAs into NDCs (Rankovic et al., 2021; Sanderman et al., 2018).

2.6.1 Prioritising strategic reserves for carbon and biodiversity

Current approaches to PCA creation do not provide for the selection of PCAs based on ecosystem services other than nature conservation and tourism. It would be a small and achievable step to add the protection of carbon-rich habitats for their role in storing and/or sequestering carbon to PCA priorities (de Lamo et al., 2020; European Commission, 2020; Jung et al., 2021; Soto-Navarro et al., 2020). In the past decade, several researchers have proposed the expansion of protected areas to include 'climate stabilisation areas' (CSAs) (Dinerstein et al., 2019; Wilson & Hebda, 2008). The current global protected areas network contains more carbon resources than outside the network (Shi et al., 2020). Studies have shown that by prioritising areas for protection with dual benefits, almost 80% of the maximum climate change mitigation benefits can be achieved, while also delivering almost 95% of the maximum biodiversity benefits (de Lamo et al., 2020) (see Chapter 3 for carbon values of key ecosystems).

Some proponents of CSAs argue that they could be in addition to the 30% protected land, freshwater and oceans agreed to in the Kunming-Montreal Global Biodiversity Framework (Dinerstein et al., 2019; Dobrowski et al., 2021). Others suggest that CSAs could be incorporated into the agreed target to protect 30% of land, freshwater and oceans by 2030. These new areas would focus on habitats that store vast reserves of carbon as well as ecosystems that are intact and remain stable to the impacts of climate change (Dobrowski et al., 2021) (see Chapter 3 for carbon values of key ecosystems).

2.6.2 Spatial mapping

Spatial approaches are used to identify key areas that contribute to both biodiversity and climate change objectives. Examples of spatial approaches are detailed in Chapter 6. Integrating hotspots for carbon density and biodiversity. It is important to note that prioritising ecosystems for their carbon mitigation potential cannot be at the expense of important and threatened key biodiversity areas with lower carbon potential.

2.6.3 Zoning carbon-rich habitats for protection

Ecological buffer management zones around and within PCAs can also have enormous value for carbon storage by limiting land and resource use in and around the PCA. For example, protecting climate refugia (i.e. areas buffered from climate change), limits impacts on these important habitats (Ranius et al., 2023). Equally important is reducing land pressures and preventing land use change, around PCAs (Kapos et al., 2022).

2.6.4 Increasing connectivity of protected areas networks

Improving landscape connectivity is an important pursuit in PCA management for climate mitigation (Hilty et al., 2020; Ranius et al., 2023). Because vegetation carbon stock and soil organic carbon stock are not necessarily correlated with each other, they should be considered separately when incorporating both connectivity and carbon considerations (O'Brien et al., 2023). One approach to selecting areas of connectivity that also contain large amounts of carbon is to overlay carbon storage spatial data with ecological connectivity maps (derived without the consideration of carbon storage) and identify areas important for both climate mitigation and biodiversity conservation (O'Brien et al., 2023). In the tropics, carbon densities in ecological corridors have been found to be at similar levels to the protected areas they connect (Jantz, Goetz, & Laporte, 2014).

On land, the percentage of protected connected land has increased from 6.5% in 2010 to 7.7% in 2018 (Saura et al., 2019), a relatively small increase considering the benefits that can be achieved through increased connectivity. Similar statistics are not available for MPAs.

2.6.5 Transboundary cooperation

Transboundary cooperation can improve outcomes for PCAs by: i) enhancing the ability of species to move across boundaries as they adapt to threats such as climate change; ii) improving PCA management through sharing resources and capacity; and iii) enhancing the overall effectiveness of PCAs through joint action. In addition, transboundary approaches support a common vision and can result in a coherent policy for a region. Transboundary cooperation is widespread. The Biosphere Reserve Program has effectively protected a transboundary area in Europe and another in Latin America. The Ancient and Primeval Beech Forests of the Carpathians and Other Regions of Europe, encompasses 18 European countries that have worked together to protect primeval forests (Various, 2025). In Latin America, the Trifinio Fraternidad Biosphere Reserve protects approximately 200 km² of cloud forests across three countries – El Salvador, Guatemala and Honduras (Various, 2023). Box 2.2 highlights examples from Africa.

Box 2.2

Examples of management actions to enhance climate change mitigation in transboundary protected areas in Africa

- Peace Parks and Trans-frontier Conservation Area (TFCA) initiatives have created a platform for identifying synergies and for promoting climate action across protected areas, with climate action measures usually identified in TFCA management plans (SADC, 2025).
- A project to improve the management of a transboundary forest landscape in west Africa working with the Economic Community of West African States (ECOWAS), the Mano River Union, and the Abidjan Convention, showed that in 2020/2021 efforts to protect these transboundary forests reduced GHG emissions by over 8.7million Mt (USAID, 2021).

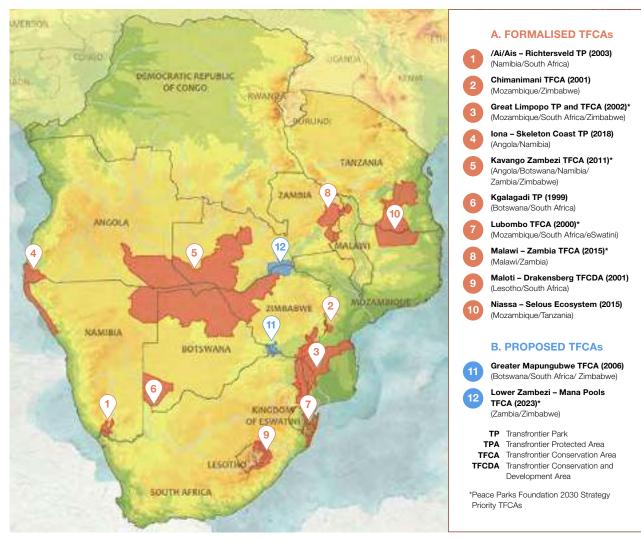


Figure 2.3 Map showing trans-frontier conservation areas (TFCAs) in southern Africa. The red areas are existing TFCAs; the blue areas are proposed. © Peace Parks Foundation

Case Study 2.4

Amazon Regional Protected Areas Program (ARPA): Large enough and key in conserving the Brazilian Amazon



Submitted by

Cláudio Carrera Maretti, Mariana Napolitano Ferreira and Britaldo Soares-Filho. University of São Paulo (USP) Brasil, WWF-Brasil, UFMG

Name of PCA and location

Amazon Region Protected Areas Programme (ARPA)

IUCN governance type

Varied

The protected area

The Amazon Protected Areas Program (ARPA) was created in 2002 through an innovative collaboration between the federal government, state agencies, private institutions, and civil society. ARPA was implemented in three phases: the first phase, 2003-2009, established 23 million hectares (230,000 km²) of conservation units; the second phase, 2010–2017, consolidated 95 conservation units, covering a total of 52.2 million ha (520,000 km²) of land; and the final phase introduced the Project Finance for Permanence (PFP) (see Chapter 8 on Finances) which facilitates the development of public policies and secures the long-term funding necessary to achieve specific conservation objectives. Currently protecting 62 million ha (620,000 km²), ARPA is the largest tropical forest conservation programme globally. The programme consists of 120 officially supported protected areas, governed by state and national agencies. The project now protects 20% of the Amazon rainforest, surpassing its initial goal (15% protected). Conservation in this area is critical to avoid the Amazonian tipping point, which would have major implications for biodiversity, climate change, and the societies that depend on it.

The project

The group estimated the emissions reductions in the ARPA-supported conservation units between 2008 and 2020. Carbon emissions were calculated based on the reduction in deforestation rates within protected and conserved areas (PCAs), using PRODES maps at a 30 m resolution. PRODES maps are Amazon-specific

deforestation maps derived from Landsat imagery (Instituto Nacional de Pesquisas Espaciais (INPE), 2015). Due to the heterogeneous distribution of deforestation throughout the Amazon, the rate was individually estimated for each PCA, based on the deforestation inside and adjacent to the area. These deforestation rates were then paired with regional biomass estimates to determine local carbon emissions from deforestation. The resulting estimates were used to calculate avoided emissions by comparing emissions from deforestation in the absence of protection to the reductions observed within the PCAs. To determine emissions reductions across different PCA types, the group categorised the data into three categories: strict preservation areas, sustainable use reserves, and Indigenous lands.

Successes

The researchers found that with ARPA support, deforestation in strict preservation areas decreased by 9%, and with additional financial support, deforestation was reduced by 30%. In sustainable use areas, ARPA support led to a 39% decrease in deforestation, and financial support resulted in a 49% reduction.

Emissions reductions in Indigenous lands amounted to 396 ± 64 Mt CO₂. Overall, protected areas in the Amazon were found to reduce deforestation by 21% (2.0 \pm 0.3 Mha/ 20,000 km²), thereby avoiding 622 \pm 81 Mt CO₂ emissions. Of this total, protected areas with ARPA support accounted for the avoidance of deforestation in 26,400 ± 25,000 ha (2,640 km²), corresponding to a reduction of 104 ± 10 Mt CO₂.

Challenges

Effectively maintaining the wide-ranging network of PCAs in such a diverse region depends on securing large and reliable funding. This financial support must be complemented by robust public policies aimed at curbing illegal deforestation. A key component of these policies is the enforcement of environmental laws, ensuring that appropriate sanctions are imposed on offenders. Achieving this requires coordinated actions that involve all stakeholders, from local practitioners to national decisionmakers, with support from the international community.

Additional resources

(Ministério do Meio Ambiente, 2010) (WWF, 2015) (WWF, 2010)

(WWF, 2017)

(Rousseff et al., 2014)

(Soares-Filho et al., 2010)

(Soares-Filho et al., 2023)

2.6.6 Recognition of Indigenous rights and title

Indigenous peoples manage or have tenure rights over approximately 38 million km² across 87 countries, and inhabit 40% of the world's protected areas and ecologically intact landscapes (Fa et al., 2020; Garnett et al., 2018). Although deteriorating, nature is declining less rapidly in lands managed by Indigenous peoples (IPBES, 2019). One global study in tropical forests found that the highest forest integrity is in PCAs, followed by Indigenous lands, with areas outside protection having the lowest forest integrity (Sze et al., 2022). In addition, it is thought that Indigenous lands comprise most of the remaining carbon-dense intact landscapes (Artelle et al., 2019). As PCAs inevitably increase globally as a result of the GBF, it is imperative to incorporate safeguards that ensure that Indigenous communities who, as a result of their stewardship, have left the world with most of the remaining intact ecosystems, are not displaced or compromised.

United Nations entities, including the CBD and UNFCCC, have recognised the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP). UNDRIP establishes rights over use and decision-making on Indigenous territories and requires their free, prior and informed consent for any state actions affecting their rights (United Nations, 2007). Recognition of the rights and title of Indigenous peoples, as well as respect for their knowledge, cultural practices and approaches to sustainability and decision-making, is fundamental to conservation, enhancing the role of natural systems in climate change mitigation and adaptation, and reconciliation.

2.6.7 Incorporating ecological resilience into protected areas management

Ecosystem resilience is defined by IPCC, AR6, WGII "as the capacity of ecosystems to cope with a hazardous event or trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure, as well as biodiversity ..." (Pörtner et al., 2022). A good understanding is emerging about the importance of ecological resilience for reducing the impacts of climate change on PCAs and enhancing the ability of PCAs to contribute to GHG emissions reduction. This includes incorporating carbon dynamics and ecological functioning into PCA management. Some examples of actions that could be taken to increase resilience are:

- Ensuring there is a robust wildfire mitigation and response plan in place.
- Increasing awareness that maintaining populations of large herbivores supports carbon storage as well as biodiversity and ecosystem functioning (Malhi et al., 2022). For example, the presence of elephants in Central African rainforests has been shown to increase aboveground biomass by 26 to 60 tonnes per hectare. The extinction of forest elephants would reduce above-ground biomass by 7% (Berzaghi et al., 2019).
- Identifying key species, populations, or ecological communities that are important for maintaining ecological functions and processes.

2.6.8 Incorporating ecosystem integrity into protected areas management

Ecosystem integrity describes the ability of an ecosystem to achieve and maintain its optimum structure and function. A high level of ecosystem integrity means that an ecosystem is self-organising and self-regenerating. It does not require human management. To assess and improve ecosystem integrity in and around PCAs, three important ecosystem characteristics are measured: species composition; structure (i.e. vegetation density and biomass, complexity of food webs); and processes (i.e. nutrient cycling, carbon sequestration and storage, etc.). The three kinds of stability are also considered: resistance to external perturbations; the ability to recover following a disruption; and persistence over longer time-scales (Rogers et al., 2022). PCA management that seeks to include climate change mitigation should consider ecosystem integrity in and around PCAs.

Case Study 2.5

Climate-focused forest management in the Whaelghinbran Conservation Forest, Wabanaki protected and restored forests, Canada



Submitted by

Megan de Graaf, Community Forests International

Name and location of protected area

Whaelghinbran Protected Area, Wabanaki Protected and Restored Forests, Maritime Provinces, Canada

IUCN governance type

Private protected area

The protected area

As of early 2023, Community Forests International had protected over 2,000 ha (20 km²) of Wabanaki forest in the Maritime provinces of Canada. Some of these forests are co-governed by Community Forests International and the Mi'kmaq, Wolastoqey, and Peskotomuhkati Nations of the Wabanaki region. Community Forests is actively working to return these forests to the care of the First Nations. The conservation forests are managed for climate change resilience, then carbon sequestration and storage capacity, then other co-benefits such as biodiversity and other ecosystem services. Community Forests International has now become the region's lead in the research, development and demonstration of both forest carbon offsets opportunities, and climate-focused forestry. This case study focuses on the Whaelghinbran protected area, a 230 ha (2.3 km²) property purchased by Community Forests International in 2012.

The project

Upon project implementation, Community Forests International inventories the forest, including the forest carbon. Biomass is measured using a sampling procedure developed in-house, based on Dr John Kershaw's 'big BAF' method (Chen et al., 2019). Biomass from forest inventory results are then converted to elemental carbon using allometric equations (Lambert, Ung, & Raulier, 2005).

In this manner, the Whaelghinbran forest was inventoried upon acquisition and calculated to be storing 12,060 tonnes CO₂e (above the regional baseline) at that time. The inventory information was then used to build climatefocused management plans for each forest property, called Forest Healing Plans. These are increasingly completed in collaboration and consultation with local Indigenous Nations. Forest Healing Plans are used to direct strategic activities towards climate resilience and mitigation goals. These include: creating climate-focused forest management resources and tools for forestry professionals; training forestry professionals in implementing carbon methods and climate-smart management; and working with Indigenous Nations. The Whaelghinbran forest has undergone four climate-related forestry interventions in this time, with the goals of increasing the climate resilience, carbon storage capacity, and biodiversity habitats of the forest. Interventions have been accompanied by continuous active management of the forest.

Successes

This group continuously monitors the success of their projects through tree species composition, growth, and carbon stocks, to understand the impact of improved forest management activities at the property level and across the totality of forests in their management. The Whaelghinbran forest was re-inventoried in 2017, and it was discovered that there have been 4,603 tonnes of CO₂e sequestered since 2012. They have since also expanded the property to include an additional 153 ha (1.53 km²), which will be inventoried later in 2025. This property is the main demonstration site for climate-focused forest management in the province of New Brunswick.

Challenges

Some challenges with these projects have included: a limited perspective of conservation by provincial and federal governments, and correspondingly limited funding for forest protection and management for climate benefit; provincial and federal governments' unwillingness to recognise underlying Indigenous land title, and respect treaties with those peoples; sluggish carbon offsets markets in the region; and limited contractor capacity for implementing climate-focused forestry.

Additional resources

(Community Forests International)

2.7 Barriers to policy integration

Some of the barriers to integrating policies for protected areas across biodiversity and climate change include: (i) inadequate institutional coordination; (ii) knowledge gaps including data and storage; iii) inconsistent funding and interest from donors on implementation; (iv) resource and capacity constraints; and (v) lack of willingness to pursue mitigation (Shrestha & Dhakal, 2019).

2.7.1 Institutional barriers

Institutional barriers are one of the biggest obstacles to meeting the multiple objectives of climate mitigation and biodiversity conservation in PCAs. These include a lack of coordination between government agencies and sectors, overlapping mandates and inconsistent policies, and contradictory legal arrangements across countries. For example, in a study in Nepal (Shrestha & Dhakal, 2019), inadequate institutional coordination was considered the largest barrier to simultaneously addressing the goals of climate change mitigation and biodiversity conservation. Likewise, institutional capacity has been identified as the largest barrier to an increase in participating in climate change mitigation programmes, such as Low-Carbon Development Plans (LCDPs) in Africa (Adenle, Manning, & Arbiol, 2017).

Wamsler and colleagues (Wamsler et al., 2020) identified the lack of an institutional and regulatory framework, which leads to creative but localised and in some cases unscalable solutions, as a key barrier to incorporating Nature-based Solutions into policies. For example, endangered species legislation usually focuses on maintaining historical species' ranges. For the identification of new PCAs, a focus on projected future ranges, the irreplaceability of some ecosystems and the future climate would be useful (Pettorelli et al., 2021; Ranius et al., 2023).

There are also structural impediments that make climate mitigation in PCAs difficult to achieve through international frameworks. On the international scale, biodiversity and climate change mitigation are currently primarily determined by the CBD and UNFCCC, respectively, that function under different levels of resources and political leverage (Pettorelli et al., 2021). Officially recognising the synergies between biodiversity and climate change, beyond statements and voluntary actions, has been resisted by Parties to the CBD and the UNFCCC.

A Liaison Group of Biodiversity-related Conventions was established in 2004, composed of the heads of the secretariats of the eight biodiversity-related conventions: CBD; Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES); Convention on the Conservation of Migratory Species of Wild Animals (CMS); Ramsar Convention on Wetlands (Ramsar), Convention Concerning the Protection of the World Cultural and Natural Heritage (WHC); International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA); International Plant Protection Convention (IPPC); International Whaling Commission (IWC) (Rogalla von Bieberstein et al., 2019).



Salt marshes are important for the carbon stored in their sediments and the feeding grounds they provide for many species, such as these Common Egrets. @ arnau2098 / iStock.com



Carbon-dense boreal forest in Finland. © Ruzdi Ekenheim / iStock.com

2.7.2 Technical barriers

Technical challenges such as the lack of data and standard methodologies, incomplete knowledge and insufficient capacity can also be a deterrent to decision-makers to integrate the biodiversity and climate change agendas. Influential groups with vested interests can often outweigh community perspectives (Wamsler et al., 2020). Processes related to PCA creation and management are increasingly focused on stakeholder engagement, which requires particular skills in relational approaches that some participants and staff might lack. Closing these knowledge gaps, harmonising indicators and methods, and sharing such information with stakeholders can help to inform policy, both with respect to existing commitments as well as in response to the GBF and revised national ambitions under the UNFCCC.

Mitigation policies and targets identified under UNFCCC are typically expressed in terms of emissions and fluxes (see Chapter 4 on Methodology for quantifying carbon sinks and stores) rather than stocks. However, one important role of PCAs in climate change mitigation is the avoided emissions from the protection of carbon stocks. As standardised methods are developed to estimate potential emission reductions from conserving carbon stocks, it will become easier to quantify the role of PCAs in climate change mitigation (de Lamo et al., 2020). Further, although oceans have now been integrated into the areas of work under the UNFCCC, and MPAs are considered an ocean-based climate solution, the extent to which MPAs can protect carbon pools and enhance carbon sequestration is an area of active research with many knowledge gaps.

2.7.3 Financial barriers

There is "substantial and chronic underfunding" of biodiversity conservation globally, estimated to be USD 700 billion (Gonon, Svartzman, & Althouse, 2024). The new Global Biodiversity Framework Fund, agreed to at CBD COP15 and set up by the Global Environment Facility in August 2023, is intended to alleviate some of the underfunding problem for biodiversity (Global Environment Facility, 2023). At COP15, countries committed USD 20 billion per year by 2025, and USD 30 billion per year by 2030 to the fund. The Global Biodiversity Framework Fund will provide resources for implementation of the GBF, which will include funding for stakeholder engagement (Wamsler et al., 2020) and integrating protected areas into climate change mitigation and adaptation (Pettorelli et al., 2021). It is, however, important to point out that as of 2 November 2024, post CBD COP16, all new plus existing funds totalled only 3.5% of the international target (Buckley, 2025). PCAs are mostly understaffed and underfunded, often preventing effective enforcement. Chapter 8 Financing protected areas for climate change mitigation, addresses some of the issues related to funding PCAs with carbon offsets.

2.8 Conclusion

There is clear scope to better recognise the role PCAs can play in climate change mitigation. Timely opportunities exist (e.g. NDC and NBSAP revisions) to scale up the role of PCAs in climate mitigation policies and in turn scale up climate change mitigation measures in PCA design and management. Despite current barriers, as more research occurs and knowledge is shared about the interconnectedness between PCAs and climate change mitigation, these challenges will be overcome. The integration of policies should not fall on the shoulders of one side only; both PCA authorities and climate change actors need to work together and in parallel if the benefits of PCAs and climate change mitigation are to be fully realised.

Chapter 3

Ecosystems with high value for carbon and biodiversity

Risa B. Smith, Neal Pastick, Olga Laiza Kupika, Tim Healy and Anouska Kinahan

3.1 Chapter highlights

- ✓ Not all ecosystems are equal in their ability to sequester and/or store carbon. Forests, grasslands/savannas and peatlands are the most important terrestrial ecosystems for sequestering CO, from the atmosphere on an annual basis. Forests (tropical, boreal and temperate), peatlands, grasslands and coastal blue carbon ecosystems are the most important for storing carbon, although forests tend to dominate because of the vast area they cover globally.
- ✓ An assessment of the climate change mitigation potential of a particular area, be it on land or in the coastal marine area, must consider both below and above-ground carbon. Some of the most important ecosystems for climate change mitigation have most of their carbon stored below ground (e.g. boreal forests and mangroves).
- ✔ Preventing natural ecosystems from releasing their stored carbon, and conserving the longterm ability of ecosystems to sequester carbon from the atmosphere, is at the core value of PCAs for climate change mitigation. This is often referred to as avoided emissions.
- ✓ Efforts are underway to understand where the places are with the highest potential for climate change mitigation and biodiversity conservation. Greater focus on overlaying biodiversity hotspots with carbon-density is needed.

3.2 Introduction

"Climate change mitigation refers to actions or activities that limit emissions of GHGs from entering the atmosphere and/or reduce their levels in the atmosphere" (IPCC, 2022).

There are two ways in which protected areas can mitigate climate change: i) by protecting carbon stores so that they are not subsequently released into the atmosphere, often referred to as avoided emissions; ii) by protecting the ability of ecosystems to sequester carbon dioxide from the atmosphere. Some ecosystems are known to sequester and store vast amounts of carbon: others do not. A caveat here is that while particular ecosystems may seem less important for climate change mitigation, on a global scale, they may be important on a regional or national scale. Consideration of climate change mitigation in PCA identification and management needs to identify the most relevant ecosystems for climate change mitigation and then match them with biodiversity hotspots (see also Chapter 6). Sometimes a PCA created for species conservation can have unexpected benefits for climate change (i.e. case study 5.1 on Climate co-benefits of tiger conservation, Sariska Tiger Reserve, India, Chapter 5).

Olympic National Park, USA. Example of a carbon-dense temperate rainforest. © Scott Walton / iStock.com



3.3 Key ecosystems for climate change mitigation

First, it is important to emphasise that prioritising protection of relatively intact and pristine areas is the most effective way to preserve carbon and biodiversity. While restoration is important, it is a common misconception that restoration can replace the loss of natural systems (Mori & Isbell, 2023). The most important ecosystems for sequestering CO₂ from the atmosphere are summarised in Figure 3.1. The most important ecosystems for storing carbon are summarised in Figure 3.2. The global distribution of stored carbon in terrestrial ecosystems is found in Figure 3.3. A similar map for global distribution of stored carbon in marine and coastal systems is not available. It is important to note that some ecosystems, and particularly coastal blue carbon ecosystems (CBCE) have a higher density of stored carbon, measured as kgC/m². However, because of their limited distribution across the globe, they do not have the same global impact as more extensive terrestrial ecosystems. On a national or more local scale CBCE may be the most important.

Global carbon sequestration potential for key ecosystems (Mt CO₂/year)

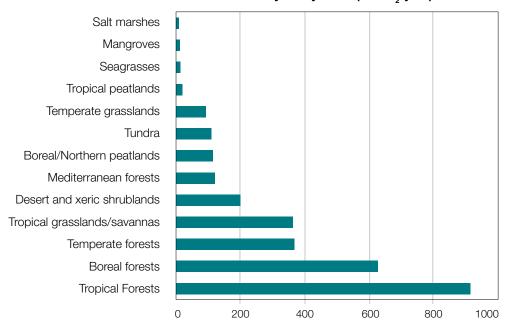


Figure 3.1 The estimated values of carbon sequestration for different ecosystems. Derived by Risa B. Smith from Taillardat and colleagues (Taillardat, Friess, & Lupascu, 2018)

Carbon storage in selected ecosystems billion tonnes (Gt) C

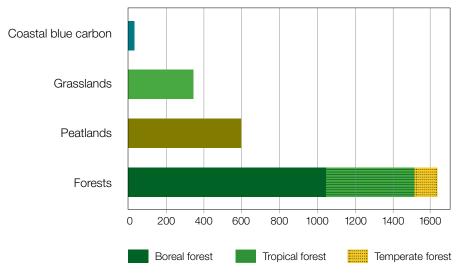


Figure 3.2 Estimates of global carbon storage in selected ecosystems. Sources for estimates are: Coastal blue carbon (mangroves, salt marshes and seagrass beds) (Macreadie et al., 2021); Grasslands (Lorenz & Lal, 2018); Peatlands (Strack et al., 2022); Forests (Woods Hole Climate Research Center et al., 2020)

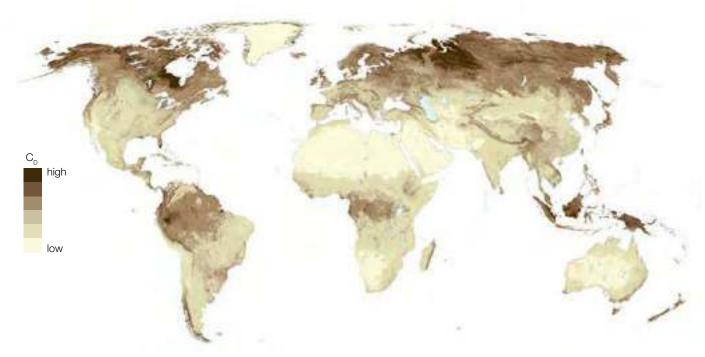


Figure 3.3 Terrestrial above and below-ground vegetation biomass carbon and soil organic carbon density to 1 m depth. Range of carbon density (C_D) is 0–4,011 tonnes/ha. Dark brown indicates high carbon-density, lighter colours indicate low carbon-density. Source: (Soto-Navarro et al., 2020). Reproduced with permission of Royal Society (UK).

Ecosystems	Percentage protected	Source
Global forests	21%	(WRI, 2024)
Global intact landscapes	46%	(WRI, 2024)
Tropical primary forests	39.0%	(WRI, 2024)
Boreal forests	2.8%	(Morales-Hidalgo, Oswalt, & Somanathan, 2015)
Temperate forests	11%	(Morales-Hidalgo, Oswalt, & Somanathan, 2015)
Global peatlands	19%	(UNEP, 2022)
Tropical peatlands	unknown	
Arctic peatlands	20.2%	(CAFF & PAME, 2017)
Temperate and boreal peatlands	~20%	(UNEP, 2022)
Global grasslands	unknown	
Native temperate grasslands	4.6%	(Carbutt, Henwood, & Gilfedder, 2017)
Savannas	unknown	
National waters (EEZ) (as a proxy for coastal blue carbon)	19%	(World Database on Protected Areas (WDPA), 2025)
Marine sediment	2%	(Atwood et al., 2020)

Table 3.1 Comparison of percentage protected for ecosystems with high carbon density. The percentage protected is likely higher for ecosystems for which the only available analysis was more than eight years ago.

3.3.1 Terrestrial ecosystems

3.3.1.1 Forests

On a global level, forests sequester (see Figure 3.1) and store (see Figure 3.2) more carbon than other ecosystems. In spite of significant losses of $\rm CO_2$ to the atmosphere from deforestation and forest degradation, global forests were still a net carbon sink of ~7.6 Gt $\rm CO_2$ e between 2001 and 2019 (Harris et al., 2021). While all forests are important for climate change mitigation, not all forests are equal in terms of the amount of $\rm CO_2$ they sequester each year and the amount of carbon that they store above- and below-ground.

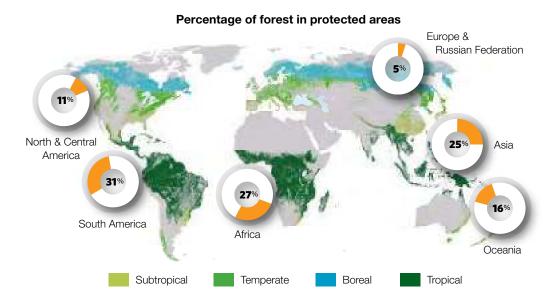
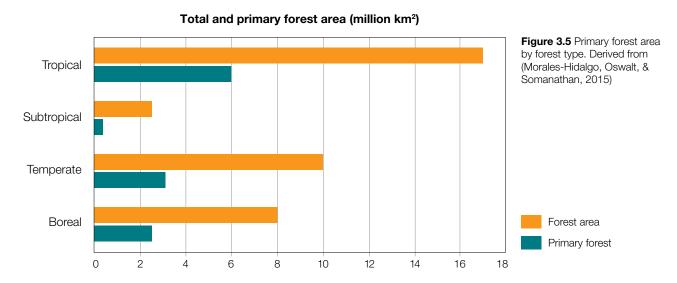


Figure 3.4 Distribution of global forest area by climatic domain (United Nations World Map, 2020) and percentage of forests protected by region (circles). By 2020, the latest year for which a full analysis was done, 18% of global forests were legally protected. However, it ranged from more than 30% in tropical rainforest, subtropical dry forest and temperate oceanic forests, to less than 10% in subtropical humid forests, temperate steppe and boreal coniferous forest. Map showing distribution of forest types. Reproduced with permission (FAO, 2020). Percentage protected derived from (FAO & UNEP, 2020).

Primary forests

Primary forests are defined as "naturally regenerated forests of native species, where there are no clearly visible indicators of human activities and the ecological processes are not significantly disturbed" (cited in Morales-Hidalgo, Oswalt, & Somanathan, 2015). They are disproportionately important for climate change mitigation because they:

- are exceptionally carbon dense;
- represent a globally significant carbon stock;
- are more resistant to natural disturbance (i.e. more stable) than plantation forests or other forms of degraded forests;
- have carbon stocks that are irrecoverable within a meaningful timeframe to prevent catastrophic climate change;
- have a high ecosystem integrity, allowing them to persist over the very long term. (adapted from Kormos et al., 2023).



Tropical forests

Worldwide, tropical forests store approximately 471 Gt carbon, above and below ground, greater than all carbon emissions from fossil fuels since 1750. Although it is estimated that 39% of primary tropical forests are in protected areas (WRI, 2022), significant forest area within protected areas is lost, sometimes due to natural disturbances such as wildfires, but often due to logging within protected areas (WRI, 2022).

Boreal forests

Boreal forests cover ~30% of the global forest area, contain an estimated 32% of global terrestrial carbon stocks, sequester ~20% of the total carbon sink of the world's forests, contain more surface freshwater than any other biome, and contain large tracts of intact, unmanaged forests (Gauthier et al., 2015). Recent increases in the length of the wildfire season, and extent and intensity of wildfires in the boreal have been attributed to climate change (Veraverbeke et al., 2017). Increasing investments in controlling boreal wildfires is a cost-effective strategy to mitigate the GHG emissions from forest fires that could be pursued by PCA managers (Phillips et al., 2022). However, just over half of boreal tree cover loss in Canada and 66.5% in Russia is attributed to wildfires, while the rest is attributed to forestry (WRI, 2022). Approximately 2.8% of the world's boreal forest is estimated to be formally protected as of 2015 (Morales-Hidalgo et al. 2015), indicating that the protection of boreal forests provides opportunities for climate change mitigation through the creation of new protected areas.

Temperate forests

Globally, temperate forests store about 119 Gt of carbon in their above and below-ground biomass and soils. Temperate forests cover about one-third of their original extent. Big old trees in temperate forests can tower >100 m and live for over a thousand years, continually accumulating and storing carbon. The carbon in primary (or old-growth) temperate forests is irreplaceable within a timeframe essential for climate change mitigation, indicating an opportunity for increased protection. This includes the coastal temperate rainforests from northern California to southeast Alaska, Mountain ash forests of Australia and Kauri forests of New Zealand. As well, primary temperate rainforests are more resistant to drought and fire than plantation forests (Law et al., 2018; Woods Hole Climate Research Center et al., 2020).

Large trees in the Styx Tall Trees Conservation Area, Tasmania. Temperate forests, like this, are extremely carbon-dense compared to other forests. @ Alec Marr



Case Study 3.1

The capacity of the Dja Wildlife Reserve, Cameroon, to store carbon



Submitted by

Roger Bruno Tabue Mbobda, Dja Wildlife Reserve, Cameroon

Name of PCA and location

Dja Wildlife Reserve, South-East Region, Cameroon

IUCN governance type

Government

The protected area

Considered one of the largest and most well-conserved protected rainforests in the world, the Dja Wildlife Reserve stretches from the southern part of the southern region of Cameroon to its eastern region, covering 526,000 ha (5,260 km²). The Dja river borders threequarters of the reserve, creating a natural barrier and protecting the 50-60 metre-high trees within. Although the PCA was created with the purpose of biodiversity conservation, direct climatic impacts on the reserve have caused managers and decision-makers to integrate climate change adaptation and mitigation into management priorities. Climatic impacts include prolonged droughts resulting in the desiccation of small rivers, alterations in the spatial distribution of faunal species and changes in the phenological patterns of certain plant species.

The project

The research team employed Landsat imagery to classify extensive vegetative cover types, which were subsequently validated through fieldwork. Using the transect method, data were collected on trees with a diameter at breast height (DBH) greater than 10 cm, defined as the measurement taken at 1.30 m above the ground. Each sampled tree was identified at the species level, and DBH measurements were recorded, along with

additional measurements taken 30 cm above the buttresses when applicable. DBH measurements were converted to biomass using equations specifically developed for the study area. The biomass of tree roots was estimated by multiplying the above-ground biomass measurements by a factor of 0.24, as per Mokany and colleagues (Mokany et al., 2016). Litter samples were collected from 1 m² plots, while grass samples were sampled from 0.5 m² plots every 1,250 m along the transect. These samples were subsequently dried in a laboratory and weighed.

Roots were extracted from 20 cm² plots every 1,250 m along the transect and were separated from the soil using water. The dried roots were then weighed to determine dry biomass. Utilising these data and established methodologies from the literature, the team then assessed the carbon stocks and carbon sequestration potential in the area (Chave et al., 2014; Mokany, Raison, & Prokushkin, 2006; Zapfack et al., 2013).

Successes

The Dja Wildlife Reserve stored an average of 210 tC/ha across 270 tree species. Notably, the most abundant individual trees were found in the lower diameter classes, indicating a favourable potential for regeneration within the population. Specifically, 82.8% of individuals were recorded in the 10-40 cm diameter class. The research team anticipates that the findings of this study will facilitate securing carbon markets in the future.

Challenges

Funding and the acquisition of satellite images for the stratification of the forest were the greatest project challenges. The intention was to use high-resolution SPOT images (from the French 'Satellite pour l'Observation de la Terre'), however the images were unavailable. Landsat images with a low resolution (30 m) above the ground were used in their place.

Additional resources

(Mbobda et al., 2018)

3.3.1.2 Peatlands

While peatlands are relatively rare, covering 1.85 to 4.3 million km², or ~2.84% of the world land area (Ribeiro et al., 2021; Xu et al., 2018), they play a disproportionately crucial role in global carbon dynamics as they store an estimated 450 to 650 Gt of carbon (UNEP, 2022) or 30-40% of the global soil carbon (UNEP, 2022). Since the 1960s global peatlands have turned from a net sink into a net source of soil-derived GHGs (Leifeld, Wüst-Galley, & Page, 2019). Only about 19% of these invaluable peatlands are within protected areas, emphasising the need for intensified conservation efforts. UNEP recommends that 88% of the remaining global peatlands that are not degraded should be protected to avoid their carbon stores being released into the atmosphere (UNEP, 2022).

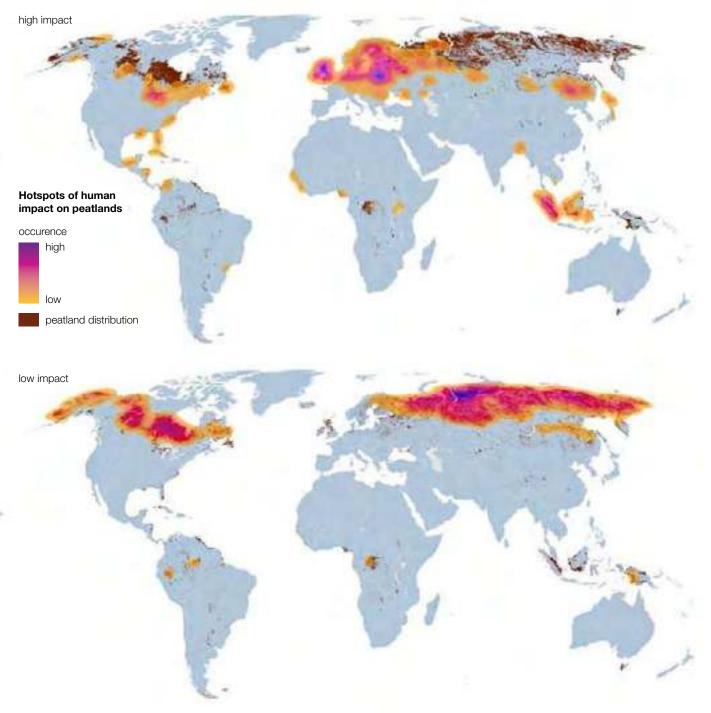


Figure 3.6 Hotspots of global human impact on peatlands. High impact areas are heavily influenced by humans and low impact areas are lightly influenced by humans. Source: Figure 2.9 in (UNEP, 2022)

Peatland distribution

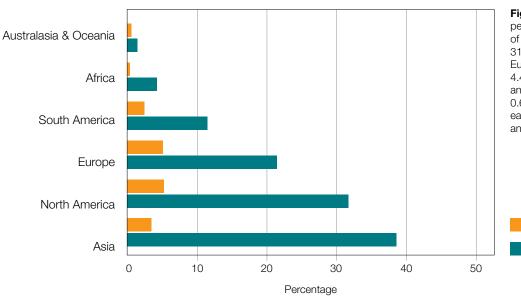


Figure 3.7 Global distribution of peatlands. The global distribution of peatland area is: 38.4% Asia; 31.6% North America; 12.5% Europe; 11.5% South America; 4.4% Africa; 1.6% Australasia and Oceania. This represents 0.6% to 5.4% of the land area of each continent. Derived from Xu and colleagues (Xu et al., 2018)

% of land area

% of global peatland area

Tropical peatlands

From 1850 to 2015, 24.7 million ha of natural tropical peatlands have been lost (Leifeld, Wüst-Galley, & Page, 2019). According to UNEP, conservation and restoration of tropical peatlands could reduce global GHG emissions by 800 Mt $\rm CO_2e$ (close to 2% of current annual global emissions), although there is considerable variation in estimates of the extent and carbon stores in tropical peatlands. The largest tropical peatlands, by area, are in Southeast Asia (~240,000 km²), Africa (~187,062 km²), South America (~485,832 km²) (Xu et al., 2018). Tropical peatlands are estimated to store 152–288 GtC, equivalent to burning fossil fuels at a rate of 10 GtC per year for the next 15–30 years (Ribeiro et al., 2021). Under certain natural conditions, as well as anthropogenic influences, tropical peatlands can act as major sources of GHG emissions such as carbon dioxide ($\rm CO_2$) and methane ($\rm CH_4$) although they are currently believed to be a net sink of $\rm CO_2$. The impacts of climate change on tropical peatlands, such as drying and increased fire severity and extent are contributing to the loss of tropical peatlands (Schmidt et al., 2024). In the Congo basin, possibly the largest tropical peatland complex in the world, only 11% of the peatlands are located within nationally recognised protected areas (Dargie et al., 2018).

Peatland forests of the Congo Basin are the largest continuous complex of tropical peatlands in the world. This photo is from Odzala-Kokoua National Park, Republic of Congo (or Congo-Brazzaville). © Roger del la Harpe / iStock.com





Carbon-dense peatlands in Canada's Arctic. @ Pi-Lens / Shutterstock.com

Arctic peatlands

The Arctic, although not necessarily under imminent threat from development, is under threat from climate change and provides habitat for millions of migratory birds and large migratory mammals, both on land and in the ocean (Mitchell et al., 2021; Soto-Navarro et al., 2020). While the global estimate for above-ground carbon in peatlands is low (~3.17 Gt C), soil organic carbon stored in Arctic permafrost soils is substantial (1,460 to 1,600 Gt by some estimates). As a result of climate change ice-rich permafrost is thawing, resulting in the release of its stored carbon (Schuur et al., 2021). The process of permafrost warming, and the subsequent release of GHGs, can be amplified by land-use decisions, natural resource extraction (Jorgenson et al., 2010; Raynolds et al., 2020), and observed increases in tundra wildfires in some areas (Moon, Druckenmiller, & Thoman, 2024). While enhancing protection of permafrost soils in the circumpolar Arctic cannot stop the warming caused by climate change, it can eliminate impacts of development. Arctic tundra, where most of the permafrost is found, has been transformed from a carbon sink to a carbon source, although there are regional differences that are important to consider when assessing the carbon dynamics in a particular area (Moon, Druckenmiller, & Thoman, 2024). In 2016, 20.2% of the terrestrial area in the circumpolar Arctic was protected (CAFF & PAME, 2017).

Temperate and boreal peatlands

Temperate and boreal peatlands have been systematically drained for agriculture, forestry and peat extraction, particularly in Europe and East Asia (See Figure 3.6). Between 1850 and 2015, 26.7 million ha of natural temperate and boreal peatlands have been converted (Leifeld, Wüst-Galley, & Page, 2019). North America peatlands cover ~158 million ha: less than 2% of peatlands have been degraded but less than 20% are in protected areas. In Europe, almost 50% of temperate peatlands have been degraded. As a result, Europe is the second largest emitter of GHGs from drained peatlands at close to 600 Mt CO₂e per year, and the highest historical emitter in cumulative terms. Approximately 20% of Europe's peatlands are in protected areas. Large-scale restoration programmes for European temperate peatlands might reverse some of the ecosystem and carbon losses (UNEP, 2022). However, recent studies have demonstrated the complexity of recovering lost carbon through peatland restoration. Although rewetting can result in a decrease in CO₂ emissions from degraded peatlands, it can also result in an increase in CH₄ emissions (Darusman et al., 2023; Escobar, Belyazid, & Manzoni, 2022), leading to the conclusion that protection of existing temperate peatlands is a high priority for retaining the climate change mitigation benefits of temperate peatlands (UNEP, 2022).

3.3.1.3 Grasslands

Grasslands are typically land on which the existing plant cover is dominated by grasses. They cover ~40% of the Earth's terrestrial area. They play an important role in the global carbon cycle, contributing 25–34% of the global carbon stock. Globally grasslands store approximately 525 to 634 Gt C, most of which is in the soil (Liu et al., 2023). Carbon sequestration is slow in grasslands (estimated at 0.5 Gt C/year for all of the world's grasslands) and once converted it can be difficult to recover the lost carbon (Lorenz & Lal, 2018).

Grasslands occur in a wide range of biogeographical contexts including tropical and subtropical savannahs of Africa, Australia, Asia and South America; the circumpolar Arctic, the boreal, temperate and southern prairies of North America and the steppes in Eurasia (see Figure 3.8). Very little of the world's ancient grasslands – those that have had minimal human intervention – persist today. Table 3.2 provides a summary of the loss of grasslands. Protection of below-ground processes is critical to the maintenance of ancient grasslands and their value for climate change mitigation (Buisson et al., 2022).

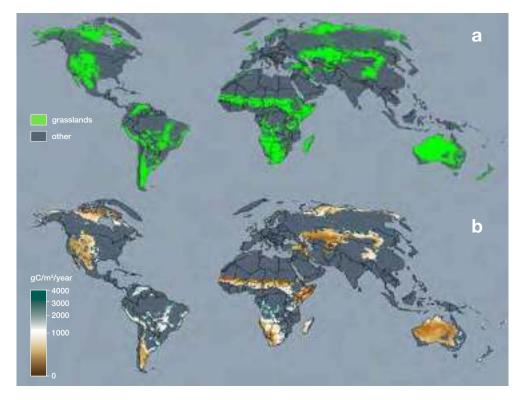


Figure 3.8 Global annual map of gross primary productivity (GPP). The maps show a) Grassland distribution; b) grassland Global Primary Productivity (GPP). GPP is used as a proxy for above-ground carbon sequestration (Isik et al., 2024). Reproduced under license CC BY 4.0.

Table 3.2 Examples of loss of grasslands during the last century. Derived from information in (Bengtsson et al., 2019) except for Eurasian Steppe which is derived from (Du et al., 2024).

Location	Percentage grassland lost or degraded
Southern Africa	60%
Northern Europe	90%
North America	80%
Eurasian Steppe	2000 to 2022. 2.83% of grassland experienced land degradation
South America	60–80%

Ancient grasslands are poorly represented in the world's protected areas system. Only 4.6% of remaining native temperate grasslands are formally protected (Carbutt, Henwood, & Gilfedder, 2017).

3.3.1.4 Savannas

Savannas are grasslands with scattered trees. They are most often located near the equator. Above-ground carbon in savannas ranges according to the extent of tree cover from 1.8 tC/ ha where trees are absent to over 30 t C/ha where there is substantial tree cover. The carbon stored in savannas is likely underestimated because of the failure of most authors to consider below-ground carbon (Grace et al., 2006).



Herd of wildebeest in the savanna. Great Migration. Masai Mara National Park. Kenya and Tanzania. © dene398 / iStock.com

3.3.2 Coastal blue carbon ecosystems

Coastal blue carbon ecosystems (CBCEs) have significant benefits for biodiversity and people, including protection from storm surges and sea level rise, wave attenuation, erosion prevention along shorelines, coastal water quality regulation, nutrient recycling, sediment trapping, habitat provision for numerous commercially important and endangered marine species and food security for many coastal communities and climate mitigation, which is the subject of this report.

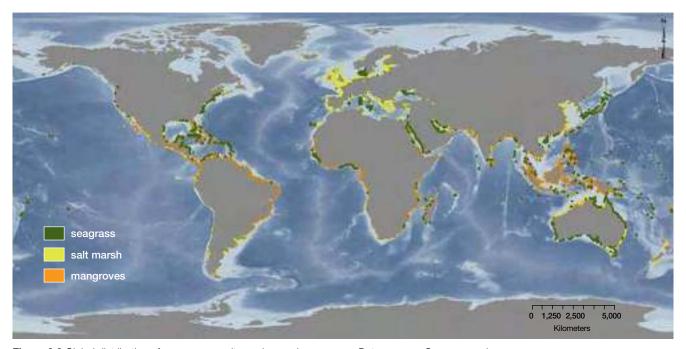


Figure 3.9 Global distribution of seagrasses, salt marshes and mangroves. Data sources: Seagrass and salt marsh coverage data are from UNEP-WCMC; mangrove data from UNEP-WCMC in collaboration with the International Society for Mangrove Ecosystems (ISME). Source: (Pendleton et al., 2012)

Chapter 3 Ecosystems with high value for carbon and biodiversity

CBCEs include mangrove forests, salt marshes and seagrass meadows, all of which are threatened by human activities. Although there is evidence that other marine ecosystems may also be important in climate change mitigation, to date the Intergovernmental Panel on Climate Change (IPCC) only recognises CBCEs as a pathway eligible for inclusion in national GHG inventories (Howard et al., 2023), and by extension in Nationally Determined Contributions to the Paris Agreement.

On a global scale, CBCEs have a small impact on reductions in GHG emissions compared to more widespread terrestrial ecosystems, such as forests. Recent estimates are that CBCE mitigation only accounts for 0.4% of global CO₂ emissions related to fossil fuel emissions. However, their significance can be much greater on a national scale, particularly in the tropics and particularly for seagrasses (Alongi, 2023). Estimates of the global extent, carbon stocks and sequestration rates of CBCEs vary, depending on the methodology by which they were calculated, local environmental conditions and assumptions about regional differences embedded in models. The most recent estimates of CBCEs are summarised in Table 3.3, below.

	Mangrove	Salt marsh	Seagrass
Global area (km²)	834	550	1,600
	1,280–1,690	320–600	1,600–2,670
Mean C stock (=density) (Mg C _{org} per ha)	738.9	317.2	163.3
	475	266	<i>327</i>
Global Mean C Stock (Gt C _{org})	6.17	1.74	2.61
Mean C Sequestration (g C _{org} /m²/year)	179.6	212.0	220.7
Global C Sequestration (Tg C _{org} /year)	14.98	11.6	35.31
Note: Gt are identified in square brackets:	[0.01498]	[0.0116]	[0.03531]
1 Gt=1000 Tg	<i>17.7–23.6</i>	8.5–9.0	11.1–27.1
Conversion rate (%/year)	0.16	1.32	1.5
	<i>0.13–0.</i> 39	0.28–2	<i>0.14–1.4</i>
C emissions (Gt CO ₂ e/year)	0.088	0.084	0.144

Table 3.3 Areal extent, carbon stocks, sequestration rates and CO₂ emission losses from habitat conversion of CBCEs. Sequestration rates in square brackets provide the estimates in Gt/year, which is the usual unit used for policy. Summarised in (Alongi, 2023; Howard et al., 2023). Ranges reflect the differences identified in these two sources. Calculations from Alongi, 2023 are in regular type and from Howard et al. are in italics.



Mangrove forest in Brazil. © Vitoriano Jr / iStock.com

3.3.2.1 Marine protected areas and coastal blue carbon ecosystems

It has been estimated that 340,000 to 980,000 hectares (3,400 to 9,800 km²) of CBCEs are destroyed each year (Howard et al., 2014). Avoiding ecosystem loss of blue carbon through protection is the highest possible mitigation which can be achieved (Howard et al., 2023). Restoration of blue carbon ecosystems is the second most important activity. One estimate is that restoration of lost CBCEs could reduce global emissions by 3% (Macreadie et al., 2021).

Case Study 3.2

Orla Marítima da Baía de Sepetiba Environmental Protection Area, Brazil



Submitted by

Mário Luiz Gomes Soares and Gustavo Calderucio Duque Estrada, Núcleo de Estudos em Manguezais -Universidade do Estado do Rio de Janeiro (NEMA/UERJ); Instituto Pereira Passos (governmental institution)

IUCN governance type

The 'Orla da Baía de Sepetiba' Environmental Protection Area is classified as an IUCN Category V protected area and is managed at the sub-national level. This PCA encompasses the segment of Sepetiba Bay located within the municipality of Rio de Janeiro.

Name of PCA and location

The Brazilian National System of Protected Areas, established under Federal Law No. 9985/2000, delineates two primary categories of protected areas (PCAs): 1) Full Protection Areas, which impose stricter restrictions on resource utilisation, allowing only indirect utilisation of natural resources, and; 2) Sustainable Use Areas, designed to facilitate nature conservation while allowing for the sustainable exploitation of a portion of resources. Within the Sustainable Use category, the Environmental Protection Area (APA) designation (acronym derived from Portuguese) permits human habitation and the presence of private properties. Managing the competing interests caused by lenient regulations within these areas has proven to be a challenge. This case study examines Sepetiba Bay, a sustainable use area renowned for its well-preserved mangrove remnants in the state of Rio de Janeiro.

The project

This case study examines the vulnerability of the 'Orla da Baía de Sepetiba' Protected Area in the context of

projected climate change scenarios. The analytical framework employed is informed by the recommendations outlined in the First National Assessment Report of the Brazilian Panel on Climate Change, which serves as Brazil's equivalent to the IPCC. The report emphasises the necessity of integrating climate change considerations into management practices, urban planning, and environmental licensing, with a particular focus on adaptation strategies to safeguard ecosystems, especially mangrove and salt marsh remnants.

Building on these recommendations, the researchers investigated the impacts of sea level rise on the mangrove forests within the 'Orla da Baía de Sepetiba' Protected Area. They developed a predictive model, supported by existing literature, which indicated that mangroves could adapt to climate change, provided there is sufficient landward space for this adaptation. In 2008, these models facilitated the classification of all mangrove forests within the municipality of Rio de Janeiro according to their adaptive capacity to rising sea levels. At that time, a portion of the mangroves in the 'Orla da Baía de Sepetiba' Environmental Protection Area was categorised as having low vulnerability to sea level rise.

However, a follow-up analysis conducted three years later reclassified the same mangrove area as having high vulnerability to sea-level rise. This abrupt change can be attributed to the authorisation granted by Rio de Janeiro's state environmental agency for the construction of a steel plant on the landward side of the mangrove forest. The establishment of this industrial facility eliminated the space necessary for the mangroves to adapt to rising sea levels, despite recommendations from the previous studies and from the First National Assessment Report of the Brazilian Panel on Climate Change.

Successes

This case study exemplifies the harmful consequences of not incorporating climate change scenarios into the management and allowing natural process in the coastal zone. The increased vulnerability of these blue carbon reservoirs will have a large impact on the ability of these ecosystems to mitigate climate change.

3.3.3 Marine sediment

Marine sediments represent a significant carbon stock of on average 2,322 Gt C in the top 1 m, which is almost twice (1.75 times) the global carbon stock in terrestrial soils. Carbon buried in marine sediments can remain there for hundreds to millions of years if left undisturbed. If disturbed marine carbon can be remineralised to CO₂. The protection of marine C hotspots has been proposed as a mechanism to mitigate the potential release of carbon in marine sediments.

Marine carbon stocks are poorly protected, with only ~2% in MPAs that protect against disturbance. Approximately 48% of marine sediments are located within Exclusive Economic Zones of countries, making it possible for countries to independently protect these important stocks (Atwood et al., 2020).

"Five times as much C is stored in the deep-sea sediment (water depths > 1,000 m) than in underlying shallow seas." Hot spots for marine C sediment have been observed off the coasts of Namibia, Peru, Baja California in Mexico, and in the Caribbean Sea, Baltic Sea and Indo-Pacific region (Atwood et al., 2020). The Arctic Ocean represents one of the last remaining marine wilderness areas (Jones et al., 2018) with only 4.7% of the marine circumpolar Arctic protected (CAFF & PAME, 2017).

3.3.4 Freshwater habitats

The role of freshwater wetlands in climate change mitigation is poorly understood. In some circumstances freshwater wetlands can be sources of GHG, especially methane, and in other circumstances they are GHG sinks (Maietta et al., 2020). There is agreement that the best way to maintain the ability of wetlands to sequester and store carbon is to protect them in their natural state. The Ramsar Convention is the only global agreement dedicated to wetland preservation (Singh, Goyal, & Saikumar, 2024), although some terrestrial PCAs provide protections for wetlands. New and emerging mechanisms have been suggested to specifically address the importance of freshwater PCAs (Moberg et al., 2024).

On a global scale, wetlands are estimated to store between 202 and 535 Gt of carbon - in the same order of magnitude as carbon fixed as oil (230 Gt) or natural gas (140 Gt) (Keddy et al., 2009). The role of freshwater habitats in climate change mitigation is poorly understood. Freshwater habitats can be carbon sinks or sources. These Arctic char are in a river in Iceland, © DanBachKristensen / iStock.com



Case Study 3.3

Carbon and hydrology management of the Great Dismal Swamp National Wildlife Refuge, USA



Submitted by

Zhiliang Zhu, USGS and Fish and Wildlife Service

Name and location of PCA

Great Dismal Swamp National Wildlife Refuge, Southeastern Virginia and Northeastern North Carolina, USA.

IUCN governance type

Habitat/species management area, government

The protected area

Great Dismal Swamp National Wildlife Refuge contains some of the most important wildlife habitat in the mid-Atlantic region. Although land surveys from the late 18th century documented over 400,000 ha of undrained wetland, today only 45,729.48 ha (457.30 km²) remains. In 1974, the Great Dismal Swamp State Park was established to preserve, protect and restore the ecosystem. Tools that forest managers currently use include hydrology, forestry, and protecting and restoring the natural ecosystem. This swamp experienced a series of catastrophic disturbances from 1985-2015, including strong winds, persistent droughts and fires, which have damaged much of the swamp area.

The project

This project seeks to address the problem that few publicly available land-change models are peer-reviewed, incorporate empirical data, and can be broadly applied to many frameworks. The reason for this, authors argue, is that land-change models require data that reflect human behaviour, management preferences, and socio-economic indicators. These often necessitate local data, making it difficult to scale the models to larger or different regions. A new version of modelling has recently been released called state-and-transition simulation models (STSM), which incorporate natural disturbance and succession regimes in an ecological system. These researchers take the STSM architecture and create a Land Use and Carbon Scenario Simulator (LUCAS) model. This model couples carbon stock-flow models as a function of land use, disturbance,

and management. They then apply this model to the Great Dismal Swamp National Wildlife Refuge to estimate the effect of land use, land management and ecosystem disturbance on carbon balance. To verify and validate the model, it is then applied to a historical period (1985–2015).

Authors first sought to understand the net ecosystem production (NEP) of the Great Dismal Swamp. The NEP reflects the annual growth minus heterotrophic respiration and does not factor in disturbance or management. This was estimated at 0.64 tC/ha/yr or a net sink of 0.97 TgC. Next, researchers sought to understand the net ecosystem carbon balance (NECB) of the ecosystem. The NECB is the long-term carbon storage potential of an ecosystem while factoring in the annual carbon losses and gains due to natural disturbances and anthropogenic land use. This calculation included six historic fire events and determined the swamp to be a net source of carbon (-0.89 TgC). Furthermore, this project provided an operational framework for using LUCAS in future scenarios.

Challenges

A major technical challenge is the disconnect between immediate management needs and the relatively long time it takes to conduct research. As well, current science capabilities produce information at a relatively coarse scale, which does not meet the precision, and high confidence, required by land managers.

Additional resources

(Sleeter, 2021)



Turtles in the Great Dismal Swamp, Virginia. © Scenic Corner / AdobeStock.com

3.4 Relevant management practices that enhance the climate change mitigation value of protected areas

3.4.1 Permanence

Permanence refers to the long-term protection of carbon sinks and stores, intended to support resilient ecosystems that can better withstand expected and unexpected perturbations. It is understood that ecosystems are dynamic and that permanence, be it created through formal protected areas designations, Indigenous Protected and Conserved Areas (IPCAs), or Other Effective Area-based Conservation Measures (OECMs), does not imply that there will be no change (Osman-Elasha et al., 2005). It does imply that additional carbon sequestered and stored through policy initiatives will be secure from human threats over the long term. Recent research suggests that a storage period of at least 1,000 years is required to have a positive effect on maintaining global temperature increase to less than 2°C, highlighting the importance of protecting carbon stores (Brunner, Hausfather, & Knutti, 2024). The permanence of carbon sequestration and storage can be hampered by natural disturbances, such as variations in temperature and precipitation, storms and wildfires. Furthermore, what has been classified as natural disturbances in the past is now influenced by climate change (Gren & Aklilu, 2016; Shah et al., 2024).

When managing protected areas for climate change mitigation, permanence of the carbon sequestering and storage aspects are essential for climate change mitigation benefits. If a protected area is degraded through harvesting or converted to other uses, its climate mitigation benefits will be lost and often reversed. Between 1892 and 2018, 519,857 km² was removed from protected areas. This is called PADDD (protected area downgrading, downsizing and degazetting) (Golden Kroner et al., 2019). Successful climate change mitigation in protected areas has to have safeguards against PADDD.

Natural Climate Solutions are most effective if they are planned for longevity and not narrowly focused on rapid carbon sequestration (Brunner, Hausfather, & Knutti, 2024; Pörtner et al., 2021). Protected areas can provide safeguards for the permanence of carbon sinks and stores in forests, as evidenced by studies in South-east Asia (Graham et al., 2021) and globally (Potapov et al., 2017). Similar studies have not been conducted in other ecosystems.

3.4.2 Managing 'irrecoverable' carbon

'Irrecoverable' carbon is nature's carbon that, if lost, cannot be recovered quickly. In other words, 'irrecoverable' carbon loss represents a temporary but significant debt from the carbon budget that hampers the ability of natural ecosystems to reduce global warming trends (Goldstein et al., 2020). Protecting existing irrecoverable carbon stores is more effective than management or restoration because of the time it takes for restoration to compensate for lost carbon (Cook-Patton et al., 2021). Approximately 50% of the world's irrecoverable carbon is stored in mangroves, peatlands, old-growth forests and marshes (Noon et al., 2021). Currently 48.3% (67.1GT) of irrecoverable carbon falls into global protected areas and Indigenous Peoples and Community Lands (IPCL), with more than a third of this carbon occurring in Brazil's protected areas, and approximately a fifth occurring in legally protected Indigenous lands in the Amazonia. Understanding and identifying these key carbon stores inside PCAs enables appropriate plans to protect irrecoverable carbon stores.

3.5 Conclusions

This chapter highlights the importance of focusing on ecosystems with the most potential for climate change mitigation. It also demonstrates the importance of managing for climate change in PCAs as one of a suite of challenges that PCAs can address. The use of global data is not sufficient to determine the most important ecosystems to protect, from the viewpoint of climate change mitigation, as the value of a particular ecosystem can vary depending on specific local characteristics.



Carbon-dense tropical rainforest in Costa Rica. © quick shooting / iStock.com



Salt marsh grasses showing deep sediments of peat in Salt Pond Bay, Cape Cod National Seashore. This can be considered irrecoverable carbon due to the long period it takes to recover the peat sediments if they are lost. © Hoicy / iStock.com

Chapter 4

Methods for quantifying carbon sinks and stores

Risa B. Smith, Clarissa Samson, Zhiliang Zhu, Olga Laiza Kupika and Thomas P. Mommsen

4.1 Chapter highlights

- ✓ Two components of carbon need to be considered for all assessments of GHG emissions reductions in protected areas: the ability of the protected area in question to sequester CO from the atmosphere on an annual basis; and the ability of the protected area to store the carbon sequestered for long periods (i.e. hundreds or even thousands of years), usually measured on an area basis.
- Measuring carbon sequestration and storage in terrestrial versus coastal blue carbon ecosystems has similarities and differences. Terrestrial and coastal blue carbon accounting methodologies are compared in Table 4.1.
- ✓ Measuring carbon in natural ecosystems for the purpose of GHG emission reduction requires measuring above and below-ground carbon. Above-ground carbon is not a proxy for total carbon.
- ✔ IPCC provides specific methodologies for measuring carbon sequestration and carbon stores in different ecosystems. Simplified versions are found in the reports of some organisations. Links to these methodologies are provided in Annex 1.
- Converting biomass to carbon involves using generalised conversion factors, which introduce significant errors in the amount of carbon estimated for particular protected areas. In the absence of taking field measurements, estimates of the carbon in species types and different biomes is also available (see Table 2). These species-specific conversion factors are more accurate than generalised global conversion factors. However, the speciesspecific factors are only available for forests.
- The choice of methodology depends on the reason for doing a carbon inventory, available data and resources.

4.2 Introduction

This chapter addresses the non-monetary aspects of carbon accounting in natural ecosystems. The measurement of carbon sequestration and carbon stocks in protected and conserved areas (PCAs) is critical for assessing how the protection of nature can mitigate the effects of climate change. Countries using the natural abilities of ecosystems to sequester and store carbon, as part of their Nationally Determined Contributions (NDCs) to the Paris Agreement, are required to provide credible assessments of the mitigation benefits of the natural ecosystems that they are including in their NDCs.

This chapter aims to:

- Explain the basic elements of the relationship of natural ecosystems to the carbon cycle and greenhouse gas emissions;
- Provide an overview of methodologies to measure carbon in a wide range of ecosystems. Links to detailed methodologies are provided in Annex 1;
- Provide an introduction to the uncertainties, complexities and pitfalls of compiling carbon inventories, including issues related to field measurements, modelling and available databases:
- Provide a comparison of methodologies in terrestrial (TE) and coastal blue carbon ecosystems (CBCEs).



Aerial view of the Brazilian Amazon. © Ildo Frazao / iStock.com

4.2.1 Basic elements of the carbon cycle and natural ecosystems

There are two basic elements of natural ecosystems that make them important in the carbon cycle, and that give rise to their promise as Natural Climate Solutions (NCS): i) the ability of ecosystems to take CO_2 out of the atmosphere, usually measured on an annual basis and; ii) the ability of ecosystems to store the carbon that has been sequestered for long periods, often measured as tonnes of C per hectare (tC/ha).

4.2.2 Carbon sequestration

The process of increasing the carbon content of a carbon reservoir other than the atmosphere (i.e. plant biomass, the soil or marine sediment) is called carbon sequestration (IPCC, 2021). It is measured as the CO_2 absorbed from the atmosphere, through processes such as photosynthesis and atmospheric methane uptake by soil bacteria, minus the CO_2 and non- CO_2 greenhouse gases (e.g. methane (CH_4)) that are released to the atmosphere through plant respiration, decomposition of dead plant biomass and soil organic matter, leaching, fire and biochemical processes. By preserving healthy plants on land and vegetation in coastal blue carbon ecosystems (CBCEs) (i.e. mangroves, seagrasses and salt marshes), PCAs can ensure the continued ability of ecosystems to sequester atmospheric CO_2 . Retaining this ability is critically important because to attain the Paris Agreement goals, not only will it be necessary to stop releasing excess CO_2 into the atmosphere, but IPCC estimates that 200 to 1,200 Gt of CO_2 will have to be removed from the atmosphere by the end of the century in order to reach the Paris Agreement 1.5°C target (IPCC, 2022)¹. This confirmed a previous estimate that up to 10 Gt CO_2 per year will need to be removed from the atmosphere by 2050, and up to 20 Gt CO_2 per year by 2100 (National Academies of Sciences Engineering and Medicine, 2019).

On a large scale, sequestration is measured as Pg $\rm CO_2e/ha/year$. Note that a petagram (Pg) is the same as a gigatonne (Gt). For smaller areas, such as particular PCAs, carbon sequestration is measured as kg $\rm CO_2e/m^2/year$. We provide tables to facilitate the conversion between units (see Box 4.1).

Carbon sequestration is an example of a carbon flux, which refers to the movement of carbon between different pools in the atmosphere, soils, oceans and vegetation. Carbon fluxes are a normal part of the carbon cycle. However, they are also affected by land-use activities that can lead to the release of stored carbon, like deforestation and peatland/wetland drainage, soil disturbance, ocean acidification and by emissions of non-CO $_{\!_{2}}$ chemicals with higher global warming potentials than CO $_{\!_{2}}$ (e.g. methane from activities such as peat removal and forestry).

Accounting for carbon fluxes from ecosystems is complex and requires models which must make assumptions about the exchange of GHGs. In marine ecosystems there are added complexities including that $\rm CO_2$ in the ocean is naturally in equilibrium with atmospheric $\rm CO_2$. Even if $\rm CO_2$ is removed from the ocean, it can take thousands of years for atmospheric $\rm CO_2$ to balance with $\rm CO_2$ in the ocean after net zero emissions are achieved (Archer, 2020; Archer et al., 2009).

4.2.3 Carbon stores or reservoirs

The carbon stored in ecosystems as a result of sequestration is referred to as carbon reservoirs or stores. Ecosystems store carbon above ground, in the trees and other vegetation, dead wood and litter, and below ground, in roots, microbes, fungi, soil and marine and coastal sediments (Plugge et al., 2016). PCAs counteract anthropogenic GHG emissions by ensuring that stored carbon, which has often accumulated over centuries or longer, remains more or less locked up in the ecosystem. In the context of PCAs this is often referred to as 'avoided emissions' if an ecosystem that is threatened by an activity that would release its stored carbon is protected. Carbon storage is usually measured as tonnes CO_2e ha⁻¹ (t CO_2e /ha). However, it is sometimes seen as kg C/m^2 when the purpose is to compare the carbon density of different ecosystems or different geographic areas. If carbon is measured, it will have to be converted to CO_2 when considering its GHG mitigation potential (see Box 4.1 for conversion rates).

It is important to note that while sampling for above-ground carbon is similar for terrestrial and coastal ecosystems, sampling for below-ground carbon in CBCEs has added complications, particularly because of the need to account for the coming and going of tides and submerged plants and sediments (also see Table 4.1 for comparisons of terrestrial and coastal ecosystems).

Box 4.1

Factors used to convert carbon in various units

Unit 1	Unit 2	Conversion factor	Source
Gt C (gigatonnes of carbon)	ppm (parts per million)	X 2.124	(Le Quéré et al., 2018)
Gt C (gigatonnes of carbon)	PgC (petagrams of carbon)	1	(Le Quéré et al., 2018)
Gt C	Gt CO ₂ (gigatonnes of carbon dioxide) or Gt CO ₂ e	X 3.671	(Montero-Hidalgo et al., 2023)
Gt CO ₂	Gt C	X 0.27 ²	(Brander, 2012)

- 1. Converting from C to CO₂ is the same as converting to CO₂e because CO₂ has a GWP of 1.
- 2. Atomic mass of C is 12, mass of O is 16, mass of CO, is 12+(16*2) = 44. Conversion factor is 12/44 or 0.27

Box 4.2

Calculating CO₂e (CO₂ equivalent)

CO₂e is a measure that standardises the Global Warming Potential (GWP) of different GHGs so that a total GWP can be calculated. From the viewpoint of emissions from ecosystems, CO2, CH4 and N2O are the most relevant GHGs. In 2023, CO₂ emissions made up 73.7% of all human-caused GHG emissions (39.1 Gt of 53 Gt total), while CH₄ emissions accounted for 18.9% (10.0 Gt) and N₂O for 4.7% (2.49 Gt) and other GHGs made up the remaining 2.7% (Crippa et al., 2023). Most experts recommend using CO₂e to account for differing GWP and atmospheric life-times to estimate warming impacts, with

CO₂ as the reference point (i.e. set to 1). Calculating CO₂e requires making a calculation based on the GWP of CO₂ plus the other GHGs. Box 4.3 provides the GWP of the most important GHGs to include. Although most studies which examine GHG emissions from natural ecosystems use CO₂e, it is often unclear whether the GWP of each GHG has been properly assessed. For instance, an emission sample consisting of 97 g CO₂ and 3 g methane will have a CO₂e of 180 g using the 100-year horizon, but a CO₂e of 336 g at the 20-year horizon, revealing the important short-term warming contribution of methane.

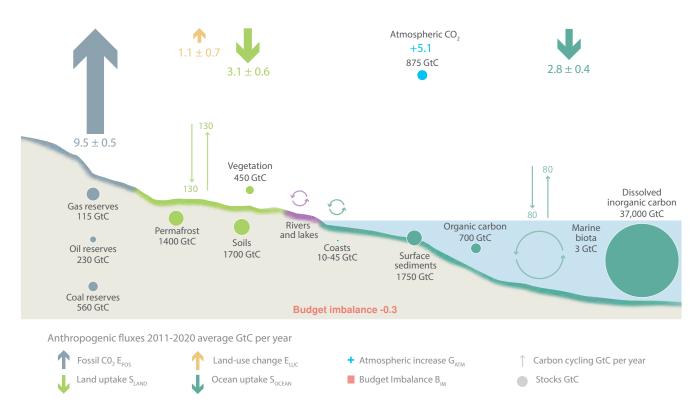
Box 4.3

Comparison of Global Warming Potentials of key greenhouse gases released from natural ecosystems

CO,, CH, and N,O are the most relevant GHGs released from disturbance of natural ecosystems. Each GHG persists for a different amount of time in the atmosphere. The half-life of 50% of CO₂ in the atmosphere is 20–100 years, 30% is centuries, 20% is millennia. CO, removal from the atmosphere involves multiple processes with different time scales. Source: Adapted from (IPCC, 2021), Table 7.15, p.1017.

Common name of GHG	Chemical formula	GWP for 20-year time horizon	GWP for 100-year time horizon	Atmospheric half-life
Carbon dioxide	CO ₂	1	1	20-100 yrs for 50% (ocean surface uptake, sequestration by terrestrial vegetation)
	CO ₂	1	1	centuries for 30% (deeper ocean mixing, long-term terrestrial carbon storage)
	CO ₂	1	1	millennia for 20% (geological processes, deep ocean circulation)
Methane – non-fossil	CH ₄	79.7 ± 25.8	27.0 ± 11	8–12 years
Nitrous oxide	N ₂ O	273 ± 118	273 ± 130	114 years

The global carbon cycle



The largest carbon pool is found in the soils of slow decomposition and cold environments in high and low latitude regions, where primary production is also slow, and in marine sediments, where anaerobic conditions prevent the release of stored carbon. In these conditions a near zero balance of carbon fluxes is maintained. Here the primary concern is climate change-induced permafrost thaw and release of soil carbon (McGuire et al., 2018). In the temperate and tropical climates, high carbon sequestration rates are found in forests and wetlands, while landscape location and land management tend to play major roles in determining the overall balance of GHG emissions, particularly of methane. Research has shown that recent restoration projects in highly managed protected areas have not only led to improved ecological functions and services, but also reduced GHG emissions compared to baseline conditions (Woo et al., 2021).

"The marine carbon cycle is complex, and the coastal carbon budget specifically has large uncertainties" that are equivalent to the amount of GHG emissions released annually through human activities (Gattuso et al., 2023). For CBCEs, the major concerns are: i) the significant historical loss of these ecosystems and subsequent release of their stored carbon into the atmosphere; ii) the vulnerability of CBCEs to sea-level rise, particularly where natural inland migration is hindered by hard coastal defences and other coastal development.

Figure 4.1 Schematic representation of perturbations in the Global Carbon Cycle for 2011-2020. The arrows represent net sequestration or emissions measured as C per year. For conversion of C to CO. multiply C by 3.67. For example, in this diagram emissions from fossil fuels of 9.5 Gt C per year is equivalent to 34.9 Gt CO per year. The circles represent total carbon stores. Source: (Friedlingstein et al., 2022). Reproduced under CC BY 4.0.

4.3 Requirements for measuring carbon sequestration and stocks in all ecosystems

4.3.1 International guidance

The Intergovernmental Panel on Climate Change (IPCC) publishes guidelines for developing carbon inventories in a wide range of ecosystems (IPCC, 2006, 2014, 2019). These guidelines must be followed by those seeking to assess the climate change mitigation potential of a specific PCA, particularly if the intent is to include that PCA in NDCs. It is important to pay attention to the various supplements to the IPCC methodologies, which usually fill gaps in previous guidelines or provide a refinement of methodologies as new information has become available. If the intent is to provide carbon inventories for the purpose of carbon offsets, using IPCC quidelines is also required, although various verification processes may have their own methodologies to consider.

The IPCC provides three tiers for greenhouse gas inventories. Moving to higher tiers improves the accuracy of the inventory and reduces uncertainty, but it also increases the complexity and resources required. Tier 3, which is the most rigorous, is recommended, although it too has uncertainties related to the models used. Many countries and organisations use Tier 1 or Tier 2 methods, or a combination of tiers, as their capacity and resources permit (see Box 4.4 for a brief description of the tiers). The IPCC guidelines and various refinements and updates provide tables with global data useful for Tier 1 or Tier 2 assessments (e.g. (IPCC, 2006, 2014, 2019)).

While field measurements provide the most accurate local results, there will always be a degree of uncertainty given that carbon processes in nature are dynamic. Several authors have provided Tier 3 quidance for specific ecosystems. For detailed methodologies see Annex 4.1, Links to guidelines for calculating GHG inventories in natural ecosystems.

When choosing a method or combination of methods it is important to adhere to the UNFCCC TACCC principle (Transparent, Accountable, Complete, Comparable, Consistent). This ensures that methods can be repeated in subsequent years to provide credible trends.

Box 4.4

Explanation of the IPCC Tiers, used to compile carbon inventories

While the tiered approach seems simplistic at first glance, the underlying technology and choices in remote sensing tools are not simplistic (Howard et al., 2023; Malerba et al., 2023).

Tier	Explanation
1	The simplest approach, relying on global emission/removal factors that apply to any country. Minimises the need for field work to generate region-specific values. On the other hand, it is also the least accurate. Tier 1 uses average emissions factors for large ecoregions of the world (e.g. boreal, temperate, tropical). IPCC guidance and software uses only Tier 1 methods. A disadvantage of Tier 1 in protected areas assessments is the high uncertainties related to baselines against which the mitigation potential of a particular PCA is measured.
2	Similar to Tier 1 but requires some country or region-specific data and usually some field data to measure soil properties and estimate emission factors. Tier 2 has increased accuracy and resolution over Tier 1 assessments. For example, a country may know the mean carbon stock for different ecosystem types within their country. In some cases where country specific data are not available, data from nearby countries that have better data and similar ecosystem characteristics can be used to reduce uncertainties over IPCC global data.
3	The most complex and rigorous approach, requiring spatially explicit models calibrated with site-specific data to improve confidence and accuracy of carbon stock and flux estimates. The Tier 3 approach often requires high-resolution remote sensing, GIS-based datasets and time series for modelling the effects of management activities on carbon fluxes in ecosystems. While IPCC recommends the use of Tier 3 for carbon inventories, most countries use Tier 1 and Tier 2 guidance.

Box 4.5

Biomass vs. carbon

When assessing carbon stocks and fluxes, estimates are first made of biomass (i.e. the sum of all of the dried weight of all of the plant material) and then that biomass is converted into carbon. Biomass does not equal carbon. Plant biomass is mostly composed of 42–47% carbon (C), 40–44% oxygen (O) and 6% hydrogen (H). Carbon stock can be calculated from biomass by multiplying the total biomass by a conversion factor that represents the average carbon content in biomass. The conversion factor ranges from 0.45 to 0.53 (see Table 4.3).

4.3.2 Availability of data products and models

Data products including maps of carbon stock, fluxes and balance estimates are publicly available for many parts of the world, released by national inventories and large-scale projects.

4.3.2.1 Maps

Maps are essential to identify the size and location of various ecosystems within a protected area. Many map products are freely available for particular countries, regions or globally. For example, a national forest carbon map server is maintained that provides map products by major carbon pools by USDA Forest Service (Wilson, Woodall, & Griffith, 2014). Wetland soil carbon stock down to 1- metre depth has been mapped at 30-metre resolution for the US (Uhran et al., 2021). Nationwide simulated net ecosystem carbon balance and associated fluxes are available as spatial maps, often calibrated with field measurements (Liu & Sleeter, 2018). Many remote sensing-derived data products such as net primary production and wildfire burn areas and emissions are available that are required input in the modelling of ecosystem carbon (Hawbaker et al., 2017).

In recent years, maps supporting Natural Climate Solutions have also been developed to aid in implementation of national and international climate policies (Fargione et al., 2018). These maps can, for example, aid in identifying the best projects for restoration of carbon density (Zhu et al., 2022). The use of any input data for policy and management applications should take care to consider uncertainties of the carbon data products including maps. Uncertainties can come from many directions, such as quality of the input data, model structure and initiation, and incorporation of management scenarios and future climate projections in the models (Luo, Keenan, & Smith, 2015).

4.4 Considerations for measuring carbon in terrestrial ecosystems

One of the biggest challenges to quantifying annual carbon sequestration and avoided emissions of stored carbon in protected areas is the availability of data at the spatial scale of a particular protected area or country or region.

4.4.1 Carbon sequestration and carbon fluxes – complexities and uncertainties

Calculations on the amount of carbon sequestered in a particular protected area can vary depending on methodology, time and spatial scale, quality of available data, definitions adopted and terms used (Chapin et al., 2006). Some important factors to include when measuring ecosystem fluxes are losses of carbon and other GHGs to the atmosphere from:

- above and below-ground respiration;
- disturbances;
- erosion and transpiration (i.e. lateral fluxes).

For example, in forested ecosystems it has been noted that estimation of above-ground carbon is often made uncertain due to excluding woody debris on the forest floor (Woodall, Heath, & Smith, 2008), and other studies have suggested that lateral carbon flux through surface water could represent up to a third of the total net ecosystem production (Butman et al., 2015).

Over space and time, balances of ecosystem carbon and GHGs are highly variable, driven by climate, ecosystem types and conditions, land and marine use, as well as management. The Second State of Carbon Cycle Report (SOCCR2) (Birdsey et al., 2018) provides an excellent review of these variabilities for North America. Likewise, Tang and colleagues (Tang et al., 2018) provide detailed methodologies for measuring carbon in China's terrestrial ecosystems, highlighting the importance of field measurements and stratifying ecosystems by factors such as precipitation.

4.4.2 Carbon storage – complexities and uncertainties

If a protected area is broad in scale and contains a variety of ecosystem types (e.g. forests, wetlands) and management issues (e.g. wildfire reduction, soil moisture improvement), a combination of approaches and methods would be necessary to capture the high variabilities and the net balances of the GHG emissions. For example, the Great Dismal Swamp National Wildlife Refuge is a protected freshwater forest wetland in eastern United States. In a study to understand potential future management directions concerning the health of the peatland ecosystem, forest survey-based biomass measurement, static chamber-derived GHG measurements, and a simulation modelling approach were used to calculate the overall balance of carbon and GHGs (Sleeter, 2021). See case study 3.3. It should be noted that often it is more important to understand what drives either potential or real changes in carbon stock and GHG emissions and ask questions about management solutions and trade-offs than simply baseline accounting. Thus, the use of simulation models is often necessary, depending on the approach taken.

Boreal forest, Canada, where carbon storage is greatest below-ground. © Lily Marcheterre / iStock.com



Case Study 4.1

Estimate of carbon storage in national parks of Korea



Submitted by

Hong-chul Park (Terrestrial) and Jung-Kwan Ahn (Marine and Coastal)

Name of PCA and location

Twenty-two national parks in Korea.

National Parks included are: Bukansan NP, Chiaksan NP, Seoraksan NP, Odaesan NP, Woraksan NP, Sobaeksan NP, Songnisan NP, Taebaeksan NP, Taeanhaean NP, Juwangksan NP, Gyeryongsan NP, Gyeongju NP, Byeonsanbando NP, Gayasan NP, Naejangsan NP, Jirisan NP, Deogyusan NP, Mudeungsan NP, Wolchulsan NP, Hallasan NP, Dadohaehaesang NP, Hallyeohaesang NP.

The project

Korea designates and manages national parks to preserve the natural ecosystem, natural and cultural scenery, and to promote sustainable utilisation by enacting the Natural Parks Act. This case study is the retroactive quantification of carbon storage in Korea's 22 national parks to create a baseline dataset as of 2022. A terrestrial assessment in all 22 parks and marine assessment in the three parks with marine/coastal components is included. The dataset will be used to compare future greenhouse gas sequestration and emissions from the national parks and contribute to the country's future climate mitigation goals. The terrestrial protected areas total 382,830 ha.



Gyeongju National Park, one of the terrestrial parks assessed for carbon storage. © Shin Won-cheol / KNPS

Methodology for terrestrial parks

Each park was first categorised into soil zones and vegetative zones. The vegetative zones were further categorised into seven different habitat types: evergreen broad-leaved forest, deciduous broad-leaved forest, deciduous coniferous forest, mixed forest, artificial forest plantation (limited to Japanese larch), mountain wetland, and alpine grassland. 30x30 m² survey plots were established within a representative of habitat type, totalling 222 plots for all of the parks. Within each survey plot, researchers identified the tree species and measured the diameter at breast height for trees with a diameter >6 cm and the total height of trees. Stand volume and biomass were then calculated using relative growth tables developed by the Korea Forest Service. For tree species missing in the Korea Forest Service equations, researchers relied on those from the United States Department of Agriculture. Biomass and stand volume were then converted to carbon storage values. Within soil plots, leaf and litter samples were collected at varying depths (0-10 cm, 10-20 cm, 20-30 cm, 30-50 cm), and the carbon content was measured using elemental analysis.

Methodology for marine parks

Each marine park was characterised into habitat types: tidal flats, mud flats and seagrass beds. For plots in each habitat type, sediment samples were taken at multiple locations using Multi sampler auger cores. Carbon content was measured using an elemental analyser.

Results

The carbon storage of terrestrial ecosystems in all 22 national parks in Korea has been analysed to be 347 million tonnes (Mt) CO₂. Carbon storage in the vegetation zone was estimated at 219 Mt CO, and in the soil zone at 128 Mt CO₂. The density of carbon in terrestrial parks was calculated to be >899 tonnes CO₂ per hectare, with 570.8 tonnes CO₂ in the vegetation and 332.2 tonnes in the soil. The average carbon storage per hectare in the terrestrial national parks of Korea is approximately twice as high as the average carbon storage per hectare in the entire forest of Korea (472.7 tonnes CO₂). For marine parks the carbon storage was 56 million tonnes, or equivalent to 204.3 tonnes CO, per ha.

Challenges

While this study focused on carbon storage, future work will focus on microbial respiration in order to allow a calculation of net ecosystem carbon uptake. Resources and time are limitations for future work.

4.5 Considerations for measuring carbon in coastal blue carbon ecosystems (CBCEs)

An internationally accepted methodology for quantifying blue carbon, which follows the UNFCCC TACCC principle (Transparent, Accountable, Complete, Comparable, Consistent), is available and described in detail (Howard et al., 2014; Kauffman & Donato, 2012). However, not all studies measuring blue carbon adhere to these standards.

4.5.1 Complexities and uncertainties of measuring carbon fluxes and storage in CBCEs

The large variation in estimates of carbon burial rates in blue carbon ecosystems makes using global averages for carbon storage highly unreliable. Variations in the literature include a 600fold difference in salt marshes, a 76-fold difference for seagrasses and a 19-fold difference for mangroves. This large variation can be due to several factors including: the local effects of burrowing animals disturbing sediments; effects of land-derived carbon in coastal sediments (up to 90%), that is carried by rivers and land run-off; effects of plant debris exported from a site. Site-specific measurements are often costly to obtain, but required to derive a credible estimate of stored carbon in coastal blue carbon ecosystems (Gattuso et al., 2023).

Long-term storage of carbon in CBCEs is made possible by the lack of oxygen in their sediments. However, these same anaerobic conditions favour production and emission of methane and nitrous oxide, two greenhouse gases with much larger climate-forcing potency than CO_o (see Box 4.3). In measuring GHG emissions from disturbed CBCEs, it is critical to account for the release of GHGs other than CO2, and also pay attention to temporal effects, including the 20-year horizon for the GWP of methane.

The long-term integrity of CBCEs is vulnerable to climate change impacts (e.g. heatwaves, sealevel rise, storm surges, loss of habitat for calcifying organisms, ocean acidification and loss of sea ice in polar regions) (Brierley & Kingsford, 2009).

Seagrass meadows, like the one depicted here, are important for carbon storage as well as biodiversity. This photo is of a grey moray eel in seagrass, Red Sea, Egypt. © Andriy Nekrasov / iStock.com



Case Study 4.2

Blue carbon study of Nusa Penida Marine Protected Area, Indonesia



Submitted by

Yusmiana P. Rahayu, August Daulat, Mariska A. Kusumaningtyas. Research Center for Conservation of Marine and Inland Water Resources, the National Research and Innovation Agency, the Ministry of Marine Affairs and Fisheries, the Republic of Indonesia.

Name of MPA and location

Nusa Penida MPA, Southeast coast of Bali Province, Indonesia

IUCN governance type

Shared (collaborative governance) between national government, state government, NGOs and communities.

The protected area

The Nusa Penida MPA, encompassing Nusa Penida Island, Nusa Lembongan Island, and Nusa Ceningan Island, was the result of a 2010 commitment by the Klungkung District Government, with support of the Ministry of Marine Affairs and Fisheries, the Republic of Indonesia. This MPA is situated in a complex environment, in which the biodiversity hotspot is influenced by the priorities of many stakeholders. This island is home to a significant tourism industry, along with high fishing pressures from both capture fisheries and aquaculture, both of which are on the rise. The objective of this MPA is marine biodiversity conservation and community sustenance, while allowing for the development of the island's economy. If the communities see benefits from these initial conservation activities, they will support future national policies for climate change mitigation actions. The purpose of the three studies below is to understand the blue carbon potential within Indonesia's coastal areas so that the nation can incorporate the climate mitigation benefits of mangroves and seagrasses into their Nationally Determined Contributions in the future.

The project

Methodology to assess carbon storage within the MPA

Researchers measured the carbon storage in the biomass mangroves of the Nusa Penida MPA (Nusa Lembongan Island) to achieve baseline blue carbon information. To do so, researchers calculated the extent of the mangrove in the MPA using Landsat 7 ETM+ using Normalised Difference Vegetation Index (NDVI). The park was estimated to be 164.57 ha. Next, the group laid a transect and established 10x10 metre plots every 10 metres in the mangrove area. The biomass of the mangrove carbon stock was measured using published allometric equations, applying data (such as diameter at breast height (DBH)) from field measurements using protocols from Howard and colleagues (Howard et al., 2014).

Methodology to assess spatial and temporal changes in mangrove forest health and density

This study integrated remote sensing technology (satellite imagery) with site observations to monitor the spatial and temporal changes in the mangrove forest health and density in Nusa Lembongan from 2003-2017. The 2003 year was used as baseline study date, prior to the implementation of the MPA, represented by the Landsat 7 ETM+ satellite imagery. 2010 marked the year of MPA establishment represented by the Landsat 7 ETM+, and 2017 was used as a comparison year after MPA establishment represented by the Landsat 8 Operational Land Imagery (OLI) and Thermal Infrared Sensor (TIRS). By utilising NDVI combined with hotspot analysis and statistical analysis, areas of vegetation health were then identified.

Methodology to assess sedimentary seagrass carbon stock

This work consisted of measuring the carbon stocks and sources of organic carbon in seagrass sediments on three islands in Indonesia, selected based on the anthropogenic settings and the resulting influence on the surrounding seagrass meadows. The three islands included Lembeh Island, a touristic island and considered as highly impacted by anthropogenic disturbances situated adjacent to a trading port (referred to as the disturbed site), Nusa Lembongan Island, a designated marine protected area (MPA), and Sangihe Island, considered as a pristine, unprotected site. This study consisted of collecting sediment samples from seagrass meadows using stainless steel auger cores. Sediment organic carbon stocks were calculated using protocols and equations from Howard and colleagues (Howard et al., 2014).

Successes

Carbon storage in mangrove biomass in Nusa Penida MPA was determined to be 90.72 MgC/ ha, with the total carbon stock of the park equating to 14,929 MgC (Kusumaningtyas et al., 2014). When comparing the mangrove areal extent prior to, during, and after the establishment of the Nusa Penida MPA, the remote sensing analysis determined a slight decline in forest health between 2003 and 2010. After the establishment of the MPA, however, there was a significant improvement in mangrove forest health, particularly on the landward side. The NDVI revealed lower growth rates prior to 2010, while the period from 2010 to 2017 showed marked improvements in health index and growth. Conversely, a decline in mangrove forest health occurred in the central portion of the forest, extending towards the sea. These findings suggest that the establishment of the MPA in Nusa Penida has had a substantial positive impact on the region's ecosystem health (Daulat, Pranowo, & Amri, 2018).

When comparing the carbon stocks of seagrasses across three islands, the highest carbon storage was found in the MPA (77.15 \pm 1.38 MgC/ha), followed by the undisturbed site (36.08 MgC/ha), and the disturbed site (21.86 ± 0.31 MgC/ha) (Rahayu et al., 2023).

Challenges

One of the challenges was the lack of blue carbon data prior to MPA establishment, which did not allow for the influence of the MPA on blue carbon storage to be compared. Therefore, regular monitoring is important. However, to monitor carbon dynamics in mangrove and seagrass ecosystems requires significant resources and financial investment (for equipment and laboratory analyses), all of which demand commitment from governments, MPA officers, and local communities.

Additional resources

(Rahayu et al., 2023) (Coral Triangle Centre) (Kusumaningtyas et al., 2014)



Seagrass bed in Indonesia. © Velvetfish / iStock.com

4.6 Comparison of terrestrial and coastal marine ecosystems

Table 4.1 Comparison of carbon dynamics (i.e. sequestration and storage) in terrestrial and blue carbon systems (Fest, Swearer, & Arndt, 2022; Howard et al., 2014).

	Terrestrial	Coastal blue carbon	Both
Carbon storage			Carbon is stored in the soil or sediment, living biomass above ground (leaves, branches, stems) and below ground (roots) and the non-living biomass (litter, deadwood).
Longevity of carbon storage	The longevity of soil carbon reservoirs in terrestrial systems can be limited by high availability of oxygen. Under aerobic conditions microbial carbon is oxidised and released back into the atmosphere.	In CBCEs, the carbon in sediments can remain trapped for long periods (centuries to millennia) because sediments are saturated with water, keeping them in an anaerobic state (low to no oxygen). This result is the continual vertical accumulation of carbon over time.	Peatland soils provide an exception to terrestrial carbon longevity. They behave like coastal sediments in that they build up carbon over long periods if they are not disturbed and the high saturation of water creates an anaerobic state.
Source of carbon	In terrestrial systems the carbon is usually produced and deposited in the same location (autochthonous).	In CBCEs, the carbon is either i) produced and deposited in the same location (autochthonous). This is the case for most of the carbon sequestered in mangroves and tidal salt marsh systems, or ii) produced in one location and deposited in another (allochthonous). This is the case for about 50% of carbon stored in seagrass meadows and in some mangroves and salt marshes where the carbon originates from adjacent terrestrial or marine systems.	
Carbon sequestration	CO ₂ is taken up directly from the atmosphere into plants to make organic carbon.	Like terrestrial plants, plants in CBCEs, such as mangroves and salt marshes, can sequester carbon directly from the atmosphere. Submerged marine plants, such as many seagrass meadows, generally cannot fix CO ₂ until it has become dissolved in seawater.	
Losses due to land/coastal marine activities	Land use activities account for ~8–20% of global emissions.	Land use activities account for about $0.15-1.02$ (0.45) Pg $\mathrm{CO_2}$ /year globally (Pendleton et al., 2012).	
Use of remote sensing	Remote sensing can be a useful tool for estimating above-ground biomass, particularly in forested ecosystems, but it is not useful for below-ground biomass.	Remote sensing can be used for above-ground biomass, particularly in mangroves. It cannot measure carbon in sediments or submerged ecosystems (i.e. some seagrass meadows), unless data are available on water optics.	

4.7 Brief explanation of most commonly used models

4.7.1 Empirical models

Empirical models use commonly available inventory and monitoring data to simulate carbon dynamics. They are most often used in modelling the carbon dynamics in forests, but can also be used in other ecosystems. The Generic Carbon Budget Model (GCBM) was developed in Canada and is widely used by many countries. Two case studies highlighted in this chapter use the GCBM and describe the methodology on how to use it: Case Study 4.1 – Estimation of carbon storage in National Parks of Korea; Case Study 4.3 – Parks Canada Carbon Atlas.

Case Study 4.3

Parks Canada carbon atlas: Assessing carbon dynamics in ecosystems in national parks



Submitted by

Tara Sharma and Alex MacDonald, Parks Canada

Name of PCA and location

Multiple national parks in Canada

IUCN governance type

Category II, government

The protected area

Parks Canada protects nationally significant examples of Canada's natural and cultural heritage and fosters public understanding, appreciation and enjoyment in ways that ensure their ecological and commemorative integrity for present and future generations. As part of a suite of work to address the twin crises of biodiversity loss and climate change, Canada has committed to protecting 30% of its lands and waters by 2030 (reinforced in the Kunming-Montreal Global Biodiversity Framework), to reducing its greenhouse gas emissions by 40-45% from 2005 levels by 2030 and achieving net-zero emissions by 2050 (Canadian Net-Zero Emissions Accountability Act). Nature-based solutions are enshrined in these commitments and other policies and plans. Establishing a baseline for carbon stocks and fluxes (as GHG emissions) from ecosystems in each national park is important to better understand the role of Canada's protected areas as nature-based solutions for climate change mitigation. This study examined 5.6 million hectares of forest (56,000 km²) in 31 national parks in Canada.

The project

The baseline estimates for this project were established by assessing the carbon dynamics (stocks and fluxes) of forest ecosystems within 31 national parks from 1990 to 2020. To develop this baseline, these researchers adapted the Generic Carbon Budget Model (GCBM), previously used by Canada to report its forest-sector based greenhouse gas emissions and removals as part of Canada's National Inventory Report under the UNFCCC. The GCBM requires data on forest inventory, the occurrence and extent of natural disturbances (such as wildfires and insect outbreaks), anthropogenic disturbances (including prescribed fires), and species-specific yield curves for trees.

These datasets were collected from both Parks Canada field staff, and provincial government datasets. The GCBM was then applied to simulate the growth, turnover, and decay of forest stands in 30 x 30 m cells to estimate the annual carbon flow among five distinct carbon pools. This resulted in annual estimates of carbon stocks and fluxes, including net primary productivity, net ecosystem productivity, net biome productivity, and net greenhouse gas emissions. The resulting estimates were compiled temporally and spatially, yielding park-level, ecozonelevel and national-scale assessments of forest ecosystem carbon dynamics, including annual and 31-year trends across the national parks.

Successes

In the 5.6 Mha (56,000 km²) of forested area studied, the forests on average stored 1,452 \pm 11 MtC and the carbon stock increased by 6.8 MtC over the entire study time. Although 28 parks were net carbon sinks in the study period, three were net GHG sources, mainly due to more frequent and larger wildfires and the increased intensity and area infested by mountain pine beetle outbreaks.

Challenges

The main challenge encountered was identifying and compiling forest inventory data for parks from different sources across the country. Parks typically have land cover information readily available, but very few parks have forest inventory data including forest age, site characteristics, and lead/dominant species information, as well as consistent data on the nature, extent and intensity of natural disturbances, which are required as inputs for this model. Similar limitations are encountered in the ongoing efforts to expand carbon dynamics assessments to other ecosystem types (e.g. grasslands, peatlands) in Canada's national parks.

Additional resources

(Sharma et al., 2023)



Unlike most national forested parks in Canada Wood Buffalo National Park, depicted here, was a net source of GHGs from 2002 to 2020 due to increased wildfires. © T Schofield / iStock.com

4.7.2 Process-based models

Process-based models are founded on a theoretical understanding of ecological processes that provide a useful framework to incorporate changes to environmental conditions. They are different to purely statistical or rule-based models that rely on previously collected data. In particular, they require explicitly stated assumptions and easier interpretation of results than simulation models (Cuddington et al., 2013). Process-based models are often used to assess the carbon sequestration and storage in ecological systems.

4.7.2.1 InVEST Model

Terrestrial use of InVEST

Integrated Valuation of Ecosystem Services & Tradeoffs (InVEST) is an example of a process-based model widely used in carbon inventories. The model forecasts the supply of ecosystem services, such as carbon sequestered and stored. It considers the values of four carbon pools: above-ground biomass; below-ground biomass; soil; and dead organic matter, and is used in conjunction with Land Use/Land Cover (LULC) maps to estimate the amount of carbon stored in a unit area. The model output provides: i) the amount of carbon that is fixed in various carbon reservoirs; ii) the cumulative net amount of carbon in a landscape; (iii) a market value estimation for the carbon reservoir.

On the positive side, InVEST is easy to use, requiring only a minimum of technical skills and is compatible with the IPCC Tier 1 approach. It is a non-destructive method that allows for carbon estimates in remote areas where data collection is difficult (Babbar et al., 2021). Examples are found in Case Study 4.4, in which InVEST was used to assess stored carbon in a national park in Romania, and in Case Study 5.1 on the Sariska Tiger Reserve, Rajasthan, India. In India researchers used InVEST to calculate the carbon sequestered and permanently stored from 2000 to 2018, in a tiger reserve. They demonstrated that a protected area created specifically for the conservation of tigers was inadvertently protecting carbon sinks and stores, compared to areas outside the reserve (Lamba et al., 2023).

A shortcoming of InVEST is that it relies heavily on information gleaned from the literature, rather than data collected in the field, making it unreliable from the perspective of carbon accounting at a particular site or for use in NDCs to the Paris Agreement.

Coastal blue carbon use of InVEST

Coastal blue carbon ecosystem (CBCE) assessments have also used InVEST in mangroves and wetlands (Cai et al., 2021; El-Hamid et al., 2022; Hernández-Blanco et al., 2022; Kacem et al., 2022; Rosa, de Paula Costa, & de Freitas, 2022). For example, the InVEST Blue Carbon Model V3.9.2 was used to map and assess the change in extent of seagrass meadows, as well as annual sequestered carbon and long-term stored carbon, in the Canary Islands (Montero-Hidalgo et al., 2023). Although InVEST can use land use/land change data derived from satellite imagery, in this case, because of the turbidity of the water and the depth of the seagrass, mapping required field measurements, using Side-scan sonar (NYDF Assessment Partners, 2019) and underwater video. The results showed that half of the 106 km² of seagrass meadows that were mapped in 2000 had been lost by 2018. In areas where seagrass had disappeared, carbon stocks also disappeared; in areas where seagrass was maintained carbon stocks doubled.

4.7.2.2 Ex-ACT model

Ex-ACT is a land-based carbon accounting system that measures changes in carbon stocks per unit of land. It includes the Agriculture, Forestry and Other Land Use (AFOLU) classification used by IPCC and inland and coastal wetlands. It accounts for CO₂, methane and nitrous oxide emissions. Results are expressed in tCO₂e per hectare. Ex-ACT was developed by FAO to integrate the mitigation effects of agriculture and forestry development at the stage of project design. It uses *IPCC 2006 Guidelines for national greenhouse gas inventories* (IPCC, 2006), supplemented by other existing methodologies, to ensure the results are scientifically credible. For natural ecosystems it uses a stock-difference approach: emissions or sinks are calculated as the change over time of carbon stocks from five different pools: above-ground biomass, below-ground biomass, litter, deadwood and soil carbon. Ex-ACT is widely used to assess the climate mitigation benefits of protected areas because it allows comparisons of CO₂ mitigation inside and outside a PCA and before and after the PCA was created (FAO, 2025; Srinivasarao et al., 2016). An example of the use of Ex-ACT is found in Case Study 4.5, Habitat restoration in Cairngorms Special Area of Conservation, Scotland.

Case Study 4.4

Economic valuation for carbon storage and sequestration in Retezat National Park, Romania



Submitted by

Robert Pache

Name of PCA and location

Retezat National Park, Romania

IUCN governance type

Government

The protected area

The Retezat National Park was created for the conservation of representative samples of the national biogeographic space. Visitors can use the area for scientific, educational, recreational and touristic purposes. The forest is sustainably managed, with both active and passive forest stands.

The project

The purpose of this project was to monitor the different management practices in the protected area, to determine how they adapt to and mitigate climate change. Baseline data were collected during the forest management planning process, including measurements of forest stand characteristics such as tree height, diameter and volume, as well as data obtained through mobile scanning technology. The research team used GeoSLAM ZEB Revo, a portable scanner equipped with 3D mapping technology, which is highly versatile and adaptable to diverse environments. The scanning process leverages the GeoSLAM algorithm, combining simultaneous localisation and mapping (SLAM), enabling rapid, dynamic mapping without the need for GPS, with a relative accuracy of 1-3 cm. To evaluate carbon storage and sequestration ecosystem services, the InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) application was employed. This tool considers four carbon pools: above-ground biomass, below-ground biomass, soil, and dead organic matter. Based on the Land Use/Land Cover maps and the amount of carbon in each of the carbon pools, the project assessed the carbon stored within a unit area over a 10-year timeframe. The carbon pools were calculated based on the standing volume from the forest management plans and using the IPCC Guidelines for National Greenhouse Gas Inventories for carbon density in

above-ground biomass, below-ground biomass and in dead organic matter, and then the carbon density in soil (Eggleston et al., 2006).

To validate the carbon estimates derived from the InVEST model, four test plots were established in distinct forest stands. A mobile scanner was employed to precisely determine the position, number, diameter and volume of each tree, to derive the carbon stored at the tree level. The plot design was circular, with an area equivalent to the 30-metre pixel size used in the InVEST model. To derive the total carbon stored by each tree from the validation plot, a formula was used, derived from unified equations based on the diameter at breast height (DBH) on spruce from previous studies. This formula was used because spruce was the majority species in all the validation plots.

Successes

The study found that the total carbon storage within the national park is 6,021,295 Mg C. Projections indicated that this value is expected to increase to 6,252,395 Mg C by 2029, representing an increase of 231,099.98 Mg C. The lowest carbon storage was observed in the park's pastures and non-forested areas.

Challenges

The big challenge is how to balance biodiversity conservation, aiming to maintain or to improve the conservation status of species and habitats, with the sustainable forest management that produces, on the one hand, the renewable materials much needed in the bioeconomy sector, and on the other multiple ecosystem services for human well-being. Part of these services will be lost by non-intervention (e.g. provisioning services through timber and non-timber products) and others will be gained (e.g. regulating services through sediment retention, water regulation, and cultural services through recreation).

Additional resources

(Pache, Abrudan, & Niță, 2020)



Retezat National Park, Carpathian Mountains, Romania. © Aron M / iStock.com

Case Study 4.5

Habitat restoration in Cairngorms Special Area of Conservation (SAC), Scotland



Submitted by

Jeremy Roberts, Programme Manager, Cairngorms Connect

Name of PCA and location

The project area is covered by a number of international and national protected area designations and is entirely within the Cairngorms National Park (approximately 13% of the National Parks area), Scotland. The PCAs included are:

- Cairngorms Special Area of Conservation (SAC)
- Insh Marshes SAC
- River Spey SAC
- Cairngorms Massif Special Protection Area (SPA)
- Cairngorms SPA
- · Abernethy Forest SPA
- Craigmore Wood SPA
- River Spey Insh Marshes SPA
- Cairngorm Lochs Ramsar Site
- River Spey Insh Marshes Ramsar Site
- Abernethy National Nature Reserve
- Cairngorms National Nature Reserve
- Glenmore National Nature Reserve

IUCN governance type

The project area (600 km²) is managed by a land management partnership with a private landowner (50%), two Government agencies (25%) and an environmental NGO (25%).

The protected area

Cairngorms Connect is a partnership between neighbouring land managers committed to an ambitious 200-year vision to enhance habitats, species, and ecological processes across a vast area of the Cairngorms National Park. When the Cairngorms Connect partnership was formed in 2014, across 60,000 hectares, the overarching goals were fourfold: (1) nature conservation, (2) net carbon reduction, (3) climate change adaptation and nature-based solutions, and (4) community involvement. To achieve these objectives, the partnership primarily employs restoration practices.

The project

The team quantified the reduced emissions resulting from project activities within 31,220 hectares of the broader 60,000-hectare project area. This project utilises the EX-ACT carbon assessment tool developed by FAO. By default, EX-ACT makes use of 'Tier 1' emissions factors: globally agreed means for broad habitat and climate regions. However, 'Tier 2' inputs can be added to refine the calculations, including emissions factors specific to local areas or site-specific information. This adjustment to 'Tier 2' values allows for more tailored results and reduces associated uncertainties. By comparing the outcomes of the project to a baseline, or 'business-as-usual' scenario, the greenhouse gas emissions benefits were assessed.

Successes

According to the carbon assessment tool EX-ACT, the project substantially reduced emissions over the 20 years with a net reduction of 301,776 t CO₂e. A reduction in the deer grazing populations from 14,049 to 624 individuals reduced their direct emissions by 87,665 t CO₂e. Furthermore, the decrease in deer populations had indirect benefits, notably an improvement in grassland conditions that contributed an additional 208,791 t CO₂e in sequestration. Reforestation efforts in native woodlands further sequestered 11,488 t CO₂e, while the rewetting of 449 hectares of eroded peatland reduced emissions from the drained state and led to a net sequestration of 4,620 t CO₂e. Some increased methane emissions occurred but were outweighed by reductions in emissions from degrading peat soils, and carbon sequestration. Similarly, 43 ha of non-native plantations were felled to allow natural regeneration of native pine forests. While the deforestation of plantations resulted in 10,788 t CO₂e emissions, these are heavily outweighed in the long term by the regeneration of native pine wood continuing to sequester carbon over long periods of time.

Challenges

The main challenge is long-term funding. This project was one of the first recipients of Endangered Landscapes and Seascapes Programme funding - USD 5 million to support the work for 5 years, from 2019–2024.

Additional resources

(Cairngorms National Park Authority & Endangered Landscapes Programme, 2024)

4.7.3 Overview of remote sensing and Geographic Information Systems (GIS)

Remote sensing involves collecting data from a distance. Typically, sensors are installed on satellites, aircraft, unmanned aerial vehicles (UAV), autonomous underwater vehicles (AUV), remotely operated vehicles (ROVs), surface vessels or ground vehicles. Sensors of various types can provide information on different ecosystem properties across a range of temporal and spatial scales. GIS, in contrast, is a system designed to capture, store, analyse, manage and present spatial or geographic data. For those interested in better understanding these technologies and their use for biodiversity and ecosystem services monitoring, including carbon sequestration and storage, see (Machireddy, 2023; Malerba et al., 2023).

4.7.3.1 Remote sensing combined with Geographic Information Systems (GIS) for terrestrial ecosystems

Remote sensing, in conjunction with Geographical Information Systems (GIS), is increasingly used to compile carbon inventories, particularly for measurement of above-ground biomass for the assessment of carbon sequestration and storage in different ecosystems. Although less accurate than conventional field work, it is also less costly, has higher resolutions, saves time and uses fewer resources in collecting data. It is particularly useful for estimations of carbon sequestration and storage in large areas that are difficult to access (Vashum & Jayakumar, 2012), a common attribute of protected areas. It is important to highlight that remote-sensing does not directly estimate the amount of biomass that is present. It measures parameters that are correlated to biomass (i.e. for forests it measures tree height, crown size, forest density, forest type, forest volume, leaf area index). Field measurements are required to validate the results obtained through remote sensing.

However, remote sensing is ineffective for assessments of below-ground biomass (Silva et al., 2017), which is the most important component of carbon stores in some ecosystems, such as grasslands, peatlands and CBCEs.

IPCC provides guidance on good practice for the use of remote sensing and GIS (IPCC, 2003). The technologies are particularly useful for verifying Land Use/Land Cover (LULC) and LULC changes, carbon estimation - especially in forests - and in conjunction with LULC classification schemes (Wallace et al., 2017).

4.7.3.2 LiDAR/radar

Light Detection and Ranging (LiDAR) is an active remote sensing technology that uses laser pulses to measure the distance between the sensor and the Earth's surface. It provides highresolution elevation data, enabling accurate terrain mapping for a variety of ecosystems and has been extensively used in forest canopy analysis, including timber volume and biomass, which is the basis of estimating the physical qualities (tree height or forest structural information) essential to quantify above-ground carbon (Machireddy, 2023; Timothy, Onisimo, & Riyad, 2016; Wulder et al., 2013).

Radar systems are similar to LiDAR. However, radar sensors on satellites and aircraft can penetrate clouds and vegetation, making it possible to collect data regardless of weather conditions (Chen & Qi, 2014).



Aerial view of Cairngorms Special Area of Conservation (case study 4.5). © Scotland the Big **Picture**

Case Study 4.6

Impact of protected areas on avoided blue carbon emissions, Indonesia



Submitted by

Daniela Miteva, Ohio State University, Duke University, The Nature Conservancy

Name of PCA and location

All protected and conserved areas with mangrove forests in Indonesia

IUCN governance type

The study spans multiple national parks and biosphere reserves as well as species management areas. Data were not available on the degree to which local communities are involved in the governance of each PCA.

The protected area

Indonesia is home to the largest area of mangrove forests in the world; however this critical ecosystem is being lost at an alarming rate. Shrimp farming, agricultural expansion, saltpans and oil spills are all causing stress to this ecosystem. While it is well-established that mangroves store a significant amount of carbon, there is insufficient research on understanding the impacts of protecting these blue carbon reserves in Indonesia. This research group sought to add to the literature by evaluating the effectiveness of protected areas in Indonesia in preventing mangrove forest loss and their associated carbon emissions. This nationwide study includes all protected areas with mangrove forests, including biosphere reserves, national parks, and species management areas.

The project

Baseline data were compiled using publicly available geospatial datasets between 2000 and 2010. Mangrove change through the timeframe of this study was not available in a single dataset, therefore the mangrove extent in 2000 (Giri et al., 2011) was combined with the MODIS VCF datasets (Townshend et al., 2011). The two datasets provided annual information on percentage mangrove tree cover within and outside protected areas at a 250-metre resolution.

The unit of analysis was the village, which was assigned a binary classification of protected or not protected. Other factors that may have impacted the placement of protected areas and mangroves during the baseline measurements in 2000 were then controlled for. These factors included population density, proximity to cities and ports, elevation and slope, mangrove extent in 1988 and 2000, area under peat, the proportion of households involved in agriculture, river length, and village areas. Researchers compared the amount of area within each village with mangrove tree cover in 2000 (both inside and outside of protected areas), to the mangrove tree cover in 2010. Avoided mangrove loss estimates were converted into estimates of avoided emissions using values from Donato and colleagues (Donato et al., 2011). Several robustness checks were performed by altering the analytical time-frame, applying different methods (e.g. matching without trimming, bias and variance corrections, alternative treatments, and post-matching partial linear models), and by controlling for potential spillovers. The results were robust across all specifications.

Successes

Protected areas in Indonesia were found to be effective in reducing mangrove loss between 2000 and 2010, with the extent of this impact varying depending on the type of protected area and the timeframe considered. An estimated 14,000 ha (140 km²) of mangroves were preserved, resulting in the avoidance of approximately 13 million tonnes of CO_oe emissions - equivalent to removing 344,000 vehicles from the road annually. Using a social cost of carbon of USD 41/tCO_a, the avoided emissions were worth over USD 540 million. The authors hypothesise that the impact observed in national parks may be driven by additional benefits such as ecotourism, which were not captured in this study.

Challenges

The biggest challenge was finding good data to proxy the mangrove change through the years.

Additional resources

(Miteva, Murray, & Pattanayak, 2015)

4.7.3.3 MODIS/Landsat/ASTER/SPOT

Moderate Resolution Imaging Spectroradiometer (MODIS) is a sensor operating on the Terra and Aqua satellites, launched by NASA in December 1999 and May 2002 respectively. They produce data that describe the land, oceans and the atmosphere and so are used widely for climate change research. MODIS uses three spatial resolutions - 250 m, 500 m and 1 km.

Landsat satellites are a series of Earth-observing satellites jointly managed by NASA and the US Geological Survey. Landsat 8 and 9 are currently active orbiting satellites. They provide the optimal ground resolution and spectral bands to track land use and document land change due to climate change, biomass changes (carbon assessments) and other natural and human-caused changes. Numerous products are available to view Landsat satellite data files, ranging from those requiring specialised software to images requiring no specialised software. There are no restrictions on the use of Landsat data downloaded from the US Geological Survey (USGS, 2025).

A cautionary note, however, is that all Landsat satellite products and MODIS for estimating above-ground biomass have resulted in inaccurate results in the tropics, due to the presence of mixed pixels and the mismatch between pixel-size and field-plot area (Timothy, Onisimo, & Riyad, 2016). Also, despite recent advances in technology, remote sensing maps and associated emissions-reporting schemes that rely on Land Use/Land Cover classifications are prone to error (i.e. misclassification). Limiting the number of Land Use/Land Cover classes can reduce errors (Funk & Budde, 2009), but also severely limit granularity (resolution) of data.

4.7.4 Remote-sensing combined with Geographic Information Systems (GIS) for coastal blue carbon ecosystems

IPCC provides guidance for blue carbon inventories (IPCC, 2014), but provides little guidance on the use of remote sensing for blue carbon assets. Malerba and colleagues (Malerba et al., 2023) have provided a road map for the use of remote sensing in CBCEs that is designed to work in conjunction with IPCC guidelines (Eggleston et al., 2006). Their road map includes: cutting-edge remote sensing technologies for mapping blue carbon habitats; methods for translating habitat maps into carbon estimates; and a decision tree to assist users in determining the most suitable approach depending on ecosystem of interest, location, budget and required accuracy. As with terrestrial ecosystems, a combination of field and remote sensing is the most cost-effective approach for developing CBCE inventories in MPAs.

Mathis and colleagues (2024) stated that "Observation-based studies on coastal ocean carbon fluxes are fraught with large uncertainty due to general data scarcity" (Mathis et al., 2024). They elaborated on the complex interplay of drivers of the coastal carbon cycle. In this context, for CBCEs the major concerns are: i) the significant historical loss of these ecosystems and subsequent release of their stored carbon into the atmosphere; ii) the vulnerability of CBCEs to sea-level rise, particularly where natural inland migration is hindered by hard coastal defences and other coastal development. As well, submerged CBCEs (i.e. seagrasses) have particular challenges, especially where seagrasses thrive in water depths that exceed the limits of optical remote sensing instrumentation or where water clarity is poor.

For CBCEs, remote-sensing is most commonly applied for vegetation biomass calculations in mangrove forests, because the most commonly available sensors (Landsat and Sentinel-2) are very accurate for distinguishing mangrove forests from other land-use types, but are less accurate for salt marshes and seagrass meadows. Newer technologies, publicly accessible computing such as Google Earth, and the increasing integration of on-the-ground blue carbon data with remote sensing is leading to improvements in accuracy of remote sensing for CBCEs (Campbell et al., 2022; Malerba et al., 2023). These authors provide a detailed review of the use of remote sensing for all CBCEs, including developing technologies for the future.

4.8 Field measurements

Global estimates of ecosystem carbon have relied heavily on remote sensing. Ground-truthing of these estimates with field measurements is important to ensure accuracy. As well, regional or local field measurements are always more accurate than global estimates. Recently Mo and colleagues (Mo et al., 2023) have compared remote-sensing estimates that quantify carbon losses from global forests with ground-sourced estimates and have found a 12% difference, at the global scale, between ground-sourced and satellite-derived estimates. The authors concluded that their work provides some confidence that in the absence of field measurements, remote-sensing data might provide an acceptable level of error, as long as these limitations are mentioned.

Field measurements involve destructive methods, in which above-ground biomass (AGB) is harvested, dried, weighed and converted to carbon content, through various techniques which involve combusting the dried biomass and subtracting the weight of the ashes from the dried biomass to determine carbon content. For below-ground carbon, soil samples have to be taken, dried and weighed, and then, similar to AGB, the samples are combusted, usually with specifically designed instruments, and the carbon content is determined. Because the determination of Soil Organic Carbon (SOC) cannot be estimated from remote sensing, FAO has compiled data from national inventories into the Global Soil Organic Carbon (GSOC) map. The FAO report provides maps and tables, by country, for SOC, which can be used in lieu of ecosystem specific field measurements for Tier 2 analysis of GHG emissions from soil (FAO, 2022).

The importance of measuring both AGB and SOC is highlighted in Figures 4.2 and 4.3 for terrestrial and coastal blue carbon, respectively.

Case Study 4.7

Soil organic carbon stock under semi-deciduous tropical forests: Téné Protected Forest, Oumé, Côte d'Ivoire



Submitted by

Koffi Kouamé Mathurin, Institut National Polytechnique Félix Houphouët-Boigny (INP-HB)

Name of PCA and location

Téné Protected Forest, Oumé, Côte d'Ivoire

IUCN governance type

Private and government

The protected area

The Téné Research Forest, spanning over 29,700 ha (2,970 km²) was developed with the goal of monitoring the regeneration of commercial species after deforestation. Long-term tree growth and biodiversity datasets have been developed from these routine monitoring efforts, implemented shortly after the research forest's establishment in 1977. This site represents permanent forests plots in a region of the sub-Sahara that faces widespread deforestation, making the protected area crucial to achieving local conservation goals.

The project

In sub-Saharan Africa, continued deforestation has caused a ~20-50% reduction in soil carbon. This is significant, as regional estimates suggest that ~68% of terrestrial carbon is stored in soils. Improved management of the soil organic carbon stocks (SOCS) will mitigate these losses, simultaneously reducing greenhouse gas emissions and improving soil quality. Proper SOCS management is difficult, however, because of a lack of local information. Forest managers are forced to rely on international databases, filled with regional uncertainties.

This group aimed to estimate local SOCS to lessen these regional uncertainties and generate crucial data for the proper management of this resource. The researchers conducted field surveys to collect carbon core samples from 0-30 cm and 0-100 cm depths. Using the FAO soil classification guide, they then identified soil types. A three-dimensional topographic map was developed using Digital Terrain Models (DTM) from Global Mapper and from Surfer. By combining the two methodologies, the distribution of the soils along topo-sequences and morpho-pedological landscapes were described.

Successes

The results determined three types of soils: plinsothosols, ferralsols and fluvisols. Overall, the carbon in 0-30 cm thickness was estimated to be on average 44.89±11.22 tC/ha, and in 0-100 cm thickness, it was on average estimated to be 61.56±14.15 tC/ha.

Challenges

Although this project was fully funded, there was no soil carbon component identified at the outset. There was therefore no budget for certain interventions and no soil carbon specialist steering the team. They are awaiting more funding to better understand certain carbonrelated issues.

Additional resources

(Koffi et al., 2023)

4.9 Destructive and non-destructive methods

4.9.1 Sampling biomass and conversion to carbon in terrestrial ecosystems

Assessing carbon in ecosystems starts with an estimation of biomass. Both destructive and non-destructive methods are available for measuring biomass. The destructive method involves harvesting all of the plants in the ecosystem (i.e. for forests this involves harvesting the trees) and measuring the dried weight of the different components of the plants. Because this method is time consuming and costly, it is achieved practically by sampling some of the biomass, using transects, and extrapolating to the larger area. This method is used for developing biomass equations that can be applied for assessing biomass and stored carbon on a larger scale.



Forest soil cross section with layers (Al generated). © predator / AdobeStock.com

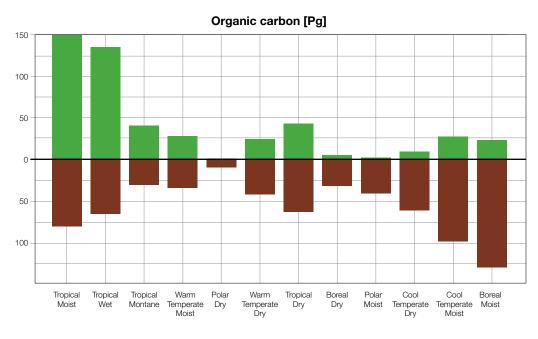


Figure 4.2 Terrestrial Soil Organic Carbon (SOC) stocks using IPCC climate regions and calculated from GSOC map v 1.6.0 (FAO, 2022) and above-ground organic carbon from (Gibbs & Ruesch, 2008). Source: Figure 6.2 in (FAO, 2022)

above-ground below-ground

Organic carbon in coastal blue carbon ecosystems [Pg]

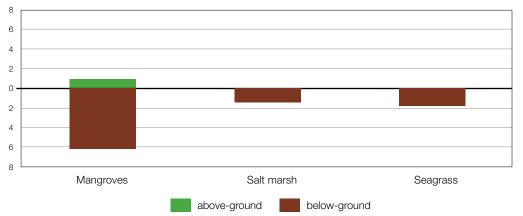


Figure 4.3 Global carbon storage above and belowground in coastal blue carbon ecosystems. Although the density of carbon per ha is higher in CBCEs than terrestrial ecosystems, the total area is much smaller reducing the global significance. Source: Derived from Table 1 in (Howard et al., 2023)

Case Study 4.8

Assessing, protecting and restoring blue carbon in Greater Farallones and Cordell **Bank National Marine Sanctuaries, USA**



Submitted by

Sara Hutto, NOAA Office of National Marine Sanctuaries, Greater Farallones Association

Name of MPA and location

Greater Farallones and Cordell Bank National Marine Sanctuaries, North-central California, USA

IUCN governance type

Government

The protected area

Greater Farallones National Marine Sanctuary was first designated in 1981 due to the region's biological richness, unique habitats, threatened and endangered marine life, shipwrecks and other cultural resources. Cordell Bank National Marine Sanctuary was designated in 1989 to protect the rich and diverse benthic marine ecosystem of Cordell Bank, a rocky undersea feature 35.4 km (22 miles) off the coast of California. Both sanctuaries were expanded in 2015 and are managed together as a single unit by the US National Oceanic and Atmospheric Administration as part of the US National Marine Sanctuary System.

The project

An assessment of carbon sequestration and storage within the sanctuaries was initially recommended in the sites' 2016 Climate Action Plan as a necessary step in ensuring that the sanctuaries protect their natural carbon sinks and prevent unintended emissions due to human activity. Sanctuary management requested information detailing carbon sink locations, how much carbon is stored, and the processes resulting in carbon accumulation, to ascertain whether current management

practices are sufficient in protecting these stores and processes. This study quantified the annual carbon sequestration of the sanctuaries' bull kelp beds, baleen whales, eelgrass beds, salt marshes, the seafloor and the organic carbon currently stored in marine sediments and vegetated estuarine sediments. For each analysis, baseline data were collected and analysed including: geographic extent; site-specific carbon accumulation rates; organic carbon content of sediments within eelgrass beds, salt marshes and the seafloor; organic carbon content of whale biomass; and geographic extent and organic carbon content of kelp biomass. All data were at least regionally specific, and in many cases locally-specific, and provided by partner agencies and academic institutions. Methods for quantifying carbon stores and sequestration were modelled after multiple published studies and are reproducible for other PCAs, including for marine sediments (Smeaton, Austin, & Turrell, 2020), eelgrass and salt marsh sediments (Howard et al., 2014), whales (Pershing et al., 2010) and kelp (Krause-Jensen & Duarte, 2016).

Successes

This project is currently focused on assessment and has not yet begun applying results to policy or management measures. Successes to date have included increased agency and public awareness through the publications as well as several presentations, briefings, interviews and appearances. We plan to track success of the application of the information collected for management via the sanctuaries' upcoming management plan review processes, including the number of management strategies that use this data to improve blue carbon protection.

Additionally, this project has coincided with an effort to restore bull kelp forests in the region, a highly collaborative effort led by the Greater Farallones Association in partnership with the sanctuaries. The role of kelp forests in absorbing and sequestering carbon is one of many reasons to invest in kelp restoration. Restoration methods are currently being tested at a number of sites in the sanctuaries, and it will soon be possible to measure the success of these methods and the resulting impact on kelp carbon export and sequestration (www.farallones.org/kelp).

The most accurate conversion of biomass to carbon is to measure the carbon directly from the dried biomass sample. This usually involves burning the dried biomass, weighing the remaining ash, and subtracting the weight of the ash from the dried biomass to derive the carbon content. This has been done enough times, and in enough different ecosystems, that carbon conversion factors have been calculated and are generally used for converting above-ground biomass and deadwood to carbon. Table 4.2 summarises the conversion factors in general use. However, these are not species or biome specific.

However, it's important to note that the US Forest Inventory Analysis (FIA) programme has recently revisited its original generic conversion of 0.50, carbon to biomass, to an average of 0.4777, after examining species specific carbon fractions for 421 species (Westfall et al., 2024). These revisions are significant because over a large forested area they will result in a significant reduction in carbon stored in ecosystems. For example, revisions for deadwood show that tropical forests likely have an overestimate of ~3Gt of dead wood carbon (Martin et al., 2021). It is also important to note that these macro level conversion factors are not reliable at a local level. Species level conversion factors are available at the Global Woody Tissue Carbon Concentration Database (GLOWCAD) (Doraisami et al., 2022).

In cases where field measurements are not available Martin and colleagues provide estimates of carbon concentration in trees across different biomes and two taxonomic groups, reproduced here in Table 4.3 (Martin et al., 2018).

Table 4.2 Conversion factors for above-ground biomass (AGB) to above-ground carbon . These factors are generally used where direct measurements are not available. Although these conversion factors are based on US forests, they are generally accepted and used in regional studies (e.g. (Manickam et al., 2014) in India).

	Converting biomass to carbon: Conversion factor (CF) (i.e. dried biomass x CF=carbon (C)	Source
Above-ground biomass	0.477 (range 0.420 to 0.538)	(Westfall et al., 2024)
Deadwood in forests	0.485	(Martin et al., 2021)
Mangroves	0.45 to 0.50	(Kennedy et al., 2014)

Table 4.3 Mean wood carbon concentration generalised across trees from four different biomes and two primary taxonomic groups. Adapted from Table 1 in (Martin et al., 2018). Confidence intervals are available in the original chart. These species and biome specific conversion factors are more accurate than generalised conversion factors given in Table 4.2.

Biome	Species type	Mean wood C (% ± SE)	Number of observations (No. of species)	Mean values provided by IPCC (IPCC, 2006)
Tropical	Angiosperm	45.6 ± 0.2	1,187 (397)	49
	Conifer	44.7 ± 0.5	114	49
Subtropical/Mediterranean	Angiosperm	45.7 ± 0.4	157 (52)	49
	Conifer	49.8 ± 0.6	99 (14)	49
Temperate	Angiosperm	46.5 ± 0.3	367 (111)	48
	Conifer	50.1 ± 0.4	228 (45)	51
Boreal	Angiosperm	49.2 ± 0.8	22	48
	Conifer	46.8 ± 0.6	54 (8)	51
All biomes	Angiosperm	46.8 ± 0.7	1,733 (557)	-
	Conifer	48.5 ± 0.8	495 (79)	-
All data	NA	47.6 ± 0.9	2,228 (636)	47

Soil Organic Carbon (SOC) provides a measurement of the amount of carbon below-ground, which is important for assessing carbon mitigation potential, not the least because the world's soils have more carbon than all the plants and the atmosphere combined. Detailed methodologies for collecting soil samples and calculating Soil Organic Carbon have been published by FAO (FAO, 2022) and have included general SOC stocks for different ecosystems at the global level, presented in Table 4.4.

Table 4.4 Soil Organic Carbon stocks by ecosystems. Source: (FAO, 2022).

	SOC stock (Gt)	SOC (t/ha)	Global share (%)
Forests	291.6	42.1	42.8
Grasslands	178.2	30.1	26.1
Croplands	140.1	35.7	20.5
Others	46.7	14.8	6.9
Wetlands	24.0	47.8	3.5

4.9.2 Determining stored carbon in coastal ecosystems

In CBCEs, below-ground soil carbon pools usually constitute 50% to over 90% of the total carbon stocks of mangroves; >98% for salt marshes and seagrass meadows. Fourqurean and colleagues (Fourqurean et al., 2015) provide step-by-step guidance on how to collect field samples and determine carbon content. They describe: available tools for taking core soil samples; methods for avoiding sampling problems; methods for drying soil samples; and determination of organic carbon content. Standard conversion factors converting dried soil to organic carbon are not available for coastal blue carbon.

For mangroves, IPCC guidelines have determined a factor of 0.45 to 0.50 (Kennedy et al., 2014) for converting AGB to $\rm C_{cro}$.

4.9.3 Non-destructive methods

Biomass can be estimated by non-destructive methods as well, a methodology that is particularly important in ecosystems where harvesting is not practical or feasible. In this method - particularly useful for estimating biomass in forests - various parts of plants are measured, including the diameter of trees at breast height (DBH), height of the tree, volume of the tree and wood density and the biomass is derived from allometric equations. Because this method has been validated over many different forests through destructive methods, the allometric equations are very robust (Vashum & Jayakumar, 2012). Estimated biomass is then converted to carbon using the conversion factors in Table 4.2.

There are no non-destructive equivalents for measuring SOC in either terrestrial or coastal blue carbon ecosystems.

4.10 Role of environmental accounts

4.10.1 System of Environmental-Economic Accounting (SEEA)

The UN System of Environmental Economic Accounting (SEEA) is a framework that integrates economic and environmental data to provide a view of the relationships between the economy and environmental assets. It has emerged as the leading method for natural capital accounting. The SEEA Experimental Ecosystem Accounting (SEEA EEA) represents an effort towards coherent ecosystem-based accounting. Some countries have used the SEEA as a base to account for ecosystem carbon, particularly in CBCEs (i.e. China for blue carbon accounting (Liu et al., 2004), Barbados, Bahamas and Jamaica and some African countries (Failler et al., 2023)).

Case Study 4.9

Protected natural areas 'La Esmeralda' conservation and production in native forests in South America



Submitted by

Julian Alberto Sabattini, (Director NPA 'La Esmeralda')

IUCN governance type

Privately managed conservation unit that prioritises sustainable management. IUCN Category V.

Name of PCA and location

Natural Protected Area 'La Esmeralda' (NPALE) is located in Las Garzas, Entre Rios Province, Argentina, a region where semi-xerophytic native forests, grasslands, and floodplains (wetlands) intersect with productive agricultural areas. This protected area serves as an ideal site for research, monitoring, education and recreation. Since 1986, extensive research has been conducted within this area, contributing to the knowledge of conserved native forests at both local and regional levels, in contrast to degraded forests. The goal of the research at this site is to create sustainable agricultural practices. These studies aim to demonstrate the economic, social and ecological benefits of sustainable agriculture, while emphasising its contribution to climate change mitigation.

The project

NPALE implements and advocates for actions designed to mitigate the impacts of climate change, including the prevention of native forest deforestation, the adoption of renewable energy solutions in local households, wildlife monitoring, and the assessment of ecosystem carbon flows. This case study estimates the carbon stock and avoided emissions within the NPALE protected area, quantifying its contribution to climate change mitigation. The following methodologies were employed:

- 1. Landsat satellite imagery to determine the spatial heterogeneity of the distinct types of native forests and agricultural areas (Sabattini, 2015).
- 2. Floristic, physiognomic and structural characterisation of vegetation through field surveys.
- 3. Quantification of above-ground carbon stocks of herbaceous, shrubby and arboreal vegetation types.

- 4. Field surveys in 500 m² plots to determine both the tree biomass using local allometric equations and the shrub and herbaceous biomass through destructive sampling over the course of one year, involving the cutting and weighing of plant material.
- 5. Soil carbon stock estimation in soils up to 30 cm, achieved through soil sampling and subsequent laboratory analysis.
- 6. Estimation of the carbon renewal rate of extensive agricultural crops considering crop rotation.

Successes

Researchers determined that the soil carbon stock in the NPALE protected area is 81.4 tC/ha (8.14 x 10⁻⁵ MtC/ha), and the above-ground carbon stock is 96.7tC/ha (9.67 x 10⁻⁵ MtC/ha). The total carbon stock is 169 tC/ha (1.69 x 10⁻⁵ MtC/ha), amounting to a total of 35,490 tonnes of carbon (0.035 MtC) stored in the 210 ha protected area. Assuming that the annual deforestation rate of the region is 1.2% (Sabattini, Sabattini, & Cian, 2021), the avoided emissions from deforestation and land use change in the La Esmeralda ANP is 761 tCO₂/year.

Challenges

Difficulty determining the estimation error of this work was a consequence of scant to null regional information. Researchers therefore evaluated the accuracy of their study by comparing their research to similar works or publications in comparable tropical and temperate ecosystems. The new challenges are to improve estimates using precision technologies such as drone aerial photography with cameras and vegetation sensors. Using these technologies, researchers are attempting to simulate or predict the above-ground carbon storage in similar areas.

Additional resources

(Sabattini, Sabattini, & Cian, 2021) (Sabattini & Sabattini, 2022) (Sabattini & Sabattini, 2021) (Sabattini, 2021)



Las Esmeralda, Argentina. Photo: Julián Sabattini

4.11 Annex 1 Links to guidelines for calculating GHG inventories in natural ecosystems

Ecosystem	IPCC Guidelines (reference)	Link to IPCC Guidelines by ecosystem	Simplified step-by-step guidance by third parties
Agriculture, forestry and	(IPCC, 2006) 2006 IPCC Guidelines	https://www.ipcc-nggip.iges. or.jp/public/2006gl/vol4.html	
other land use	(IPCC, 2014) Wetlands Supplement	https://www.ipcc.ch/ publication/2013-supplement- to-the-2006-ipcc-guidelines- for-national-greenhouse-gas- inventories-wetlands	
	(IPCC, 2019) 2019 Refinement	https://www.ipcc-nggip.iges. or.jp/public/2019rf/vol4.html	
	(IPCC, 2003) Good Practices Guidelines 2003	https://www.ipcc-nggip.iges. or.jp/public/gpglulucf/gpglulucf_ contents.html	
Forests	(Aalde et al., 2006)	https://www.ipcc-nggip.iges. or.jp/public/2006gl/vol4.html (Chapter 4)	Refinement of IPCC 2006 default values for above-ground biomass in tropical and subtropical forests. (Rozendaal et al., 2022) https://doi.org/10.1088/1748-9326/ac45b3
	(Domke et al., 2019) supplement focuses on soil carbon, below- ground biomass	https://www.ipcc.ch/report/2019- refinement-to-the-2006- ipcc-guidelines-for-national- greenhouse-gas-inventories	
Freshwater wetlands	(Kennedy et al., 2014) IPCC 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands	https://www.ipcc.ch/ publication/2013-supplement- to-the-2006-ipcc-guidelines- for-national-greenhouse-gas- inventories-wetlands https://www.ipcc-nggip.iges. or.jp/public/2006gl/vol4.html	
Peatlands	(Blain et al., 2006)	https://www.ipcc.ch/ publication/2013-supplement- to-the-2006-ipcc-guidelines- for-national-greenhouse-gas- inventories-wetlands https://www.ipcc-nggip.iges. or.jp/public/2006gl/vol4.html https://www.ipcc-nggip.iges. or.jp/public/2006gl/vol4.html (Chapter 7, Peatlands Section)	(Agus, Hairiah, & Mulyani, 2011) https://apps.worldagroforestry.org/downloads/Publications/PDFS/MN17335.PDF (Kauffman et al., 2016) Measurements of carbon and GHG emissions in tropical peat swamp forests. https://www.cifor.org/publications/pdf_files/WPapers/WP86CIFOR.pdf
	(IPCC, 2014)	https://www.ipcc.ch/ publication/2013-supplement- to-the-2006-ipcc-guidelines- for-national-greenhouse-gas- inventories-wetlands	(Natural Resources Wales, 2023) Peatland carbon assessment methodology, Wales
Grasslands	(Verchot et al., 2006)	https://www.ipcc-nggip.iges. or.jp/public/2006gl/vol4.html (Chapter 6)	(Richter et al., 2021)
Blue carbon ecosystems	(Kennedy et al., 2014)	https://www.ipcc.ch/ publication/2013-supplement- to-the-2006-ipcc-guidelines- for-national-greenhouse-gas- inventories-wetlands (Chapter 6)	(Howard et al., 2014) https://www.cifor.org/publications/pdf_files/Books/ BMurdiyarso1401.pdf (Kauffman & Donato, 2012) for mangroves https://doi.org/10.17528/cifor/003749 (Fourqurean et al., 2014) (Fourqurean et al., 2015) https://ro.ecu.edu.au/ecuworks2013/989 (Maxwell et al., 2023) – maps of Soil Organic Carbon in salt marshes in 29 countries.
			(Malerba et al., 2023) https://doi.org/10.1016/j. earscirev.2023.104337 provides step-by-step guidance on the use of remote sensing for carbon inventories in CBCE
Soil Organic Carbon			(FAO, 2022) provides tables by country on carbon stored in soils https://doi.org/10.4060/cb9015en

4.12 Additional resources

Dlamini provides a very readable example of how a carbon inventory for the LULUCF emissions was created in Eswatini. Issues with IPCC toolkits and methodologies are addressed (Dlamini, 2022).

In the second state of carbon cycle report (SOCCR2), Birdsey and colleagues (Birdsey et al., 2018) provide an excellent review of the variabilities in the carbon cycle driven by climate, ecosystem types and conditions, land and marine use and management for North America.



Taking a sediment core in mangroves, Australia. © Tenedos / iStock.com



Ancient carbon-dense forest in the interior of British Columbia, Canada. © SL_Photography / iStock.com

Chapter 5

Methodology for quantifying biodiversity

Toni Lyn Morelli, Sarah Weiskopf, Maria Isabel Arce-Plata, Jaime Burbano-Girón, Kadambari Devarajan, Shannon Dickey, Elizabeth A. Fulton, Hamed Gholizadeh, Tobi A. Oke, Gretta Pecl and Darren J. Ranco

5.1 Chapter highlights

- ✓ Incorporating biodiversity monitoring into climate mitigation actions provides safeguards against unintended negative consequences on biodiversity and promotes co-benefits for biodiversity. This is a basic requirement for use of Natural Climate Solutions (NCS)¹ or Ecosystem-based Management (EBM).
- Guidance on the best biodiversity indicators to use can be found in the Kunming-Montreal Global Biodiversity Framework. It provides headline indicators as well as more detailed measurements for all goals and targets in the framework. Those most relevant to measuring the effects of climate change mitigation actions on biodiversity are highlighted in this chapter.
- ✓ Measuring biodiversity can be complex. Field measurements, remote sensing and ecological modelling approaches are complementary and the most accurate depictions of biodiversity are usually obtained by combining methods.
- ✓ Different models are used for different ecosystems. Paying particular attention to using the right model for the ecosystem in question is important. For example, terrestrial and marine ecosystems may require different modelling approaches.
- Molecular tools, such as eDNA barcoding, offer a biodiversity monitoring technique which is particularly useful in submerged ecosystems, such as freshwater and coastal blue carbon ecosystems.
- Community science is useful to add to collective knowledge on biodiversity monitoring and engaging the public in biodiversity conservation.

5.2 Introduction

Protected and Conserved Areas (PCAs) are usually created and managed for multiple values, with biodiversity conservation being the primary value for most PCAs (see Chapter 1). When using Natural Climate Solutions (NCS) or Ecosystem-based Management (EBM) approaches to climate change mitigation, it is important to ensure that there are no unintended negative consequences on biodiversity and co-benefits for biodiversity are sought. This requires baseline biodiversity information and periodic monitoring.

The Convention on Biological Diversity (CBD) has developed a monitoring framework to measure progress (CBD COP 15 2022) towards the GBF. The framework consists of:

- headline indicators for national, regional and global monitoring;
- global level indicators (collated from yes/no responses in national reports and used to provide a count of the number of countries having undertaken specific activities);
- component indicators (which are a list of optional indicators that may apply at global, regional, national and sub-national levels);
- complementary indicators (which are a list of optional indicators for thematic or in-depth analysis of each goal and target).

Further details of the monitoring framework can be found in Decision 15/5: *Monitoring framework for the Kunming-Montreal Global Biodiversity Framework* (CBD COP 15, 2022). See Table 5.1 for headline indicators and related targets that they measure. These indicators are used to track national progress towards the GBF. However, those designing sub-national or regional PCA frameworks can use them as well.

Biodiversity can be measured at different scales, both spatially and temporally, and at different levels and attributes of biological organisation (Noss, 1990). The Kunming-Montreal Global Biodiversity Framework (GBF) (Convention on Biological Diversity, 2022, December 18) includes goals and targets across scales, with Targets 1 and 3 focused on spatial planning and PCA creation, Targets 2 and 4 focused on restoration and species management to prevent extinction, Target 5 focused on fish stocks, Target 8 on minimising climate change impacts, Target 11 on ecosystem services, and Target 21 on biodiversity information for monitoring the GBF.

^{1.} In this report the term 'Natural Climate Solutions' (NCSs) is used to refer to human actions that make use of the properties of natural ecosystems to protect, restore and improve management of forests, wetlands, grasslands, oceans and agricultural land to mitigate and adapt to climate change. NCSs are often used interchangeably with the more general term 'Nature-based Climate Solutions' (NbCSs). NbCSs are similar, but they can make use of engineered ecosystems in addition to natural ecosystems. See also glossary of terms used.

Table 5.1 Selected Convention on Biological Diversity headline and component² indicators most relevant for climate change mitigation in protected and conserved areas, as identified in the Kunming-Montreal Global Biodiversity Framework (GBF) (Convention on Biological Diversity, 2022). Headline indicators are in **bold**; component indicators are in brackets and in regular type. Indicators that are both headline and component indicators are only mentioned once, as headline indicators.

KM GBF Targets	Headline and component indicators
1,3	Red list of ecosystems
1,2,3,4,8	Extent of natural ecosystems (priority retention of intact/wilderness areas, Intactness Index, Ecosystem Integrity index, Species Habitat Index, Biodiversity Habitat Index, Living Planet Index)
2	Area under restoration (maintenance and restoration of connectivity of natural ecosystems)
3	Coverage of protected areas and other effective conservation measures (OECMs) (protected area coverage of key biodiversity areas, protected area management effectiveness, Protected Area Connectedness Index, Species Protection Index)
4, 5	Red list index
4	Proportion of populations within species with an effective population size >500
5	Proportion of fish stocks within biologically sustainable levels (Living Planet Index for harvested species)
1,3	Percentage of land and sea area covered by biodiversity-inclusive spatial plans
8	No headline indicator (total climate regulation services provided by ecosystems by type as used in the UN System of Environmental-Economic Accounting, national greenhouse inventories from land use and land-use change)
11	Services provided by ecosystems
21	Biodiversity information for monitoring the Kunming-Montreal Global Biodiversity Framework (species status index)

A list of component and complementary indicators, for each headline indicator, are found in Table 2 of the CBD Decision 15/5 (CBD COP 15, 2022). Common techniques used for biodiversity monitoring are summarised in Box 5.1, below: *Summary of tools for measuring GBF headline indicators*.

Measuring biodiversity can be key to implementing new PCAs successfully; it can capture what is driving the state and change of ecosystems both locally and regionally/globally. Similarly, when managing existing PCAs, site-level metrics can be used, and are likely to focus on monitoring state and change of ecosystems, species and genetic diversity over time.

Monitoring will be critical, as although reducing carbon emissions is generally positive for biodiversity, some climate change mitigation actions can negatively impact biodiversity (Pettorelli et al., 2021). For example, afforestation in areas that were not formerly forests, especially with monocultures, can be detrimental to native ecosystems, and building dams for hydropower can alter the habitat for freshwater organisms and block fish migration (Smith et al., 2022). However, co-benefits between biodiversity conservation and climate change mitigation are also possible. For example, increasing plant diversity can increase biomass production and ecosystem resilience, contributing to increased carbon sequestration and long-term carbon storage (Brosse et al., 2022; Feng et al., 2022; Mori et al., 2021).

^{2.} Component indicators are optional indicators that, together with the headline indicators, cover components of the goals and targets of the GBF which may apply at the global, regional, national and sub-national levels. We have included component indicators because they are most relevant for readers of this report.

5.3 Measuring biodiversity for climate change mitigation

Biodiversity can be measured in many ways (e.g. headline indicators of CBD, Table 5.1) using different tools (see Box 5.1 below). Although different metrics collectively can provide complementary information about changes in biodiversity, they can be inadequate individually (Hillebrand et al., 2018; Oke et al., 2022). Local-scale measurement of species diversity, comparisons of species diversity between two communities and regional assessments of species diversity are common measures, where 'species' is the target level of organisation. Species diversity is perhaps the most visible and intuitive feature of any ecosystem, although it may not capture ecological functions and processes or the potential for adaptation (i.e. evolutionary or genetic diversity changes). Other notions of biodiversity such as taxonomic and structural diversity (e.g. (Lausch et al., 2016)) can also be measured.

5.3.1 Considerations for the biodiversity/climate change nexus

For the biodiversity/climate change nexus it may be more effective to focus on basic measures of species diversity, abundance, and functional diversity for a variety of reasons:

- There is evidence that species diversity, particularly for terrestrial plants, correlates positively with above-ground carbon stocks (Chen et al., 2016; Dimobe et al., 2019; Mori et al., 2021). However, hot spots for species diversity do not always overlap with hot spots for carbon density (e.g. peatlands (Oke & Hager, 2020)). See also Chapters 6.
- Sometimes species abundance can be a more illuminating metric for the biodiversity/carbon nexus than species diversity. For example, a recent review by Malhi and colleagues (Malhi et al., 2022) illustrates the complexity of the relationship between wild animal abundance and climate change mitigation and adaptation in both terrestrial and marine environments. As an illustration, carbon storage in sediments is increased by wild animals in tundra, temperate woodlands, tropical wet forests, temperate grasslands and the deep ocean. On the other hand, carbon storage in soils and sediments is decreased in boreal forests and salt marshes by wild animals and can sometimes increase and sometimes decrease in savanna, deserts and seagrass ecosystems (Malhi et al., 2020).
- Climate change and biodiversity can affect aspects of ecosystem functioning, such as stability, resistance, resilience, primary productivity, nutrient cycling and decomposition. The relationship can go both ways. It is useful to capture measures of functional diversity when seeking to implement management actions that enhance the climate change mitigation potential of biodiversity (see Hisano, Searle, & Chen, 2018; Lausch et al., 2016).

Some companies are developing techniques that consider biodiversity in the carbon finance market (Morrell, Dodds, & Cameron, 2023).

Barren ground caribou in Denali National Park Alaska. © twildlife / iStock.com



Case Study 5.1

Climate co-benefits of tiger conservation, India



Submitted by

Aakash Lamba. National University of Singapore

Name of PCA and location

Tiger Reserves, India

IUCN governance type

Government

The protected area

Established in 2005, the National Tiger Conservation Authority in India designated key protected areas as 'tiger reserves'. These reserves were developed with the purpose of strengthening the nation's dwindling wild tiger population. The designation secured additional funding for the protected areas, along with heightened visibility and improved management tools, including advanced conservation technology.

The project

An independent research group assessed the current government-led management of the tiger reserves in India to determine the climate change mitigation benefits of these 'species' conservation programmes. They sought to determine whether the increased funding and management tools had an additional benefit to climate change mitigation, in the scenario where it was not the primary management objective. Researchers collected baseline deforestation data using the publicly available Global Tree Cover Loss dataset developed by Hansen and colleagues (Hansen et al., 2013). Cumulative deforestation was

compared between tiger reserves in India that underwent enhanced conservation measures by the National Tiger Conservation Authority of India (treatment group) and protected areas that did not undergo this intervention but still had tiger presence (untreated group). A control was then modelled within the treatment group through the Synthetic Control Method (SCM). Researchers used this method to develop a 'counterfactual' scenario for each tiger reserve, calculating the expected forest cover change if no conservation efforts were made. By comparing these synthetic controls to observed forest loss, avoided forest loss and its effects on carbon emissions were calculated. Researchers then calculated the economic benefits of these findings, using data on the avoided social cost of carbon emissions and the potential revenue from carbon offsets. Finally, each reserve's success was evaluated based on averted forest loss results, providing insights for future conservation strategies.

Successes

The policy had a net positive benefit, with over 5,802 hectares of averted forest loss, corresponding to avoided emissions of 1.08 ± 0.51 MtCO $_2$ e between 2007 and 2020. This translated to USD 92.55 ± 43.56 million in ecosystem services from the avoided social cost of emissions and potential revenue of USD 6.24 ± 2.94 million in carbon offsets over the study period.

Challenges

Attributing species conservation actions to climate outcomes is a challenging link to establish, especially given the wide range of confounding factors that influence the performance of protected areas. Additionally, having a perfect control group is difficult. Observational studies that observe impact evaluations are limited by the availability of suitable data. These challenges were overcome by employing novel techniques for data analyses, specifically by using the SCM, which can be used to effectively simulate counterfactual scenarios for causal inference.

Additional resources

(Lamba et al., 2023)

National Tiger Conservation Authority https://ntca.gov.in/



Royal Bengal Tigers in Panna Tiger Reserve, Madhya Pradesh, India. © ePhotocorp / iStock.com

5.3.2 Field methods

Biodiversity can be measured using a wide array of field methods, including radio telemetry, satellite tracking and camera traps (also known as trail cameras) which have gained popularity as non-invasive tools to reliably survey animal presence, population size and activity. They can be deployed over a range of spatial scales (Devarajan, Morelli, & Tenan, 2020) and developments in associated software, modelling techniques, and best practices guidelines are rapidly evolving (Devarajan, 2021; Dupont et al., 2021; Palencia et al., 2022). Some examples of field methods for measuring biodiversity are listed in Table 5.2.

Table 5.2 Summary of some field methods used for measuring biodiversity. (Note that this is not a comprehensive list.)

Method	Use	Sources
Acoustic monitoring	Survey technique used extensively for birds, bats, insects, some frogs and in marine environments for cetaceans, some fish and other water column dwelling fauna.	(Sugai et al., 2019).
Live and pitfall trapping	Sample arthropods and small mammals	(Brown & Matthews, 2016; Costello et al., 2017).
Collection of biological material	Collection and analyse scat, fur, feathers, molts	(Costello et al., 2017).
Videos	Monitor animals, especially useful in marine realm	(Costello et al., 2017).
Visual surveys	Monitor plant quadrants, line transects	(Buckland et al., 2007; Lupi et al., 2017)
Point-intercept method	Monitor grasslands grazed by livestock or native herbivores	(Godínez-Alvarez et al., 2009)
Environmental DNA (eDNA)	Monitor species presence and assess populations. Collect genetic material shed into the environment by an organism. Used especially in aquatic ecosystems.	(Thomsen & Willerslev, 2015) (Deiner, Yamanaka, & Bernatchez, 2021) (Compson et al., 2020)

5.3.3 Environmental DNA (eDNA)

Taking biodiversity measurements in submerged ecosystems is not straightforward: field operations often require special equipment or extensive modifications to techniques. Molecular barcoding such as environmental DNA (eDNA) can help overcome these challenges. eDNA barcoding offers a cost-effective and rapid approach to quantifying biodiversity across the entire phylogeny of organisms (i.e. microbes, plants and animals (Compson et al., 2020; Deiner et al., 2017)). This technique can be scaled to cost-effectively assess the state of an ecosystem and observe shifts in species distributions including early detection of invasive species (Yoccoz, 2012). Additionally, eDNA can be used to detect endangered and cryptic species at different spatial and temporal scales. Thus, molecular tools can be valuable for improving conservation knowledge (Jerde et al., 2011). As genetic techniques have advanced so has eDNA. For example, eDNA metabarcoding couples high-throughput sequencing (a molecular tool) with genetic sequences from eDNA to allow non-invasive surveys of species richness in many ecosystems (Deiner et al., 2017).

5.3.4 Sampling standards

The ForestGEO network has established rigorous standards for the non-destructive sampling of trees and conversion of tree measurements to above-ground biomass estimates (Chave et al., 2005). In grasslands, the relative abundance of each grassland plant species is often approximated by percentage cover, ideally from permanent plots. The Nutrient Network has standard protocols for estimating plant cover in grasslands (Borer et al., 2017). Another common approach for non-destructive sampling is the point-intercept method, especially in grasslands that are grazed by livestock or native herbivores. Sampling species populations is useful for understanding and managing carbon mitigation in protected areas by providing information on ecosystem biodiversity, including nutrient cycling and erosion control. Many of the methods used in terrestrial environments are relevant to various ecosystems, including freshwater and saltwater habitats such as streams, salt marshes, seagrass beds and mangrove forests. However, many traditional monitoring strategies are challenging due to reliance on taxonomic expertise, time, and labour (Beng & Corlett, 2020).

5.3.5 Community science advances

Public participation in science, or community science, is growing in popularity for routine biodiversity monitoring, with species observations from non-scientific professionals contributing over 50% of the observations to international and global biodiversity databases, such as Global Biodiversity Information Facility (GBIF) (Chandler et al., 2017). Further, many studies report the benefits of simple training and community involvement in local conservation (Larson et al., 2020). Specifically, widely available applications such as iNaturalist and eBird can serve as early detection tools to identify and prevent the establishment of invasive species (Hartmann et al., 2022). Community science can also involve highly trained members of the public in structured standardised monitoring, such as the case with Reef Life Survey (https://reeflifesurvey.com/ about-rls/) where trained SCUBA divers record size and abundance data of thousands of reef-dwelling species observed across thousands of sites worldwide. Additionally, large-scale collaborative efforts using eDNA can effectively assess the regional biodiversity of a habitat due to the low cost of equipment and field sampling experience required (Agersnap et al., 2022; Miya et al., 2022). Thus, monitoring projects that include educational opportunities are essential for increasing the understanding of environmental challenges within the broader community and for encouraging policy support (Couvet et al., 2008). Such projects, like Redmap Australia (the Range Extension Database and Mapping Project hosted by the Institute for Marine and Antarctic Studies in Australia), have been shown to be effective at both improving participants' understanding of climate change and generating ecological data that are trusted by the broader community (Nursey-Bray, Palmer, & Pecl, 2018; Pecl et al., 2019).

The information collected by volunteers is increasingly important for biodiversity monitoring and species recovery. The group in this photo are helping in a conservation program for the recovery of a rare fish in Thailand. © Verin Makcharoen / iStock.com



5.4 Remote sensing

Several researchers (Alleaume et al., 2018; Pettorelli et al., 2021; Timmermans & Kissling, 2022; Vihervaara et al., 2017) have evaluated the potential use of remote sensing products to measure essential biodiversity variables. Timmermans and Kissling (Timmermans & Kissling, 2022) report that 35 monitoring elements (with 50 unique indicators), used to track the state of terrestrial biodiversity for the GBF, can be measured with spatial information products. For a discussion on the use of remote sensing to measure carbon see Chapter 4.

Remote sensing technology can reduce the cost and time of measuring different phenomena over time at broad spatial scales and complement fieldwork (Cawse-Nicholson et al., 2021; Schimel et al., 2019; Turner et al., 2015). Specifically, recent advances in data processing, satellite missions (current and forthcoming), and increasing availability of airborne and proximal measurements continue to provide a wealth of data necessary for monitoring biodiversity in space and time; for example, through species mapping, habitat mapping (e.g. mapping landcover or climatic conditions), or quantifying habitat heterogeneity and geodiversity - defined as the variability of abiotic conditions that enable a population of species to exist at a given space and time (Loke & Chisholm, 2022; Zarnetske et al., 2019). Remote sensing has also been used to infer species richness, species compositional turnover (Luque et al., 2018; Rocchini et al., 2018; Schweiger & Laliberté, 2022), various other aspects of terrestrial vegetation, and in fewer cases, microbial diversity, diversity of insects, and diversity in aquatic systems.

High spectral resolution imaging spectroradiometers have encouraged the estimation of plant traits related to physiology and biochemistry (Homolová et al., 2013). Therefore, this technology can complement field measurements of plant traits (Kokaly et al., 2009) and be used for species discrimination (Homolová et al., 2013). Aerial Laser Scanning (ALS) and Light Detection and Ranging (LiDAR) have been applied to measure plant structural traits, benthic habitat composition and the three-dimensional structure of ecosystems. These instruments have been used with passive remote-sensing to scale above-ground carbon stocks from plot to regional and global scales (Abelleira Martínez et al., 2016; Asner et al., 2012; Baccini et al., 2012).

These novel streams of data make critical contributions to monitoring progress towards biodiversity conservation goals (Alleaume et al., 2018; O'Connor et al., 2015; Timmermans & Kissling, 2022). In the context of rapid climate change, biological invasions and land-use landcover change, remote sensing will be a key tool for monitoring the GBF. However, developing a global biodiversity monitoring system based on remote sensing technology still requires considering confounding factors related to analysis and sampling design.

5.5 Ecological modelling

Making use of ecological models to understand where species are currently distributed and where they might be found at different times will be essential. Models can also be used to extrapolate into unsampled space and in the future, fed with data collected using the field methods described above.

Multiple modelling approaches have been developed to capture a variety of biodiversity attributes such as species distribution and abundance, functional diversity, genetic composition, community composition, and ecosystem structure and function (Adde et al., 2023; Fulton et al., 2011; Ikeda et al., 2017; Landguth et al., 2017; Pacifici et al., 2015). However, the best model depends on the overall goal of the conservation action. For example, to protect overall species diversity or focus on specific threatened species?

5.5.1 Correlative models vs process-based models

Common approaches to modelling biodiversity include correlative and process-based models. Correlative models can be easiest to create but are less generalisable. Process-based models incorporate ecological mechanisms and, although more data- and time-intensive, can provide better predictive power when extrapolating in space and time (i.e. with climate change projections) (Dormann et al., 2012; Geary et al., 2020; Sequeira et al., 2018). Nonetheless, choosing between these two types of models can also depend on whether the question is about species vs. community vs. ecosystem (Ferrier, Jetz, & Scharlemann, 2017). Fortuitously, a broad range of modelling options exist, allowing for fit for purpose model selection that matches the question at hand and available data (Dormann et al., 2012).

Available model types include: hierarchical models such as occupancy models (Devarajan, Morelli, & Tenan, 2020); increasingly complex species distribution and habitat suitability models (Peterson, Cobos, & Jiménez-García, 2018); food-web-based models (Coll et al., 2019); sizeand trait-based models (Scott, Blanchard, & Andersen, 2014); and integrated models that are capable of capturing processes across the entire food web including the human dimensions (Moullec et al., 2019). While some of these approaches directly model biodiversity, others represent means to indirectly represent some dimensions of biodiversity via the combination of species or functional groups being tracked. Examples of the latter include dynamic global vegetation models, which are used to simulate plant-ecosystem processes (Sitch et al., 2003). Models that link biodiversity and ecosystem functions and services like carbon storage have been lacking but, recently, researchers have been developing techniques to link these types of models more effectively (Mokany et al., 2016; Weiskopf et al., 2020).

Further, each of these models are more readily used in particular environments. For instance, process-based food-web models have been used mostly for marine systems and less commonly for terrestrial systems. In contrast, direct modelling of biodiversity is rare in marine ecosystems, partly due to data limitations. This is slowly changing as there is increasing awareness of the value of this modelling approach for capturing various ecological mechanisms (Gagné et al., 2020; Oylinlola et al., 2022). More recently, approaches analogous to marine ecosystem models have been developed and applied to simulate the functional composition and ecosystem function of whole terrestrial ecosystems (Harfoot et al., 2014).

5.5.2 Scenarios

Models are not only used to explore and explain past and current biodiversity, but also to quantify biodiversity and especially change in biodiversity into the future - for example, in response to global change, or as a result of specific developments or management interventions. These future-focused modelling efforts require assumptions pertaining to unmodelled aspects such as policy settings or other external drivers which set the context for the numerical simulations. Scenarios are used to define the bounds or trajectories for these drivers (Nicholson et al., 2019). Different kinds of scenarios include (IPBES, 2016):

- exploratory scenarios for considering a range of plausible futures;
- intervention scenarios that screen potential policy performance (e.g. using ex-ante assessments) to find those that meet policy goals;
- or ex-post assessments of policy outcomes to see if they met expectations.

Irrespective of the foci of the different scenario types, they are all sources of uncertainty because they are only partial descriptions of the world (focusing on key drivers). Nevertheless, they help ground and increase the decision-making utility of model outputs.

5.5.3 Uncertainties and limitations

All scenarios and models have strengths and weaknesses; it is important to be clear about their uncertainties and limitations. For instance, models must have a balance between their complexity and the data available to avoid modelling challenges (Ludwig & Walters, 1985). Additionally, it is critical to evaluate models over time, against observed data, to reduce uncertainties (Dietz et al., 2021; Myers et al., 2021). To overcome challenges in model selection and uncertainties, a common approach is ensemble modelling, where multiple modelling algorithms are applied independently to a dataset and then combined into a single model allowing the possibility to explore uncertainties (Geary et al., 2020). Furthermore, Bayesian statistics can resolve problems relating to complex data structure, incomplete data, and zeroinflated data (Coll et al., 2019).

Case Study 5.2

Kahuzi-Biega National Park, Democratic Republic of Congo. Employing carbon accounting to support biodiversity conservation



Submitted by

Josué Aruna, Congo Basin Conservation Society **CBCS-Network**

Name of PCA and location

Parc National de Kahuzi-Biega PNKBDRC, South Kivu Province

IUCN governance type

Government

The protected area

Kahuzi-Biega is a National Park in the Democratic Republic of Congo, implemented with the intention of protecting the local biodiversity hotspot, namely the endemic species of gorillas and elephants. This 600,000 ha (6,000 km²) protected area faces a multitude of threats, including mining, illegal poaching, logging and oil drilling. These activities continue without interference from the Congolese government, forcing non-profits such as the Congo Basin Conservation Society (CBCS) to advocate for local change.

The project

Kahuzi-Biega National Park is confronted with numerous threats that undermine its ecological integrity. In response, the CBCS has recognised that enhancing the park's resilience to climate change necessitates direct intervention to address these threats. A significant concern is the proposed acquisition of part of the park's peatland complex for oil drilling. In an effort to combat this, the CBCS is mobilising grassroots public pressure and activism to prevent the land purchase.

Additionally, the CBCS is working to mitigate logging pressures from the local community by educating residents on the harmful impacts of logging and promoting sustainable alternatives for heating in the villages. Another initiative involves encouraging agroforestry, which integrates crops and livestock into existing ecosystems, thus reducing the pressures that contribute to deforestation. The CBCS is also actively engaged in the restoration of 224,646 hectares (2,246 km²) of the protected area while fostering public awareness of the park's ecological value. These efforts aim to garner broad community support for continued conservation activities. Collectively, these actions contribute to climate change mitigation by decreasing deforestation, enhancing carbon sequestration, and promoting sustainable land-use practices.

Challenges

Although there are many threats to this protected area, the group cites a lack of funding as being their greatest challenge.

Additional resources

(Congo Basin Conservation Society)



Gorilla in Democratic Republic of Congo. @ AlejandroPalacio / iStock.com

5.5.4 Identifying the overlap between biodiversity and carbon density

While there has been some work to identify where protected areas could have the greatest benefits for carbon storage and biodiversity conservation (Crouzeilles et al., 2020; Soto-Navarro et al., 2020), more emphasis on the role of biodiversity itself in promoting climate change mitigation is warranted. Thus, it is important both to create PCAs in places that are hotspots for biodiversity and carbon sequestration or storage, and also important to maintain or increase biodiversity within existing protected areas to increase mitigation potential. Measuring and monitoring biodiversity can help achieve both goals (see also Chapter 6).

5.6 Measuring biodiversity for climate change impacts and mitigation

Different methods exist to measure biodiversity and carbon; here, we highlight examples organised by field methods, remote sensing, and ecological modelling approaches. Where and how to monitor biodiversity and its impacts on climate change mitigation (and vice versa) is context-dependent, and will involve decisions about:

- what level of biodiversity to measure (e.g. genetic diversity, species composition, ecosystem structure, and functional ecological groups) (Burbano-Girón et al., 2022);
- · what is required for meeting conservation objectives (e.g. threatened species protection or ecosystem restoration);
- potential for co-benefits such as increasing water supply and carbon storage (Jung et al., 2021; Smith et al., 2022; Strassburg et al., 2020);
- potential for complementarity of multiple biodiversity features (e.g. refugia potential, climate corridors, environmental diversity) (Stralberg et al., 2020).

5.6.1 Comparison of biodiversity monitoring methods

Opportunities arise when combining advanced modelling approaches with novel field methods that allow spatial and temporal resolutions of biodiversity documentation (Altermatt et al., 2020; Carraro et al., 2020; Martel et al., 2021). Field methods can provide detailed information on biodiversity at local scales, and can be useful for site and protected area level management. For example, field methods can track how restoration activities improve biodiversity and carbon sequestration. Airborne and satellite remote sensing is a cost-effective way to obtain biodiversity and ecosystem functioning data across larger areas, including remote and difficult to access places (O'Connor et al., 2015; Shiklomanov et al., 2019). While remote sensing is very powerful in assessing various aspects of terrestrial plant diversity, it is very limited in its capability to assess microbial diversity, diversity of insects and diversity in aquatic systems (unless in relatively shallow waters). Combining remote sensing with other approaches, especially environmental DNA methods, results in a more holistic assessment of biodiversity, even integrating across the aquatic-terrestrial interface (Altermatt et al., 2023; Zhang et al., 2023). Furthermore, models can be useful at local and regional/global scales (e.g. modelling species distributions within a protected area or globally) and provide more comprehensive coverage than observational data alone. Additionally, models can be used for large-scale spatial planning. However, modelling indicators depend on observational data to set initial conditions and validate results. Field, remote sensing and modelling approaches complement one another in achieving desired biodiversity and climate change mitigation outcomes.

5.6.2 Matching GBF targets to methods

The monitoring framework for the GBF includes different types of indicators that will be useful at different scales. Headline indicators are a small set of high-level indicators that all Parties will report and use to track progress within the programme's goals and targets and can help monitor biodiversity at national, regional or global scales (see Table 5.1). Some of these indicators (e.g. extent of natural ecosystems or coverage of protected areas) may be useful for spatial planning and creating protected areas. However, headline indicators may not always capture all important aspects of goals and targets, and can be supplemented by component (see Table 5.1) and complementary indicators (e.g. Protected Area Connectedness Index).

Many of the GBF indicators are based on observations from field data or remote sensing. Models can be useful in tracking multiple components of goals and targets and for conservation planning to evaluate potential outcomes from different management actions. Figure 5.1 depicts a framework for using modelling to integrate remotely-sensed and fieldbased observations in deriving indicators linking implementation of actions to achievement of outcomes under the GBF. While this particular example focuses on area-based actions targeted toward achievement of outcomes under Goal A, the same broad approach could be applied to linking other GBF goals and targets.

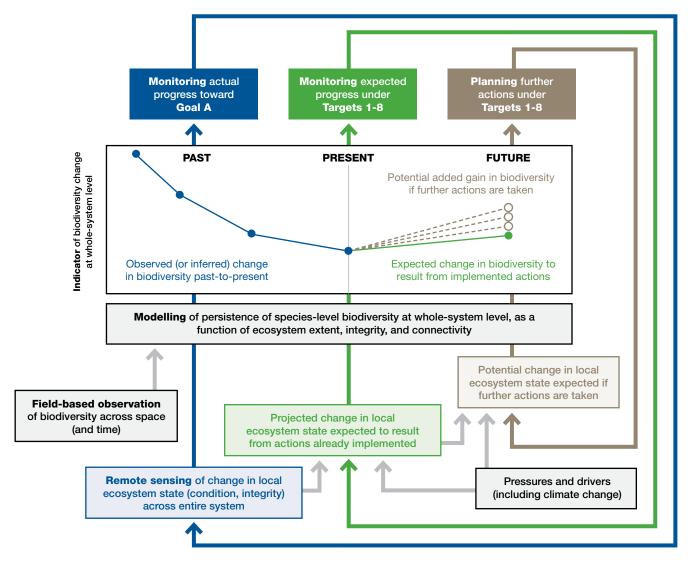


Figure 5.1 Example framework describing how modelling can be used to integrate remotely-sensed and field-based observations to derive indicators supporting achievement of Goal A of the Kunming-Montreal Global Biodiversity Framework (GBF) through implementation of area-based actions under Targets 1 to 8 (e.g. ecosystem protection or restoration). The coloured pathways depict three different roles which an integrative indicator such as the Biodiversity Habitat Index (Kim et al., 2023) identified in the GBF Monitoring Framework as a component indicator for Goal A, can play in this process: 1) monitoring actual progress toward the achievement of Goal A, by using remotely observed change in ecosystem condition or integrity to infer past-to-present change in the persistence of species-level biodiversity (blue pathway); 2) monitoring expected progress toward achieving Goal A, accounting for the yet-to-be-manifested benefits of area-based actions already implemented (green pathway); and 3) planning and prioritising further area-based actions by assessing the additional gain in biodiversity which would potentially result from alternative actions under consideration (brown pathway), including through the production of spatial priority maps. Adapted from (Millette, 2022).

5.6.3 Summary of measuring biodiversity

Box 5.1

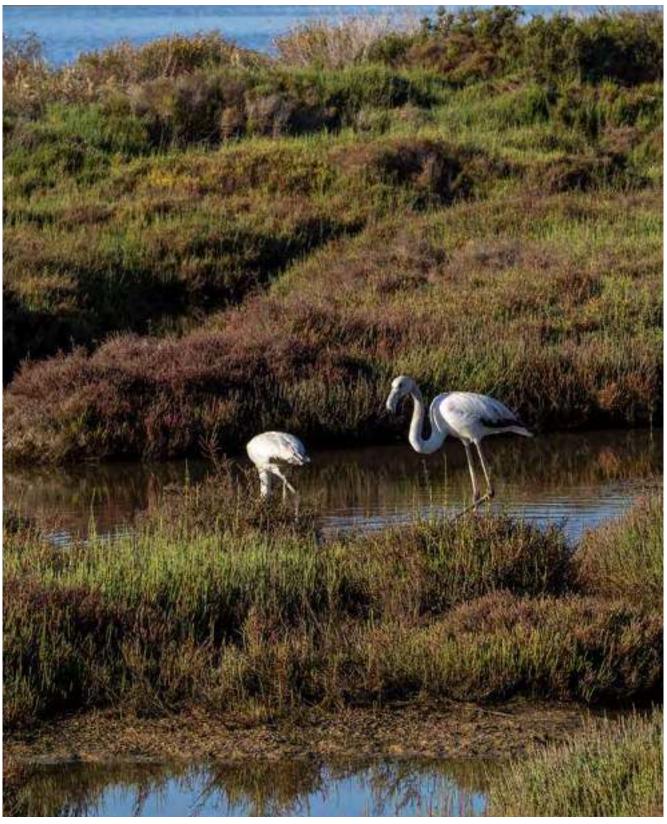
Summary of tools for measuring biodiversity components of the headline indicators in the Kunming- Montreal Global Biodiversity Framework

Species diversity	Genetic diversity	Functional diversity	Structural diversity
 Radio telemetry Satellite tracking Camera tracks Acoustic monitoring Live & pitfall traps Quadrats and line transects Percentage cover Point-intercept method Collection of biological material Ecological modelling 	 DNA sequencing DNA barcoding eDNA metabarcoding Ecological modelling 	Airborne remote sensingEcological modelling	 Quadrats and line transects Point-intercept method Aerial laser scanning Ecological modelling

Conservation decision-makers often use biodiversity data to decide how to allocate conservation resources, including through using spatial prioritisation algorithms (Margules, Nicholls, & Pressey, 1988; Moilanen et al., 2009). For example, mapping carbon stocks and biodiversity allows for the identification of areas of potential co-benefits for climate change mitigation and biodiversity conservation (Soto-Navarro et al., 2020), while mapping degraded areas and estimating carbon sequestration allows for the identification of synergies among restored forests that could sequester carbon, reduce species at risk of extinction, and improve connectivity (Crouzeilles et al., 2020). Identifying these areas is the first step for initiating combined efforts that facilitate the implementation of climate and biodiversity-related commitments.

Monitoring biodiversity is an important component of conservation planning, implementation and evaluation of success. For example, conservation corridors play a critical role in climate change adaptation by creating the connectivity needed for species to move in response to changing environmental conditions (Morelli et al., 2020). Conservation corridors can also support complementary objectives such as enhancing carbon storage (Jung et al., 2021). Mapping connectivity of the landscape (or seascape) before an intervention helps locate where improved connectivity may be necessary, while monitoring after an intervention can identify if changes have contributed positively to the composition and structure of the ecosystem.

No matter how biodiversity is measured, including users who understand the policy environment in the research design from the beginning means that model inputs or project outcomes do not have to be retrofitted for a specific outcome later, thereby saving time and effort (Enquist et al., 2017; IPBES, 2016; Saltelli et al., 2020; Weiskopf et al., 2020).



Flamingos in the salt marshes of the Ebro Delta Natural Reserve, Catalonia, Spain. © Javier Sanz Mairal / iStock.com

Chapter 6

Integrating hotspots for carbon-density and biodiversity

Risa B. Smith and Shane Orchard

6.1 Chapter highlights

- ✓ Developing tools that identify the area of overlap between carbon richness and high biodiversity are in the early stages of development. However, these types of tools are key to addressing climate change mitigation and biodiversity conservation synergies for the creation and management of PCAs.
- ✓ While methodologies for measuring carbon sequestration and stores are well established (see Chapter 4), choosing the best measurements for biodiversity, when identifying the carbon/biodiversity overlap, is less straightforward (see Chapter 5).
- Global maps that have been constructed by aggregating local or regional scale data can be a source of information for identifying carbon-dense/high-biodiversity areas. Most authors will provide the disaggregated data on request.
- ✓ The terrestrial examples highlighted in this chapter focus on the derivation of mapping products and identification of overlaps between measures of biodiversity and carbon density. Areas that provide fresh water supply have been included as an additional consideration.
- ✓ The examples highlighted focus on analyses for two coastal blue carbon ecosystems, mangroves and seagrass meadows. Mapping examples of carbon-density/biodiversity overlaps were not available for salt marshes.
- Marxan, a software designed to support conservation decision-making, is profiled as a decision-support that has been frequently used to address decisions related to the climate change mitigation/biodiversity nexus. However, it is not the only tool available.

6.2 Introduction

Addressing biodiversity loss and climate change in lock-step requires a paradigm shift for protected areas policymakers from "saving nature" to "harnessing the benefits of nature to save ourselves" (Roberts, O'Leary, & Hawkins, 2020). Many authors have now recognised the need to address these two global issues together and have suggested actions (Cannizzo et al., 2024; Convention on Biological Diversity, 2024; Cook-Patton et al., 2021; Cook-Patton et al., 2020; Dinerstein et al., 2019; Girardin et al., 2021; Locke et al., 2021; Pörtner et al., 2021; Smith et al., 2020; Smith et al., 2019; Strassburg et al., 2010). However, it is challenging to maximise the role of existing or new protected areas in addressing both climate change and biodiversity loss (Arneth et al., 2020). Unlike methodologies for measuring carbon stores and sequestration (see Chapter 4), or biodiversity (see Chapter 5), international standards have not been agreed to for identifying the places - terrestrial, coastal and marine - where carbon-rich/high biodiversity areas overlap. Available methodologies are mostly in the research phase. However, significant methodological progress has been made that allows for a broad global picture and a more precise regional picture of the location of these overlaps.

It is important to note that not all biodiversity hotspots, or other areas of high biodiversity value, are carbon-dense and vice versa. Results so far indicate that the spatial scale of analyses and the metrics used for biodiversity impact results. Studies that only look at vertebrate richness as an indicator of biodiversity often find weak correlations, particularly at the regional scale, while those examining a broader array of biodiversity indicators, including plant and animal richness, biodiversity indices, Key Biodiversity Areas, Important Bird Areas or other measures of biodiversity, find better correlations (Di Marco et al., 2018; Jung et al., 2021). For example, protected areas have been shown to be successful in protecting carbon stocks and biodiversity in a regional study in Southeast Asia (Graham et al., 2021) and a national study in the United States (Zhu et al., 2022), compared to areas outside protected areas. Research locating carbon-rich/high-biodiversity ecosystems has focused on forests, on the terrestrial side. On the coastal marine side, it is assumed that mangroves, seagrasses and salt marshes are all important for biodiversity so the emphasis has been on assessing carbon stores and annual sequestration.

Case Study 6.1

Climate co-benefit of biodiversity conservation in Kazakhstan's steppe



Submitted by

Genevieve Stephens, RSPB

Name of PCA and location

Bokey Orda State Protected Area, West Kazakhstan

IUCN governance type

Government/State Protected Area

The protected area

The 720,000-hectare (720 km²) Bokey Orda and Ashiozek State Protected Area is home to the world's largest population of Saiga Antelope, which congregate there every spring to give birth. Established in July 2022, the protected area was created to safeguard this critical habitat and has the potential to support a fully functioning ecosystem, including an assemblage of fungi, vegetation, wild grazers, scavengers and predators. Since its establishment, the Royal Society for the Protection of Birds (RSPB) and the Association for the Conservation of Biodiversity of Kazakhstan (ACBK) have been working closely with protected area staff to conduct baseline biodiversity surveys, develop the first 5-year management plan, design and deliver ranger training, and build relationships with local communities.

The project

The Altyn Dala Conservation Initiative was established in 2005 to prevent the imminent extinction of the Critically Endangered Saiga Antelope. It has since been dedicated to preserving and restoring Kazakhstan's vast steppe, semi-desert, and wetland ecosystems and supporting the establishment of over 5 million hectares (50,000 km²) of PCAs across the country. The Initiative is a multi-national partnership comprising the Association for the

Conservation of Biodiversity of Kazakhstan (ACBK), the Government of Kazakhstan's Ministry of Ecology and Natural Resources, the Royal Society for the Protection of Birds (RSPB), Frankfurt Zoological Society (FZS) and Fauna and Flora International (FFI). In 2021, the Altyn Dala Conservation Initiative was nominated as one of ten World Restoration Flagships by the United Nations, and in 2024 the partnership was named the winner of the Earthshot Prize in the Protect and Restore Nature category.

The steppe grasslands of Kazakhstan have undergone decades of large-scale land use change, including extensive cultivation, resulting in significant losses of soil carbon to the atmosphere. Additionally, following the dissolution of the Soviet Union in 1990, these grasslands experienced abrupt fluctuations in the distribution and population density of both wild and domesticated grazers. As a result, regions that have been undergrazed now face a heightened risk of steppe fires, while overgrazed areas suffer sustained soil degradation and drought. The cumulative impact of these factors has driven the encroachment of desertification, which threatens the livelihoods of local communities while undermining the integrity of the ecosystem.

By investigating the soil carbon stocks, losses, and potential gains within and around the Bokey Orda Protected Area, this study aims to assess the extent of grassland degradation and identify optimal areas for targeted restoration efforts. Simultaneously, the feasibility of generating carbon finance through future restoration interventions is being explored, with the goal of supporting local communities and incentivising the adoption of less-intensive agricultural practices. The study began with a comprehensive literature review, which involved systematically searching, screening and synthesising relevant academic sources relating to temperate grassland carbon dynamics. Key information was extracted and presented to project collaborators, to inform the design of the field survey. The literature review exposed the need to better understand the complex relationship between grazing and carbon sequestration and storage in temperate grasslands. As such, the survey was designed to sample points across a gradient of domestic grazing intensity, while considering the effects of soil type, climate and presence or absence of wild herbivores.

Fifty sampling points were surveyed across the protected area. At each point, soil samples were collected from depths of 0-15 cm and 15-30 cm, as changes in carbon are most evident in the topsoil. In addition to soil sampling, botanists cut and weighed the biomass within a 10x10 metre quadrant and recorded the vegetation species present. A 100 m transect, adjacent to each point, was then walked and the number of livestock dung counted, as a proxy measurement of grazing intensity. The soil samples were sent to a laboratory in Kazakhstan, where their total organic carbon, total Nitrogen, pH, electrical conductivity, and bulk density were determined. An analysis of the comprehensive dataset is currently underway.

Successes

As the protected area was only recently established, it is too soon to identify success. However, research is ongoing across the site and the impact of restoration interventions, including on soil health and carbon will be monitored. Over time, relevant training will continue to be provided to local rangers to enable them to lead on longer-term monitoring studies, using the Spatial Monitoring and Reporting Tool (SMART) to synthesise and share outcomes.

Additional resources

(Royal Society for the Protection of Birds, 2022) (Wyss Foundation, 2022)



Red fox in Kazakhstan steppes. © ecomike / iStock.com

6.3 Mapping the biodiversity/ climate change nexus

A few studies have attempted to map the biodiversity/climate change nexus at different scales.

6.3.1 Mapping carbon-dense/high biodiversity terrestrial areas

6.3.1.1 Example 1. Mapping co-benefits for carbon storage and biodiversity to inform conservation policy and action (Soto-Navarro et al., 2020)

Soto-Navarro and colleagues (Soto-Navarro et al., 2020) have created high-resolution maps of the overlap between carbon-density and biodiversity, with the intent that their results could be used at regional or national scales to identify the most promising areas for addressing biodiversity and climate change simultaneously. These data have been used as baseline data for several regional and national studies.

This study used multiple steps:

- creation of a high-resolution map of above and below-ground carbon stored in biomass and soil;
- quantifying biodiversity using two new complementary biodiversity indices, proactive biodiversity index (Blp) and reactive biodiversity index (Blr);
- identifying overlap of carbon and biodiversity hotspots, using the two indices and the map;
- Identifying the overlap between carbon-dense/high biodiversity areas and protected areas.

While the identification of carbon-dense areas is fairly straightforward, the identification of important biodiversity areas is more complex. The proactive biodiversity index represents areas of high importance for biodiversity that are largely intact. These are the areas in urgent need of protection to ensure the long-term persistence of biodiversity. The reactive biodiversity index, in contrast, represents the last refuges for species whose habitat has been greatly depleted across their range.

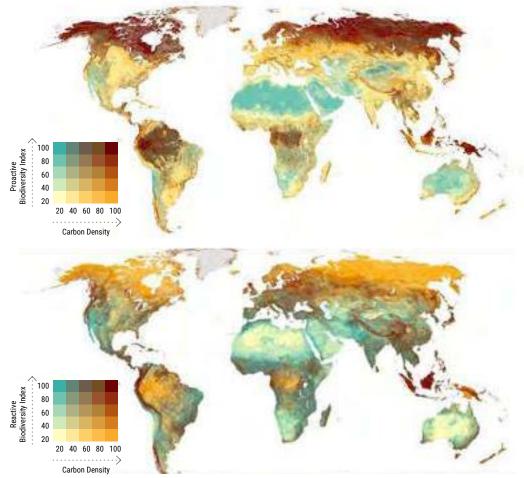


Figure 6.1 Global map of areas of overlap between high biodiversity and carbon density. The top map depicts the area of overlap between areas of high local biodiversity (high species richness, range-size rarity, high local intactness and high average habitat condition (proactive biodiversity index) with carbon richness. The bottom map depicts the area of overlap between areas of high local biodiversity, low average habitat condition and high threats (reactive biodiversity index) with carbon richness. The dark brown areas depict the areas of highest overlap. Source: (Soto-Navarro et al., 2020). Reproduced with permission from Royal Society (UK).

Caveats

Because this work is still in the research phase, important caveats need to be highlighted. The carbon maps represent carbon stocks. They do not represent emissions potential from land-use change. While almost all carbon stocks are emitted from land-use change that removes biomass, emissions from soil carbon stocks are more complex and nuanced. As well, the two biodiversity indices are fairly complex but they lack incorporation of genetic diversity and rely on species data that are biased towards vertebrates and vascular plants.

6.3.1.2 Example 2. Areas of global importance for conserving terrestrial biodiversity, carbon and water supply (Jung et al., 2021)

Jung and colleagues (Jung et al., 2021) mapped, at a 10 km resolution, the overlap between terrestrial biodiversity of conservation importance, carbon and water supply, with the intention of helping countries meet their goals at the Convention on Biological Diversity (CBD) and the UN Framework Convention on Climate Change (UNFCCC). To measure biodiversity, the authors included species' habitat necessary to qualify for the conservation status of 'Least Concern' following IUCN Red-List criteria. For carbon storage they assessed above and below-ground biomass carbon, although they did not consider soil carbon. For water supply they used the volume of potential clean water by river basin (Jung et al., 2021). These authors used a multicriteria spatial optimisation framework to investigate synergies between biodiversity, carbon and water supply. When optimising for all three criteria, top-ranked areas were distributed across all continents, latitudes and biomes. Table 2 of the supplementary information published by (Jung et al., 2021) provides priority rankings for each country for biodiversity and carbon, biodiversity and water supply, water supply and carbon, and all

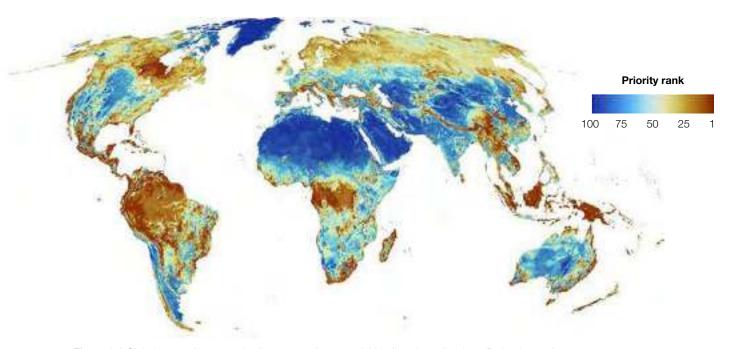


Figure 6.2 Global areas of conservation importance for terrestrial biodiversity and carbon. Darker brown is most important, darker blue is least important for the biodiversity/carbon overlap. All features were jointly optimised with equal weighting given to each feature and ranked by the most (1-10) to least (90-100) valuable areas to conserve globally. The map is at 10 km resolution in a Mollweide projection (Figure 3a in Jung et al., 2021). Reproduced with permission from Springer Nature.

6.3.1.3 Example 3. Nature Map Earth

Nature Map offers freely available global maps of terrestrial biodiversity, carbon stocks and water supply. These maps are intended to give an integrated view of biodiversity, carbon stocks and water to, among other things, help policymakers integrate strategies that tackle biodiversity loss and climate change, including land-use change. The maps support Target 1 of the Kunming-Montreal Global Biodiversity Framework on spatial mapping (Convention on Biological Diversity, 2022). Nature Map has been applied by Fundación Bariloche and partners in Argentina and is being explored by several other countries (SDSN Secretariat, 2020).

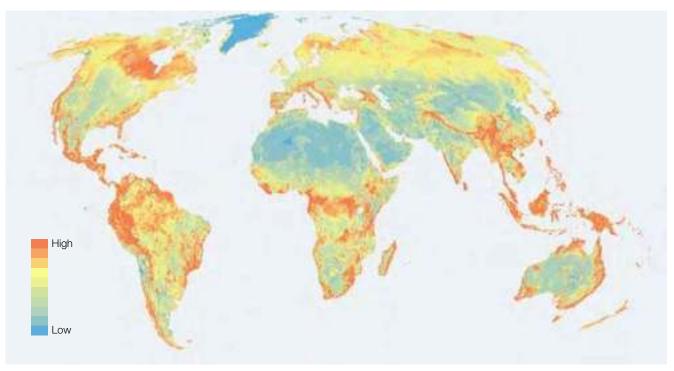


Figure 6.3 Areas of global importance for terrestrial biodiversity and carbon. Dark orange represents areas of high importance, blue represents areas of low importance (SDSN Secretariat, 2020).

6.3.2 Synergies among the three terrestrial examples

Jung et al. (2021), Soto-Navarro et al. (2020) and SDSN (2020) identify places of importance for both biodiversity and carbon. These can be thought of as places where further investigation is warranted for new or expanded protected areas that would feature biodiversity and carbon hotspots. As the methodologies and organising framework are different, it is not possible to conduct a direct comparison of the priority places. Examples of high priority areas identified in these studies are:

- The montane rainforests of Peninsular Malaysia, northern Borneo and West Sumatra and mangroves of the Sunda Shelf;
- The montane alpine meadows of Kinabalu in the Indomalayan realm;
- The southeastern montane rainforest, freshwater swamps of New Guinea and Sulawesi and Halmahera rainforests of southeastern Asia in the Australasian realm;
- The Amazon Basin in the Neotropics;
- The Palaearctic and Nearctic realms of southern Hudson Bay, Alaska-Yukon, Siberian Taiga, Canadian Arctic and Central Siberian tundra;
- Pacific Northwestern forests of North America.



Polar bear in peatlands of Hudson Bay lowlands which have been identified by all analyses as an important area for the biodiversity/climate mitigation overlap. © Andre Erlich / iStock.com

6.3.3 Identifying carbon-rich/high biodiversity coastal blue carbon areas

The evidence that blue carbon ecosystems, and particularly mangroves, seagrasses and salt marshes, are important for biodiversity is unequivocal: mangroves provide food, breeding grounds and nursery sites for many terrestrial and marine organisms, including commercial species and juvenile reef fish (Carugati et al., 2018); seagrass meadows create nursery grounds for many species that live in the wider marine ecosystem, provide habitat for numerous important and endangered marine species and food security for coastal communities (Montero-Hidalgo et al., 2023); salt marshes (or tidal marshes) form links between terrestrial and marine ecosystems, habitat for wildlife, nursery grounds for fish and breeding/feeding grounds for birds (Teixeira, Duarte, & Caçador, 2014). If undisturbed, these ecosystems store carbon for long periods, and once lost it can take decades or more to recover, which leads to the conclusion that protection should be prioritised as having the best mitigation value (Howard et al., 2023).

All coastal blue carbon ecosystems are declining in extent. During the last 20 to 25 years mangroves extent has declined by 0.16% per year; salt marshes area have declined by 1.32% per year; seagrasses have declined by 1.5% per year (Alongi, 2023). Current research efforts are focused on: i) marine spatial planning to strengthen blue carbon ecosystems and enhance their role in climate stabilisation and safeguarding marine biodiversity (Gattuso et al., 2023); ii) identifying the global extent of remaining blue carbon ecosystems; iii) quantifying the carbon stored and actively sequestered by blue carbon ecosystems (see Chapter 4 on Methodology for quantifying carbon sinks and stores).

Mapping the overlap between carbon-density and biodiversity hotspots has not been an active area of research for blue carbon. Building on IPCC Guidelines for coastal blue carbon (see Chapter 4. Methodology for quantifying carbon sinks and stores) to include other marine ecosystems would help to better identify the full range of MPAs that could be important for the biodiversity/climate change nexus (Rankovic et al., 2021; Sanderman et al., 2018). Below are a few of many examples that demonstrate the relationship between biodiversity and carbon-density in mangroves, and seagrass meadows. For salt marshes similar/comparative studies were not available.



Carbon-dense mangroves in Louisiana, USA. © Sam Hardin / iStock.com

Case Study 6.2

Integrating carbon stocks and landscape connectivity for nature-based climate solutions in Ontario, Canada



Submitted by

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Name of PCA and Location

Ontario Protected and Conserved Areas Network. Ontario, Canada

IUCN governance type

Private and government

The protected area

Given Canada's climate and biodiversity commitments and urgency for action, there is great benefit to identifying areas that maximise co-benefits of climate change mitigation and biodiversity protection when planning for new protected and conserved areas as well as while prioritising ecosystem restoration. In Canada, public land primarily is administered by the provinces, territories and Indigenous governments. Consequently, the creation of new protected and conserved areas and priority restoration sites requires coordination with many entities. Focusing on the Canadian province of Ontario, this project sought to demonstrate how regional climate and biodiversity actions can support national targets. Ontario stands out as an area of interest for climate change mitigation actions because of the vast, irrecoverable carbon stocks found within the province's northern peatlands and intact boreal forest.

The project

This study explored the spatial overlap of existing protected and conserved areas in Ontario with hotspots for carbon storage and ecological connectivity. Using maps of connectivity (Pither et al., 2023) and terrestrial carbon stocks (separated into estimates of forest carbon and soil carbon) (Sothe et al., 2022), the researchers employed a bivariate mapping approach to identify

important areas of overlap between landscape connectivity and carbon layers. The analysis involved calculating quantiles at 20% intervals for the connectivity, forest carbon, and soil carbon layers, followed by the reclassification of raster cell values on a scale from 1 to 5 based on their respective percentile ranges. The connectivity map was then overlaid with each carbon map to produce two bivariate maps: connectivity by forest carbon and connectivity by soil carbon. Cell values for the bivariate maps were calculated using all unique combinations of the two layers, resulting in 25 different cell values (5 \times 5 matrix). Areas where cells from both layers are within the top 20% represent areas most important for protection, while areas in the lowest 20% for both layers may indicate areas important for restoration. Based on the GBF targets for terrestrial land conservation, a 30% protection goal was established.

Successes

The researchers found that 13% of hotspots for connectivity and forest carbon were protected, while 1% of hotspots for connectivity and soil carbon were protected. Their results show that there is great opportunity to expand protection of areas most important for carbon storage and landscape connectivity, and in doing so, help make meaningful contributions towards ambitious national climate change and biodiversity targets.

Additional resources

(O'Brien et al., 2023)



Forest in Algonquin Park, Canada, representative of the forests where the overlap between carbon stocks and landscape connectivity has been studied. © Elenathewise / iStock.com

6.3.3.1 Example 1. Co-benefits of protecting mangroves for biodiversity conservation and carbon storage (Rahman et al., 2021).

Rahman and colleagues (Rahman et al., 2021) have demonstrated, using a structural equation model, a strong relationship between carbon-density and biodiversity in the mangroves of the Sundarbans Reserved Forest, Bangladesh, which is one of the largest mangrove forests in the world and among the largest carbon deposits in the tropics (Donato et al., 2011). In particular, these authors have demonstrated that mangrove stands with high species richness (i.e. diverse tree assemblages) exhibit higher carbon storage than less diverse stands. From the perspective of choosing mangroves for protection, these results indicate that protecting mangrove forests with high species richness is more efficient in capturing and storing carbon in plant biomass and sediment than replanting mono-specific mangrove stands. Of note is the hypothesis that rising sea levels will lower the carbon-density of mangroves, because it will result in more salt-tolerant species which have characteristics that lower biomass carbon.

Details of the methodology used are described in the paper and data are summarised in the supplementary information. For carbon-density, these authors analysed above and belowground forest carbon inventory in 90 mangrove forest plots (supporting data are found in the supplementary information). For biodiversity, they calculated: i) species diversity using species richness (no. of species per plot) and the Shannon Diversity Index; ii) functional diversity using functional dispersion and iii) functional composition using Community Weighted Means as a proxy. Abiotic characteristics were also measured.

Several other studies support the findings of Rahman and colleagues (Rahman et al., 2021), that mangrove species diversity has a positive effect on carbon sequestration and storage. Two examples are:

- a survey of 234 mangrove field plots on the coastline of Hainan Island, China (Bai et al., 2021);
- a study using 25 sampling plots in Kanhlyashay natural mangrove forest, Myanmar (Aye, Tong, & Tun, 2022).

6.3.3.2 Example 2. Seagrass meadow stability and composition influence carbon storage (Bijak, Reynolds, & Smyth, 2023)

The wide variability in estimates of carbon storage in seagrass meadows can be at least partly attributed to carbon dynamics of different seagrass species. Bijak and colleagues (Bijak, Reynolds, & Smyth, 2023) have conducted one of the few studies that looked directly at the influence of seagrass meadow diversity (i.e. species composition and species diversity) on carbon storage capacity. Their results demonstrated that meadows dominated by a longlived, large-bodied species, Thalassia testudinum in this case, stored the greatest amounts of carbon. They also found that species diversity had a smaller effect. The study area was located in a sub-tropical mixed-species seagrass meadow along the northeastern Gulf of Mexico (Cedar Key, Florida, USA). In terms of guidance, this study supports a strategy of protecting the long-lived seagrass meadows that exist, over allowing their destruction and restoration, which will not have the same short-term benefits as the original meadow.

Fish in seagrass bed, Cabo de Gata Nijar, Andalusia, Spain. © Damocean / iStock.com





6.3.3.3 Example 3. Salt marshes

To date, no examples have been found that specifically show the overlap between biodiversity hotspots and carbon storage or sequestration in salt marshes. However, it is important to note that most salt marshes have high biodiversity conservation values due to a combination of coastal development and lowland drainage that has led to large reductions in their former extent. Biodiversity measures that identify areas of high conservation values (e.g. ecosystem risk assessments, Key Biodiversity Areas) are useful tools for identifying synergies between biodiversity and carbon values in salt marshes.

Po Delta salt marsh, Italy, representing a typical salt marsh with high biodiversity and carbon values. © ermess / iStock.com

6.4 Decision-support tools

6.4.1 Example 1. Marxan

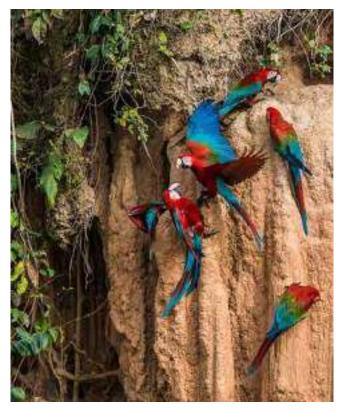
Marxan is a "freely available software designed to help decision-makers find solutions to conservation, and other spatial planning problems". It has been used for the identification of protected areas that solve several conservation goals, in both terrestrial and marine systems (Serra et al., 2020). It is available on Microsoft's Planetary Computer. There are many examples of the use of Marxan for conservation planning, and increasingly the conservation of carbon-rich areas has been added to other conservation values.

The example provided here is a study by Pusparini et al. (2023) which sought to identify high-priority areas to add to the current PCA network on the island of Sulawesi, Indonesia. The authors used Marxan version 2.43 to identify priority areas for conservation that would satisfy four conservation goals: i) preservation of carbon-rich areas (above and below ground); ii) preservation of forest cover and forest types; iii) preservation of biodiversity (endangered and critically endangered species); and iv) preservation of Karst ecosystems. Their results showed, among other things, that the top areas for soil organic carbon are poorly represented in the current protected areas network. Maps were produced that identify the most promising areas for protection that maximise conservation goals and meet the GBF. The detailed methodology and data can be found in the supplementary material (Pusparini et al., 2023).

In summary, three scenarios were run: protect 17% of the conservation targets as per the 2020 Aichi Biodiversity Targets; protect 30% of the conservation targets as per the Kunming-Montreal Global Biodiversity Framework; protect 50% of the conservation targets based on the 'Half-Earth concept'. While the approach appears to require a lot of data, all data used were publicly available and based on existing indices, including: the IUCN Red List https://www. iucnredlist.org/search; Forest Landscape Integrity Index (Grantham et al., 2020; Table S4); GLOBIO Mean Species Abundance (Globio, 2020); Biodiversity Habitat Index (GEO BON, 2015); and the proactive and reactive biodiversity indices (Soto-Navarro et al., 2021).

6.5 Advancing the biodiversity/climate change nexus

While these Guidelines focus on integrating climate change mitigation into PCA identification and management, underlying them is an understanding that care has to be taken to ensure climate change mitigation actions enhance, or at a minimum do not harm, biodiversity values. While there is a plethora of research identifying how to measure biodiversity or measure the role of natural ecosystems in the carbon cycle, much more work is needed to aid in decisionmaking that ensures biodiversity and climate change mitigation actions are mutually supportive. Some seminal work, identified here, provides tools to help in this integration. However, more case studies, building on the work done to date, are needed to improve the identification of synergies between climate mitigation and conservation objectives.



Macaws, like the ones depicted here, are an example of a species who thrive in the carbon-dense rainforests of the Amazon and Mexico, @OSTILL / iStock.com



Mangroves provide habitat for many species as well as vast carbon reserves. This photo shows blue crabs in a mangrove in Colombia. © HumbertoJose92 /iStock.com

Chapter 7

Role of restoration to enhance climate change mitigation in protected areas

Megan Critchley, Ben Lucas and Shane Orchard

7.1 Chapter highlights

- ✓ When considering restoration to support climate change mitigation in protected areas it is important to ensure that the ecosystem to be restored, and the restoration proposed, are likely to have an impact on carbon sequestration and storage. The impact of restoration is ecosystem dependent.
- ✓ Using an adaptive management approach for restoration projects can support the integration of climate change mitigation. This will include considerable prior planning, consultations with people who will be affected, monitoring and making adjustments as needed.
- Evaluate whether natural or active restoration will have the bigger impact on climate change mitigation. There is a place for both depending on the situation.
- ✓ Evaluate the consequences and appropriateness of specific restoration projects. They require an honest evaluation of the climate change mitigation benefits and assurances that risks to communities and biodiversity are avoided.
- ✓ If appropriate, explore opportunities for climate financing. If the impacts on mitigation can be clearly demonstrated, funds earmarked for GHG reductions can be leveraged for restoration.
- ✓ Ensure that the rights, title, intellectual property and data sovereignty rights of Indigenous people are respected.

7.2 Introduction

All modelled pathways to limit warming to 1.5°C or well below 2°C require mitigation using some form of Natural Climate Solutions (NCS). Although protection of healthy but at-risk high carbon ecosystems has the most immediate benefits for the global climate and biodiversity, restoring degraded ecosystems makes a significant contribution to climate change mitigation over the longer term (Cook-Patton et al., 2021; Griscom et al., 2017; IPCC, 2019). The Convention on Biological Diversity (CBD) recognises the importance of restoration to deliver gains in ecosystem resilience and recovery of carbon sequestration and carbon stocks. Progress towards achievement of the 2020 target to restore 15% of degraded ecosystems was not achieved, and the new target in the Kunming-Montreal Global Biodiversity Framework (GBF) increased the ambition to restoration of 30% of degraded ecosystems (Convention on Biological Diversity, 2022, December 18; Secretariat of the Convention on Biological Diversity, 2020).

As an example, the EU Nature Restoration Regulation recognises the contribution that restoration of ecosystems can make in maintaining, managing and enhancing natural sinks and to increasing biodiversity while also fighting climate change. This includes restoration of protected areas (European Commission, 2024).

There is a plethora of information and guidelines on ecosystem restoration in general, and particularly on the enhancement of carbon sequestration and storage through restoration in specific ecosystems. This chapter will focus on two aspects of restoration of degraded ecosystems: i) restoration of degraded ecosystems within protected and conserved areas (PCAs); and ii) restored ecosystems outside of PCAs that could be protected to secure the longevity of restoration.

Burning undergrowth to prevent large fires in Australia. @ Alfio Marciagli / iStock.com



7.3 Ecosystem considerations for restoration projects

Restoration is always considered in the context of a landscape, where connectivity with PCAs, land-use intensity, causes of degradation and likelihood of reversals are important (Mappin et al., 2019; Tambosi et al., 2014). Factors including the type of ecosystem being restored, method of restoration, local climate, and physical and chemical context will all impact the degree to which GHG emissions are halted and reversed through ecosystem restoration (Table 7.1).



Cattle grazing in the Ngorongoro Conservation Area, Tanzania. @Tomás Guardia Bencomo / iStock.com

Table 7.1 Consequences for ecosystem degradation and potential restoration of key ecosystem types on atmospheric carbon, and ecosystem-specific methods for restoration.

Ecosystem	Degradation effects on carbon	Restoration effects on carbon	Methods of restoring (biodiversity and carbon outcomes)
Forest	Tropical deforestation contributes 12–20% of annual global GHG emissions (Watson & Schalatek, 2020). Deforestation and degradation activities remove or reduce forest biomass, which emits carbon through a decrease in sequestration and emissions caused by burning or decay.	Restoring converted or degraded forests can increase forest biomass and associated carbon storage above and below ground.	Where severe declines or local extinctions have occurred, reintroductions (e.g. tree planting) may be needed alongside the removal of drivers (e.g. intense grazing). In other cases, removing degradation drivers can allow forests to regenerate naturally (Di Sacco et al., 2021). The time required to reach maturity depends on the starting state, species, climate and disturbance levels.
Grasslands	Grassland disturbance (e.g. grazing and trampling), land conversion or events such as wildfires can reduce vegetation biomass and diversity (Dudley et al., 2020). This can expose soils to the atmosphere or cause erosion, resulting in carbon emissions (Wen et al., 2013).	Restoring grasslands can increase vegetation biomass and diversity. As vegetation increases, more carbon is sequestered and stored in the soil and soil erosion is reduced. This is a very slow process in grasslands.	Grasslands can be restored actively (e.g. through reseeding) (Slodowicz, Humbert, & Arlettaz, 2019) or passively by addressing the drivers of degradation to promote recovery (Wang et al., 2018), and utilising traditional and Indigenous knowledge (Selemani et al., 2012).
Peatlands	Degradation and conversion of peatlands results in a shift from a carbon sink to a carbon source. As the water table decreases, soils dry and become exposed to the atmosphere. In this state they emit CO ₂ and other more potent GHGs such as methane (Greifswald Mire Centre & Wetlands International European Association, 2023).	Restoring and rewetting peatlands can reverse the emission of CO ₂ to the atmosphere and promote its sequestration into soils. Rewetting also results in short-term increases in methane emissions, but these are eventually balanced so the long-term result of rewetting is reduced GHG emissions (Greifswald Mire Centre & Wetlands International European Association, 2023; Günther et al., 2020).	Drained peatlands can be immediately rewetted by halting water extraction, such as by blocking drainage canals. In some cases, reprofiling peat and replanting sphagnum moss is needed, and recovery can be very slow (Greifswald Mire Centre & Wetlands International European Association, 2023).

Ecosystem	Degradation effects on carbon	Restoration effects on carbon	Methods of restoring (biodiversity and carbon outcomes)
Wetlands and inland waters	Inland waters represent an active part of global carbon cycling and receive at least 1.9 Gt of carbon annually (Cole et al., 2007). The degradation of wetlands is associated with substantial release of this carbon via GHGs including CO ₂ and methane (Limpert et al., 2020). Healthy rivers and watersheds are also essential mechanisms for transport of carbon from the terrestrial biosphere to the ocean – a key carbon sink (Galy, Peucker-Ehrenbrink, & Eglinton, 2015).	Restoration effects on carbon capture and storage can involve both above and below-ground carbon sinks depending on the ecosystem. For example, the restoration of floodplain forests can increase woody biomass, while the restoration of wetlands can improve their sediment capture and burial functions which are important for belowground carbon.	Reconnecting floodplains and re-wetting wetlands (Hinshaw & Wohl, 2021; Limpert et al., 2020), not only restores the water table and wetland habitats linked to carbon sequestration, but also delivers nutrients to restored terrestrial ecosystems, improving sequestration potential (Nahlik & Fennessy, 2016). Restoring healthy hydrological systems (e.g. remeandering rivers, native species reintroductions) is an important part of this.
Mangroves	Mangroves can become degraded through activities such as wood harvesting, or conversion to aquaculture ponds and rice paddies (Hagger et al., 2022). They are some of the most carbon dense ecosystems in the world, and their degradation can emit significant amounts of carbon (Adame et al., 2021).	Restoring mangroves can increase carbon storage in both their biomass (in branches and roots) and their associated soils.	Historically, mangrove restoration has involved active planting. However, the success rates of these projects have been low (Sasmito et al., 2023). Restoring hydrological conditions is a key factor in success and can also promote a natural recovery process. Where this is possible it can result in more functional, biodiverse mangrove forests (Ellison, Felson, & Friess, 2020).
Salt marsh	Salt marshes are degraded through drainage for land use intensification or reclamation, conversion for coastal developments, and the effects of pollution and erosion. Key risks include the loss of belowground carbon stored deep in their soils (Wildfowl and Wetlands Trust, 2025).	Restoring salt marshes can recover their functions relatively quickly (a few years), and result in increased carbon storage in buried sediments (Wildfowl and Wetlands Trust, 2025).	Restoration approaches may include replanting native salt marsh species, removing invasive species, using living shorelines to increase marsh elevation by trapping sediment and protecting against waves, using fencing to assist in the trapping of sediment, and protection from waves to allow recovery (Möller et al., 2021).
Seagrasses	Seagrass meadows are vulnerable to degradation through disturbances (e.g. boat anchoring, marine infrastructure), overgrazing and changing sea temperatures. Reduced vegetation coverage can limit their ability to bury carbon into their sediments and can release stored carbon through oxidation (Waycott et al., 2009).	Restoring seagrass vegetation coverage can increase the burial of carbon into biomass and associated sediments (Johannessen, 2022).	Seagrass restoration can occur both actively and passively. Active restoration includes distributing seeds or physically planting seagrass plants. Drivers of degradation can also be removed to encourage natural regeneration (Tan et al., 2020).
Macroalgal forests	Macroalgal forests, such as kelp, can become degraded through human disturbance, increased herbivory (such as sea urchin grazing) and eutrophication (Tamburello et al., 2022). This reduces their complexity and biomass, and therefore their ability to sequester carbon.	The extent to which macroalgal forests contribute to global carbon storage is not well understood. Increased macroalgal forest biomass can improve carbon sequestration associated with in situ macroalgal biomass and increased transport to deep ocean sediments. However, there are significant scientific uncertainties around the role of macroalgae in climate change mitigation, hence, at this point in scientific knowledge, macroalgae are not targeted for climate change mitigation (Howard et al., 2023; Ross et al., 2023).	Macroalgal forest restoration can be both active and passive (removing drivers). Active restoration is often required to re-establish local populations. This can require either in-situ (onsite) or ex-situ (in a laboratory) cultivation, and use of cages to prevent herbivore grazing (Cebrian et al., 2021).

Case Study 7.1

Restoration of peatlands in a protected area network, Finland



Submitted by

National Parks, Finland (2023)

Name of PCA and location

Whole Finnish terrestrial protected area network

IUCN governance type

Government

The protected area

Peatland complexes are extremely important ecosystems for climate change mitigation. Peatlands continuously sequester carbon from the atmosphere, and store 1/3 of the global soil carbon. The drainage of peatlands, however, promotes the decomposition of previously anaerobic soil organic matter, and releases emissions. Peatland drainage account for 20–30% of global methane emissions. In Finland, peat drainage practices for forestry purposes have reduced the country's peat coverage from 10.4 million hectares (104,000 km²) to 8.7 million hectares (87,000 km²). Further, 50,000 ha (500 km²) of these drained peatlands lie within protected area boundaries, having been drained prior to their establishment.

The project

National Parks Finland implemented a peatland restoration project to address the biodiversity loss from peat drainage, with the co-benefit of climate change mitigation. Between 1989 and 2018, 25,000 ha (250 km²) of peatlands were restored. Peatland restoration mainly occurred in national parks, with some sites in state parks and privately protected areas. Peatland restoration used an excavator to block drainage ditches and remove trees from naturally open or sparsely wooded mires along the banks of drainage ditches. Tree removal is essential, as moisture is lost through trees. Other restoration actions included raising water levels, slowing water flows, and diverting water to make natural flow channels.

Successes

Although National Parks Finland did not measure the carbon benefits of their restoration projects, they did state that "Natural peatlands in Finland typically accumulate about 10–30 grammes of carbon per square metre per year" (Turunen et al., 2002). Further, on average, the Finnish peatland carbon sequestration rate is 21g C/m²/year (0.21t/ ha/year) (Turunen et al., 2002). The entire restoration project is therefore estimated to sequester 52,000 tCO₂ annually.

Additional resources

(Metsähallitus) (Similä, Aapala, & Penttinen, 2014)



Extraction of peat, shown here, removes the deep carbon-rich soils which have taken thousands of years to form. @ longtaildog / iStock.com

Case Study 7.2

Management of secondary vegetation around Calakmul Biosphere Reserve, Mexico



Submitted by

Víctor M. Kú-Quej, Jesús Chi-Quej, Jorge Mendoza-Vega. Productores Forestales de Calakmul A.C.

Name of PCA and location

de la Biosfera de Calakmul Reserva, Calakmul, Mexico

IUCN governance type

Government

The protected area

The municipality of Calakmul, Mexico, is home to one of the largest and most intact tropical forests in the Americas. Recognising its ecological significance, the Mexican government has established several protected areas within the region, including Calakmul and Balam-kú Biosphere Reserves, the Balam-Kin Flora and Fauna Protection Area and ejido voluntary conservation areas. In total, these protected areas cover 81.6% of the municipality's land area. Despite the area's immense natural and cultural wealth, Calakmul is also one of the most inequitable regions in the country, which places considerable pressure on the protected areas. In response, various stakeholder groups are working to balance the improvement of landowners' quality of life with the conservation of natural resources, while contributing to climate change mitigation. One strategy being advocated by the association 'Producers Foresters of Calakmul A.C.', a group representing 32 communities and covering approximately 1.4 million hectares (14,000 km²), is the management of secondary vegetation. This involves thinning and enriching the vegetation with commercially valuable species, aiming to enhance both economic opportunities and environmental sustainability.

The project

This study aimed to assess the differences in carbon stocks resulting from various thinning treatments. Thinning efforts were applied to up to 60% of the vegetative cover in secondary forest areas, targeting misshapen, dead, and suppressed trees, as well as those without commercial value. Commercially valuable trees included species for timber (construction), firewood, fences, fodder, honey, and edible and medicinal plants.

Forest enrichment involved the introduction of species that could benefit producers, such as fruit trees, fodder, or timber species, interspersed at varying densities.

The research sought to evaluate the impact of thinning and forest enrichment on tree species diversity, richness, and carbon storage. To do so, the area was divided into five distinct treatment types: plots with two thinning interventions, plots with three thinning interventions, plots with two thinnings enriched with pepper plants (Pimenta dioica), plots without thinning but enriched with cedar (Cedrela odorata) and mahogany (Swietenia macrophylla), and a control group with no management interventions. A total of 29 one-hectare plots were selected within the study area, with six plots per treatment and five control plots, as part of the Mexican Carbon Program (Orihuela-Belmonte et al., 2013).

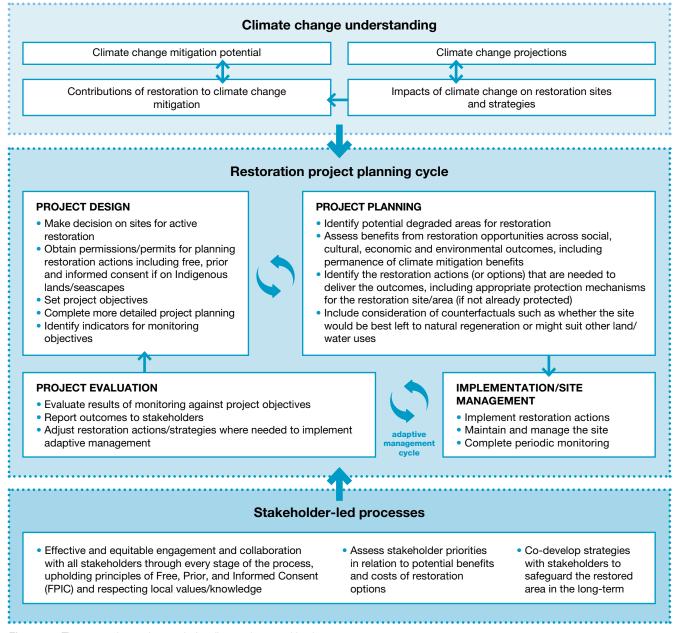
Heights of trees were estimated using a regression created using 40 individuals of the dominant species. Above-ground biomass was calculated using diameter at breast height (DBH) measurements for all trees greater than 10 cm, applying formulas from Cairns and colleagues (Cairns et al., 2003). For trees with a DBH between 2.5 and 10 cm, formulas from Hughes and colleagues (Hughes, Kauffman, & Jaramillo, 1999) were used. Root biomass was calculated following Cairns and colleagues (Cairns et al., 1997). Soil organic carbon was assessed by sampling at three depths: 0-10 cm, 10-20 cm, and 20-30 cm, if the effective depth of the soil allowed. Finally, species richness and diversity were estimated using published indices from Moreno (2001) and Simpson (1949) (Moreno, 2001; Simpson, 1949).

Successes

The results indicated no significant differences in total carbon stocks (including living biomass, dead biomass, and soil carbon) between treatments. Additionally, there were no significant differences in plant species diversity and richness. No increase in carbon stocks was observed at the time of assessment when compared to natural forests. While no immediate carbon benefits were detected, the absence of ecological deterioration suggests that the intervention is beneficial for ecosystem health. Furthermore, landholders are benefiting from sustainable agricultural practices, and the interventions contribute to reducing forest fires, minimising deforestation, restoring degraded forests, and promoting the rational use of natural resources. It is anticipated that carbon sequestration will increase with thinning compared to unmanaged forests; however, the elapsed time between thinning and the carbon pool assessment may not have been sufficient to capture these differences.

Additional resources

(Mendoza-Vega et al., 2023)



 $\textbf{Figure 7.1} \ \ \textbf{The restoration project cycle for climate change mitigation}.$

7.4 Planning a restoration project

Restoring damaged ecosystems requires obtaining buy-in from people dependent on the area being restored. Ignoring the people that will be affected by restoration will ultimately undermine its success (Kohler & Brondizio, 2017; Santini & Miquelajauregui, 2022). On land that is subject to the rights and title of Indigenous people, ethical considerations, free prior and informed consent, permission to use local or traditional knowledge and data sovereignty must be addressed (Robinson et al., 2021). The process of planning for restoration can include discussion of areas that could be restored and then protected to support the permanence of the restoration efforts. A good restoration planning process always follows an adaptive management approach (see Figure 7.1). Good processes involve engagement of all affected parties, including stakeholders and Indigenous people. There must be opportunities for people to voice concerns and share knowledge, including ensuring that land tenure and Indigenous rights are respected (Berkes, Colding, & Folke, 2000; Keenleyside, 2012).

A successful restoration planning process geared at climate change mitigation is depicted in Figure 7.1. The important elements are:

- Inclusion of multiple forms of knowledge, including scientific, Indigenous, local;
- Establishment of broad goals, including climate change mitigation but also including multiple benefits, such as the possibility for local livelihoods (Bardsley & Edwards-Jones, 2006; Di Sacco et al., 2021; Gross et al., 2016);
- Consideration of the specific elements of the ecosystem to be restored and its local context. For example, i) is the area connected to intact ecosystems, primary forests, or PCA? ii) does the action support ecosystem resilience? iii) what are the risks of climate change itself leading to a loss of carbon and therefore undermining the success of the restoration effort? iv) does the action support adaptation measures to respond to climate change adaptation in addition to mitigation? (i.e. restoration of an area upland to a vegetated coastal system to prevent coastal squeeze caused by sea level rise) (Falk & Millar, 2016; Mappin et al., 2019; Martínez et al., 2014; Orchard et al., 2020; Tambosi et al., 2014);
- · Consideration of the opportunity costs of the interventions. Lightly modified lands are likely more suitable for protection and recoverable through restoration than heavily modified lands in active use (Mappin et al., 2019);
- Building in long-term monitoring. Engaging local people in the monitoring helps maintain positive outcomes and mitigate against reversals (Cross et al., 2019; Young & Schwartz, 2019). In the context of climate change mitigation, monitoring can use the techniques outlined in Chapter 4 on measuring carbon and Chapter 5 on measuring biodiversity.

7.5 Considerations

7.5.1 Natural regeneration

Evidence suggests that in most cases natural regeneration is preferred to active restoration, as it can yield more resilient, functional and biodiverse ecosystems (Alongi, 2023; Di Sacco et al., 2021; Oliver & Morecroft, 2014) and be less expensive (Di Sacco et al., 2021). This can be true for both terrestrial and coastal blue carbon ecosystems. From a carbon storage perspective, it may take longer to accumulate carbon stores compared to active restoration interventions. In the context of existing PCAs, there can be less social pressure to actively restore an ecosystem after a major event, such as a wildfire, because most protected areas are also managed to allow for evolutionary processes to unfold (MacKinnon, Sobrevila, & Hickey, 2008).

7.5.2 Active restoration

While natural regeneration is preferred, sometimes changes to hydrology and land use, local extinctions or tipping points being exceeded may make natural regeneration unfeasible. Options for active restoration in these cases include: the use of novel ecosystems; translocation; and assisted migration. These approaches allow for planting and species relocations that will be better adapted to the projected future climate (Hällfors, Aikio, & Schulman, 2017; Hobbs et al., 2014; Orchard et al., 2020; Volpe et al., 2024). Where non-native, cheaper or fast-growing species are proposed for restoration, impacts on biodiversity and ecosystem functioning needs to be investigated to avoid unintended negative consequences.

Restoration is not limited to just the vegetation and soils of ecosystems - protecting and restoring wild animals and their functional roles (also known as trophic rewilding) can enhance natural carbon storage and sequestration. For instance, restoring natural grazing processes has been shown to result in fewer and less intense wildfires. As vegetation biomass is regulated, roaming herbivores can redistribute seeds and nutrients whilst increasing the productivity of the vegetation they graze (Rewilding Europe, 2022; Schmitz et al., 2023).

7.5.3 Longevity

Ecosystem restoration is relevant both within and outside protected areas (Meng et al., 2023; Tang et al., 2010). Restoration of ecosystems within protected areas can strengthen their effectiveness for biodiversity conservation while improving ecosystem resilience, including ecosystem services such as carbon storage and sequestration.

Case Study 7.3

The role of protected areas in the maintenance and recovery of carbon stocks in mangroves, Guanabara Bay, Brazil



Submitted by

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Laboratório de Geoquímica Orgânica Marinha -Universidade do Estado do Rio de Janeiro (LAGOM/UERJ);

Grupo de Pesquisa em Geoinformação e Dinâmicas Ambientais - Universidade Federal Fluminense (GIDA/UFF);

Laboratório Përisi: ecologia, conhecimento e democracia - Universidade Federal Fluminense (Përisi-UFF);

Enauta Energia S.A. (O&G company) Onda Azul Institute (NGO).

Name of PCA and location

Guapimirim Environmental Protection Area, Guanabara Ecological Station and Barão de Mauá Municipal Natural Park (PNMBM), in Guanabara Bay, southeastern Brazil

IUCN PCA Category

V/ Ia/ II

The protected area

The Guanabara Bay (GB) is located within coastal southeastern Brazil's largest metropolitan area. This region faces multiple environmental pressures, including urban expansion, landfill development, deforestation, uncontrolled disposal of domestic and industrial waste, and oil spills. Despite these significant conservation challenges, GB is home to approximately 9,118 hectares (91.18 km²) of mangrove forests, which constitute 73% of the mangrove forests in the metropolitan area of Rio de Janeiro.

The Guapimirim Environmental Protection Area (APA Guapimirim), designated as an IUCN Category V area in 1984, was created to safeguard a vital mangrove ecosystem that had previously suffered extensive deforestation due to firewood harvesting. In 2006, a portion of this protected area was designated as the Guanabara Ecological Station (ESEC Guanabara), classified as an IUCN Category Ia. Although these mangrove forests are still undergoing ecological regeneration, they represent the last remaining refuge in GB and constitute one of the principal mangrove remnants in the state of Rio de Janeiro. In 2012, the Barão de Mauá Municipal Natural Park (PNMBM) was officially designated as a new protected area. Recognised as an IUCN Category II, the park was established to conserve a restored mangrove forest within the heavily impacted region of GB.

The project

This case study examines the role of the three previously described areas in the maintenance and recovery of mangrove carbon stocks. Carbon estimates were obtained from sample plots distributed across the three conservation units, assessing carbon storage in above-ground biomass, below-ground biomass and soil sediments.

Above-ground biomass was quantified through a comprehensive forest inventory, followed by the application of allometric models (Estrada et al., 2014; Soares & Schaeffer-Novelli, 2005). Below-ground biomass was assessed using soil cores collected to a depth of one metre. These cores were then processed in the laboratory, where roots were washed, sorted and dried. The conversion of above- and below-ground biomass to carbon was conducted using structurespecific conversion factors (Rodrigues et al., 2015).

To estimate carbon stock in the sediments, one metre cores were also collected. They were then treated and analysed in the laboratory using an Organic Elemental Analyser to determine carbon content. Additionally, the area covered by mangroves within each conservation unit was estimated over various periods from 1985 to 2020 through a temporal analysis of satellite imagery (Landsat).

The carbon density estimates (tC/ha) for the three components were integrated and extrapolated for entire mangrove areas, enabling the estimation of total carbon stocks (tC) across different time periods for each conservation unit.

Successes

Since the establishment of the protected area, the mangrove coverage within the APA Guapimirim and the ESEC Guanabara has increased by 58%, from 3,999 hectares (39.99 km²) in 1985 to 6,302 hectares (63.02 km²) in 2020. In a similar trend, the mangrove forests of the PNMBM expanded from 77 hectares (0.77 km²) in 2015 - three years after the protected area's establishment – to 87 ha (0.87 km²) in 2020.

This ecosystem regeneration has also led to a significant increase in carbon stocks, which rose from 1,778,755 tC (1.78 MtC) in 1985 to 2,803,130 tC (2.8 MtC) by 2020 within the APA Guapimirim and ESEC Guanabara. Likewise, the carbon stocks in the PNMBM mangroves increased from 32,001 tC (0.032 MtC) in 2015 to 36,157 tC (0.036 MtC) in 2020. Notably, 77% of the carbon stored in Guanabara Bay mangroves is concentrated within these protected areas.



Mangrove coverage has increased by 58%, from 1985 to 2020, since the establishment of Guapimirim Environmental Protection Area in Guanabara Bay, Brazil. @Macio I. Sá / AdobeStock

Restored ecosystems can be later degraded (Reid et al., 2017). Providing protection for restored areas prevents a reversal of the restoration effort and protects the investment in GHG mitigation provided by the restoration project. The type of protection provided to restored areas can vary depending on the nature of the site. For example, Other Effective Area-based Conservation Measures (OECMs) may be more appropriate than other forms of protection (see IUCN, 2021 for details on the differences between these designations) (IUCN-WCPA, 2019).

Climate change can threaten the longevity of an ecosystem restoration initiative. Assessing the resilience of a restored ecosystem is an important part of the planning process. If the historical species are expected to be unable to survive as a result of climate change, restoration can consider the creation of 'novel ecosystems' that provide the same ecological functions but are more resilient.

Examples include the phenomenon of coastal squeeze caused by anthropogenic barriers to the inland migration of coastal ecosystems under sea-level rise (Martínez et al., 2014; Orchard et al., 2020). These barriers must be assessed among the threats to ecosystem resilience, and conversely, they present a target for restoration strategies (Orchard & Schiel, 2022). Thus, there is an interaction between the securing of future space and the implementation of active restoration strategies such as assisted migration as a Natural Climate Solution.

7.5.4 Risks

Climate change can result in a reversal of a restoration activity. For example, it can increase the likelihood and intensity of disturbances such as wildfires and insect outbreaks, resulting in release of the stored carbon that has been restored.

Despite the benefits of restoration, there are risks and historic examples of restoration activities resulting in negative impacts on stakeholders, communities and the environment (Aerts & Honnay, 2011; Buckley & Crone, 2008). For example, almost half of the Bonn Challenge forest restoration projects have a negative impact on biodiversity because they involve commercial monoculture plantations of exotic trees (Brancalion et al., 2025). Forest restoration with a single species planting has been shown to result in reduced carbon sequestration and a less resilient forest (Messier et al., 2022). When restoration is linked to carbon financing and the generation of carbon credits, an increasingly lucrative industry, care has to be taken to consider Indigenous land tenure and stakeholder rights, to avoid the often cited and legitimate concerns related to land grabbing and destruction of culturally significant sites.

Ecosystems should not be 'restored' to non-natural states for the sake of enhanced carbon sequestration and storage. For example, dense woodlands should not be planted on natural grasslands (Dudley et al., 2020). On the other hand, restoration with a view to carbon enhancement can have significant co-benefits. For example, restoring mangroves and salt marshes can contribute to enhancing protection for coastal communities from erosion and inundation during storms (Zhang et al., 2012).

Until recently, restoration actions to mitigate climate change have often focused on tree planting. However, planting the wrong tree in the wrong place can result in negative consequences for carbon (e.g. planting on peatlands), biodiversity (i.e. reducing high quality grassland habitats by afforestation in grasslands), and people (i.e. replacing food producing agricultural land with trees) (Dudley et al., 2020; Ratnam et al., 2020; Seddon et al., 2019).

7.5.5 Financing restoration for climate change mitigation

Restoration is costly. Efforts have been made to scale up financing for restoration, particularly if it can be shown to reduce GHG emissions and thereby help countries meet their responsibilities under the Paris Agreement. In addition, restoration projects can access financing through the new Global Biodiversity Framework Fund (Global Environment Fund, 2023), to contribute to the Kunming-Montreal Global Biodiversity Framework, Target 2, to restore 30% of degraded terrestrial, inland water and coastal and marine ecosystems by 2030 (Convention on Biological Diversity, 2022).

Over the past few years REDD+ has financed forest restoration projects designed to reduce deforestation or restore degraded forests that contribute to GHG emission reductions. In more recent years carbon offsetting, which provides market mechanisms for selling carbon credits that contribute to reducing GHG emissions, have become popular and lucrative. Besides the significant amount of funds raised through these mechanisms, they have also been under scrutiny for a variety of reasons related to a lack of rigorous standards, infringement of Indigenous rights and title, and social impacts. These are discussed in more detail in Chapter 8: Financing protected areas for climate change mitigation.

7.6 Conclusion

Ecosystem restoration makes a vital contribution to climate change mitigation, alongside actions to protect and sustainably manage healthy ecosystems. Restoration to enhance climate change mitigation is about much more than just planting trees. Many - but not all (see Chapter 3: Ecosystems with high value for carbon and biodiversity) – ecosystems, terrestrial, coastal and marine, make substantial contributions to removing carbon from the atmosphere and storing it for the long term. Establishing protected and conserved areas can provide a mandate to restore degraded ecosystems to a healthy condition and maintain them in a healthy state, or can safeguard newly-restored areas. Robust planning with the inclusion of stakeholders is essential for the design and implementation of restoration interventions that can contribute to climate change mitigation, whilst improving biodiversity, human health and well-being outcomes.

Case Study 7.4

Peniup restoration project in Gondwana Link, Australia



Written by

Madeleine Ankenman from a report by Justin Jonson, Gondwana Link

Name of PCA and location

Peniup, Southwest of Western Australia

IUCN governance type

Private

The protected area

Located in southwestern Australia, Gondwana Link has the vision of re-connecting the region to maintain and restore ecosystem function and biodiversity. The group achieves this vision by establishing government-protected areas through public advocacy and creating privately protected areas via land acquisitions and conservation covenants. The Peniup project is a 2,406 ha (24.06 km²) property, acquired as part of the Gondwana Link restoration initiative. The purpose of the property was to protect the existing bushland, to restore key habitats, and to increase connectivity to a larger protected area network.

The project

The Peniup project is a restoration initiative with the objective to re-establish a viable, biologically diverse ecosystem, with an informed design and heterogeneity in its plant associations. Due to partial project funding from carbon credits, the project also integrates carbon

sequestration objectives. These goals were achieved through the planting of the Yate tree (Eucalyptus occidentalis), which was selected for its high carbon storage potential among endemic tree species. In response to concerns that climate-induced drying may threaten the long-term survival of Yate trees, lignotuberous mallee species were also planted at the site. A total of 93,000 important seeds for carbon sequestration were grown into seedlings and planted, representing 30% of the species across each soil landscape. Additionally, the project developed a methodology for quantifying carbon in the low-rainfall region of southwestern Australia, aimed at future carbon credit applications. Using destructive tree sampling, diameter at breast height (DBH) measurements were correlated with both above- and below-ground carbon storage.

Successes

The group found that stem diameter measurements at 1.3 m (DBH) were highly correlated with above and belowground biomass, and stored carbon. Trees with multiple stems were correlated with biomass using the stem diameters at 0 cm, 10 cm and 30 cm and using canopy density, which was estimated using digital aerial photography. By addressing the information gap necessary for acquiring carbon credits, the methodology developed in this study has already been successfully utilised to attract investment in the restoration of native woodland ecosystems in southern Australia.

Challenges

The researchers emphasise that overcoming ecological thresholds is dependent on the initial project decisions. Putting in extra effort in key areas of planning and implementation of the project sets it up for success.

Additional resources

(Jonson & Freudenberger, 2011) (Jonson, 2009) (Jonson, 2010)

Chapter 8

Financing protected areas for climate change mitigation

Clarissa Samson, Aminur Rahman and Shane Orchard

8.1 Chapter highlights

- ✓ If the situation is right and the standards are rigorous, explore leveraging funds earmarked for GHG emissions reductions when looking to fund climate change mitigation in protected areas. Like all aspects of implementing the Paris Agreement and the Kunming-Montreal Global Biodiversity Framework, funding from a variety of sources will be required to incorporate climate change mitigation into PCA management and creation, including market-based and non-market-based instruments and public, private and corporate funds.
- Do the work to explore the array of programmes available to fund climate change mitigation. The wide variety of market and non-market-based schemes for financing climate change mitigation offer many opportunities to leverage climate financing for the dual purposes of climate change mitigation and biodiversity protection. However, navigating the array of programmes can be daunting.
- ✓ Assess the benefits and risks associated with the use of carbon finance mechanisms.
- ✓ Ensure that carbon offset programmes used for this purpose are credible. Choosing the right types of carbon offsets requires learning from past mistakes, building on the successes and incorporating new approaches where necessary.

8.2 Introduction

Previous chapters have outlined the necessary policies to support climate change mitigation in protected and conserved areas (PCAs), the most promising ecosystems for this purpose, methodologies to quantify biodiversity and carbon or the overlap between biodiversity and carbon, and the role of restoration. This chapter focuses on mechanisms to finance PCAs for climate change mitigation. This is particularly important, considering the discrepancy between existing pledges to curb GHG emissions and the magnitude of the task and the known role of nature in helping to reach GHG emission reduction targets. Although governments have recently increased their financial commitments to curb GHG emissions, there is widespread understanding that governments will not be able to do this alone. It requires an 'all-hands-ondeck' approach (Barbier, Burgess, & Dean, 2018; Bishop, Emerton, & Thomas, 2006; Maxwell et al., 2020). Although it is noteworthy that some authors have argued that increased reliance on non-governmental funds can be misguided and needs careful scrutiny (Kedward et al., 2023). A combination of financial models and sources of financing could effectively incentivise GHG reduction technologies at source of emissions as well as protection and other forms of conservation as a way of supporting the rapid removal of carbon from the atmosphere or reducing emissions from land conversion and ecosystem degradation.



Amazon rainforest, Yasuni National Park, Ecuador - an example of an ecosystem with high values for both climate change mitigation and biodiversity. © Maris Maskalans / iStock.com

To address the chronic shortage in funding biodiversity conservation and the maintenance of ecosystem services provided by nature, including climate regulation, the Global Environment Facility Assembly launched, in August 2023, the new Global Biodiversity Fund (GBF). "This new fund will mobilize and disburse new and additional resources from public, private and philanthropic sources, with a focus on the sustainability of biodiversity and ecosystems" (Global Environment Facility, 2023). These funds will support implementation of the Kunming-Montreal Global Biodiversity Framework (GBF), which has several targets addressing increases in PCAs, climate change and ecosystem resilience (Convention on Biological Diversity, 2022).

Recognising that various market-based schemes, including carbon markets, are becoming a more common avenue to fund climate mitigation using natural ecosystems to sequester and store carbon, this chapter discusses:

- the potential role as well as the risks of using market-based instruments to finance the expansion or improved management of PCAs for climate change mitigation;
- ways to ensure that finance for climate change mitigation does not inadvertently undermine biodiversity;
- ways to ensure that finance for climate change does not undermine the rights and title of Indigenous communities.

In many cases, incentive-based programmes that are meaningful for local people have been explored as a way of addressing social and economic concerns related to the creation of protected areas (Gross-Camp et al., 2012). This can include various forms of payment for protecting carbon sequestration and storage, as well as other ecosystem services. Some of the tools in use include monetary compensation, revenue-sharing schemes, and conservation concessions whereby economic incentives are given to local people who have engaged in conservation activities (Dawson et al., 2024; Muchapondwa & Ntuli, 2024; Spiteri & Nepalz, 2006). In recent years the concept of protection has been expanded to recognise that various forms of sustainable use can happen in PCAs without damage to the ecosystem services that they are designed to protect, while at the same time enhancing the well-being of people who live in PCAs. For example, people living inside PCAs in the Brazilian Amazon are better off than people living outside PCAs, by all indicators of human well-being, as a result of various co-management schemes with local communities (Campos-Silva et al., 2021). The introduction of concepts such as Other Effective Area-based Conservation Measures (OECMs) has helped (Jonas et al., 2024).

8.3 Mechanisms for funding PCAs for climate change and biodiversity

Protected and conserved areas (PCAs) are generally financed in three ways (Bishop, Emerton, & Thomas, 2006):

- annual budget allocations from governments;
- user fees and/or environmental taxes that are earmarked for parks and conservation;
- grants and donations from individuals, corporations, non-governmental organisations, and international donor agencies such as multilateral development banks.

While much of the funding for PCAs comes through national governments, international donors, and non-government agencies, revenues generated through market-based instruments for goods and services from PCAs (such as tourism charges, resource user fees, permits, taxes, carbon credits) are also being used in many localities. There is a growing trend towards overcoming free-rider problems associated with PCAs as public resources, through concessions received from those who benefit from their ecosystem services. Figure 8.1 shows the general typology of PCA financing mechanisms.

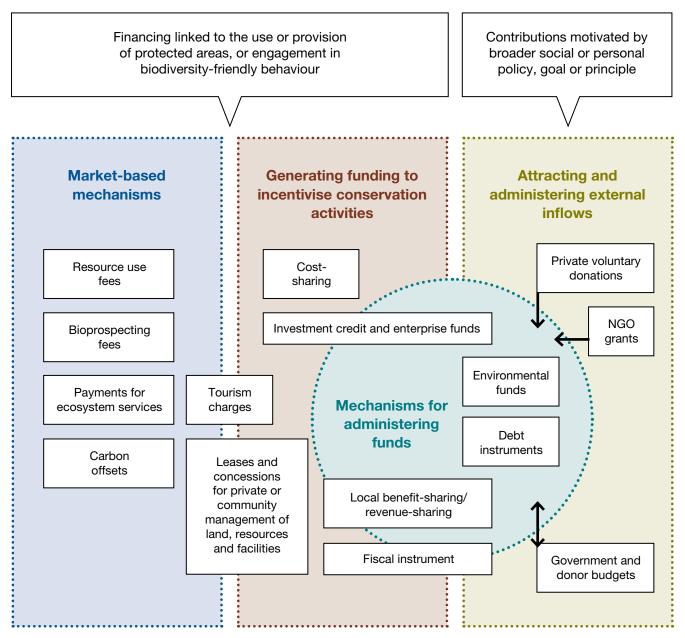


Figure 8.1 A typology of PCA financing mechanisms. Adapted from (Bishop, Emerton, & Thomas, 2006).

8.3.1 Indirect investments in biodiversity

Apart from direct investments in nature conservation through carbon market mechanisms, indirect funding from carbon taxes and Emission Trading Systems (ETSs) may be used for financing PCAs. A recent study on carbon market revenue utilisation in 40 OECD and G20 countries showed that, out of EUR 159.2 billion (~USD 168 billion) of excise taxes on fuels (38% of EUR 419 billion (~USD 442 billion) excise tax revenue), only EUR 4.39 billion (~USD 5 billion) was spent on green and environmental projects, including PCAs. Most of the revenue from carbon taxes has been channeled to other sectors in almost all the countries. Compared to carbon taxes, a relatively lower proportion of the revenue generated through ETS (EUR 103 million or ~USD 109 million out of EUR 7 billion or ~USD 7.4 billion) was spent on forestry, water, waste, land & biodiversity management, protection and conservation (Marten & Van Dender 2019).

8.4 Carbon finance mechanisms

8.4.1 Market-based carbon finance

There are two types of carbon markets: those that are part of governmental greenhouse gas emissions (GHGE) reduction schemes (compliance markets); and those that result from private initiatives (voluntary markets) (Tjon Akon, 2023). Given the volumes of literature on carbon markets, this chapter is intended as a very brief overview of available mechanisms to fund the management of climate change mitigation in new and existing PCAs.

Box 8.1

Carbon credits and carbon offsets defined

Carbon markets provide a mechanism to trade in carbon credits, which are tokens representing the avoidance or removal of greenhouse gas emissions, measured in tCO₂e. When used for carbon offsetting, they "involve a financial transfer from one entity seeking to gain credit for a reduction in emissions to another offering to deliver this emissions reduction" (Natzler et al., 2022). However, carbon credits may also be purchased by organisations as a contribution to their Corporate Social Responsibility or marketing strategies irrespective of whether they require an offset. Growing demand has led to the

expansion of carbon offset protocols for different ecosystems including wetlands, soil organic carbon, peatlands and coastal marine systems (i.e. blue carbon). An appropriate level of rigour for the monitoring, reporting and verification of carbon projects will be essential for maintaining the integrity of each credit issued on the market. Once achieved, vast areas of protected wetlands and marine ecosystem could be registered in carbon credit and offset programmes, and this could provide additional funding for PCA establishment and management.

Box 8.2

Explaining biodiversity offsets vs carbon offsets

Confusion on the differences between biodiversity offsets and carbon offsets has arisen in both policy and public discussions. Biodiversity and carbon offsets are different tools developed for different purposes in relation to different policies and different objectives. Biodiversity offsets are non-market-based instruments intended to prevent and mitigate negative impacts on biodiversity from development projects. The goal of biodiversity offsets is no net-loss (NNL), although more ambitious goals such as 'net gain' or even 'net positive impact' have been added by some governments. The implementation of biodiversity offsets is associated with a hierarchy of avoid, minimise, remediate, offset (Droste et al., 2022; OECD, 2016).

Habitat banking is a recent addition to the biodiversity offset hierarchy, used by some jurisdictions to replace offsets (Theis et al., 2022).

A carbon offset is a tradeable unit that represents a tonne of CO_2 equivalent of GHG emissions avoided or sequestered from the atmosphere. This credit can be purchased by an emitter to offset their own emissions, either voluntarily or due to a compliance obligation. In the context of biodiversity, carbon offsets are used to protect or restore carbon sinks and stores in the biosphere. Carbon offsets sometimes, although not always, represent a 'Nature-based Climate Solution' (Cambridge Zero Policy Forum, 2021).

8.4.1.1 International compliance mechanisms

International compliance mechanisms such as REDD+ and Clean Development Mechanism (CDM) are governed by the United Nations and other international agencies, targeting both GHG emission reduction at sources as well as increases in carbon sequestration through protecting natural ecosystems that take carbon out of the atmosphere and store it. The REDD+ programmes are mainly focused on the forestry/forest management sector with limited inclusion of agriculture (e.g. agroforestry systems). Although REDD+ projects have received some funds through the voluntary offset market, a majority are paid for by multilateral and bilateral donors such as the World Bank, UN-REDD initiative, and the Norwegian government (Fletcher et al., 2016). The REDD+ projects have been primarily implemented at the national and sub-national level in developing countries. In some cases, REDD+ projects have been implemented in protected areas (e.g. in Cambodia) (Pauly, Crosse, & Tosteson, 2022). According to a recent study, REDD+ activities listed in the Lima Information Hub for REDD+ resulted in emissions reductions of 6.3 Gt (billion tonnes) CO₂e (Granziera, Hamrick, & Comstock, 2021). In contrast, CDM projects have been mainly developed for the renewable/non-renewable energy, waste disposal and industrial sectors. Only a few CDM projects are in the forestry sector (e.g. approximately 0.7% are afforestation or reforestation (A/R) projects in 2023) (UNFCCC, 2023).

There is growing interest in using carbon credits to fund restoration and protected areas for Indigenous and local communities.

Case Study 8.1

REDD+ improved forest ecosystem conservation in PCAs in Cambodia



Name of PCA and location

Three REDD+ projects were registered in Cambodia: i) the Keo Seima Wildlife Sanctuary REDD+ Project (KSRP), IUCN category IV, in 2010; ii) the Tumring REDD+ Project (TRP), in 2015, consisting of community forests, IUCN category VI, and non-protected land; and iii) the Southern Cardamom REDD+ Project (SCRP) consisting of the Southern Cardamon National Park, IUCN category II, and Tatai Wildlife Sanctuary, IUCN category IV, in 2015. All of these protected areas were under significant threat of deforestation from illegal and unsustainable timber harvesting, land grabbing, and agricultural expansion.

Successes

Pauly and colleagues (Pauly, Crosse, & Tosteson, 2022) evaluated these REDD+ projects and found some evidence of effectiveness in reducing deforestation

compared to adjacent non-REDD+ areas. For example, two REDD+ project areas (KSRP and SCRP) have been 158% more effective at preventing forest loss compared to the nearby protected areas where no REDD+ initiative was implemented. The TRP REDD+ project area has also seen significant reduction of deforestation rate compared to its adjacent protected areas. Despite the presence of other conservation activities led by NGOs, the protected areas nearby have experienced an increasing deforestation rate. REDD+ initiatives in the KSRP and SCRP protected areas have invested the carbon credit revenue in developing extensive patrolling and security systems supported by law enforcement agencies, and they employ local community members who were not previously engaged in forest management in the PCAs. This investment has had a profound impact on forest protection. For instance, since initiation of REDD+ in SCRP in 2015, around 32,000 patrols were conducted, which reduced illegal activities such as logging and poaching animals significantly. Furthermore, the carbon revenue from REDD+ was invested for developing ecotourism at SCRP, which has generated approximately USD 767,000 in revenue from 20,000 visitors and supported about 5,700 community members (Pauly, Crosse, & Tosteson, 2022). This case study provides a good example of the effectiveness of the REDD+ funding mechanism for improving forest management in protected areas.

8.4.1.2 Domestic compliance mechanisms

Domestic compliance markets have focused on a wide diversity of project types including energy, industry, agriculture, forestry, livestock, waste, landfill and wetlands. In contrast, an analysis of 17 major Emissions Trading Schemes (ETSs) showed that, in 2021, most of the projects are in the power, industry and buildings sectors. No ETSs have included forestry projects in their system, except in New Zealand (International Carbon Action Partnership & Partnership for Market Readiness, 2021).

Several projects in carbon crediting and offset markets are focused on natural ecosystem protection and/or management. Most carbon registries include forest-based carbon offset projects to some degree, while few include grasslands and wetland ecosystem projects. Agriculture land management, nitrogen management, soil enrichment, and rice cultivation-related projects for agroecosystem management are being considered by most of these markets. Carbon projects in peatlands are currently registered by Verra and are being considered by other carbon registries. Some voluntary carbon registries such as Plan Vivo and Social Carbon are developing methodologies for marine ecosystems, areas of biodiversity importance, and private conservation areas; however, they have not yet registered any projects for those ecosystems.

8.4.1.3 Payment for ecosystems services (PES)

PES schemes involve payments to landowners to manage their lands so that clearly defined ecosystem services from nature, such as climate regulation, are provided to other individuals or society (Reed et al., 2022). A recent review found that there are now over 550 PES programmes around the world, with combined annual payments of USD 36 billion (Salzman et al., 2018). Although PES programmes are being used in many countries to protect different ecosystem services, payments for climate change mitigation, watershed services and biodiversity conservation are the most widely used. This includes the protection of forests to maintain water quality, prevent flooding and maintain land-based carbon. Key to the success of PES programmes is that the payments a landowner receives for protecting an ecosystem service, such as that provided by forest protection, are expected to be equal to or more than the revenue from timber sales. The mechanisms for successful PES programmes vary widely depending on local, regional or national circumstances (Salzman et al., 2018).

The majority of PES programmes are funded by governments and involve intermediaries, such as non-government organisations. Some notable programmes which can serve as models are: The US Conservation Reserve Programme, which pays about USD 1 billion a year to landowners to 'rent' 140,000 km² of 'environmentally-sensitive land'; China's Grain for Green programme, which pays farmers for not clearing forested slopes for farming, with an estimated total cost of USD 95 billion; Costa Rica's Pagos por sericios ambientales (PSA), which has evolved since its establishment in 1997 and has, in recent years, been funded by a combination of a fuel tax and international support (i.e. the World Bank, Global Environment Facility, the German Government's contribution through the KfW Bank) – with an estimated savings of 11 million tons of carbon emissions between 1999 and 2005 (Karousakis, 2007).

8.4.1.4 Results-based funding mechanisms

Unlike the majority of public climate finance, where 95% of funds are paid upfront, resultsbased climate finance (RBCF) is paid when results are achieved, namely once GHG emissions reductions have been verified as real and additional. The emissions reductions are retained by the country that has generated them and can count towards that country's NDC. Natural Climate Solutions, such as the creation of protected areas to avoid GHG emissions, are particularly well suited to RBCF.

The idea of RBCF is to leverage private money to obtain reductions in GHG emissions, including from the land use sector. The focus is on the results, rather than how the results are achieved. Some cautions with this approach are the potential for perverse incentives and the high cost of monitoring to verify results (Vieira, 2021).

An example of a results-based mechanism is that created by the LEAF Coalition, which is a public-private initiative whose aim is to halt tropical deforestation by 2030. Carbon credits are offered for forest protection projects. LEAF aims to raise and deploy the finance needed to make tropical forests worth more alive than dead. The LEAF coalition agreement with Pará (a Brazilian state) will result in 12 Mt of carbon emission reductions and generate USD 180 million. A similar agreement with Ghana will result in 5 Mt of carbon emission reductions and generate USD 50 million. LEAF funding is conditional on verified reductions in deforestation. Examples of LEAF projects can be found all over the world, including Costa Rica, Ghana, Brazil, Republic of Congo, Bolivia, Kenya, Vietnam (Leaf Coalition, 2023). These projects are too new to assess their results.

8.4.2 Allocation of carbon taxes to protected areas

Leveraging on the huge potential of natural ecosystems, funding mechanisms for PCAs could be greatly diversified to include multiple sources. A recent report by Cabrera and colleagues (Cabrera et al., 2021) suggested that countries should utilise carbon taxes or other revenues generated from carbon markets as sustainable financing for PCAs. Such revenues may be additional to those gained from carbon credit selling. For example, Colombia began allocating 5% of the carbon taxes on fuels to protected areas in 2016 through a country-wide signature programme, HECO (Heritage Colombia), which aims (among four other objectives) to improve the effectiveness of the management of protected areas (Cabrera et al., 2021).

Gokova Bay MPA in Turkey, depicting extensive seagrass beds - an example of a carbondense blue carbon ecosystem with high biodiversity values. © Wanlop / AdobeStock



8.4.3 Benefits of carbon markets

The mitigation potential of carbon sequestration through natural ecosystems amounts to an estimated 30% reduction of overall global emissions, a value that is consistently cited and is fuelling the demand for carbon credit schemes to finance nature conservation (Griscom et al., 2017; Roe et al., 2019). Nature-based carbon offsets, unlike technological reduction and removals, can generate co-benefits for biodiversity and ecosystem services, in addition to supporting climate stability. Furthermore, there is a push to address challenges from both the supply and demand sides of these opportunities. Carbon credit and offset programmes present a climate mitigation tool with the potential to spark corporate climate mitigation action by providing a convenient pathway for more reluctant companies to commit to climate targets through their ability to use carbon markets (Streck, 2021). At the same time, increasing pressures being placed on corporations to achieve carbon neutrality through emissions reduction efforts may reduce reliance on and demand for credits from carbon offset projects.

Many companies are turning to Natural Climate Solutions, which may include finance for mitigation strategies in PCAs and other climate change responses. Attention to carbon emission reduction and offsetting has the potential to drive climate ambition even for sectors that cannot immediately achieve their climate targets through direct GHG emissions reductions. These sectors will have greater reliance on compensation activities (i.e. carbon offsets) for emissions that are harder to abate (Streck, 2021). Examples include industries such as aviation and shipping, where low-carbon alternatives have received little investment (Seymour & Langer, 2021).

Those with belief in the potential for offset markets to mitigate climate change argue that carbon markets can provide benefits for countries with limited access to foreign investment. Although developing countries are already a major supplier of carbon credits, this approach has further potential as a source of income for local communities in these countries given the lower abatement costs that may be available in some industries. Similarly, there may be more opportunity for nature-based carbon projects (e.g. restoration of high-carbon ecosystems) in areas with lower intensity of land use or demand for space between current land uses. In these circumstances carbon projects may present additional opportunities for landowners or managers that can help to incentivise ecological restoration and PCA establishment.

8.5 Role of governments in carbon markets

Often with carbon markets, if carbon credits from PCAs are not sold on the open market, governments may sometimes decide to use the credits for meeting their Nationally Determined Contribution (NDC). For example, national governments have sometimes purchased carbon credits from REDD+ programmes (Granziera, Hamrick, & Comstock, 2021). Through this direct financing mechanism, governments and international donor agencies can take on the burden of funding the carbon offset programme in PCAs. There is a risk that by purchasing carbon credits for PCAs, governments and donors will not create an additional source of funding for PCAs, but rather reallocate money previously spent on PCAs to fund carbon offset programmes. Alternatively, the same agencies may not be interested in providing additional funds for carbon offsetting programmes in PCAs because of the perception that PCAs will naturally play their role as carbon sinks regardless of their inclusion in carbon offset programmes. This highlights the importance of research to establish the additional climate mitigation benefits that can be generated by establishing new PCAs or improving the management of existing ones. As observed in Cambodia (case study 8.1) (Pauly, Crosse, & Tosteson, 2022), adding REDD+ programmes to existing PCAs has provided additional funding for improving their management and resulted in both improved wildlife protection and reduced deforestation. Similar results could be expected in other PCAs if they are managed similarly with additional financing.

8.6 Risks of carbon markets

"Government must put in place stronger guidance, regulation and standards to ensure purchase of carbon credits is not used as a substitute for direct business emissions reductions, and to improve the integrity and transparency of carbon credits. In the absence of these measures, there is a real risk that voluntary carbon markets slow progress towards Net Zero or damage other priorities such as climate adaptation and biodiversity" (Natzler et al., 2022 p.8 para.1).

Carbon offset schemes run the risk of incentivising certain behaviours that may undermine ecosystem-based approaches to climate change mitigation. For example, they have been criticised for incentivising the production of credits as a way of substituting for the rapid phase out of fossil fuels, and the methods used have not always been inclusive of local communities. It can be argued, therefore, that carbon offsets should not be used as a substitute for direct emission reductions by companies and individuals. By extension, this implies that they cannot be the main avenue for financing PCAs as a way of achieving climate change mitigation. For these reasons, controls that limit the use of carbon offsets should be integrated into the policy and regulation of climate finance and have a key role to play in incentivising the rapid reductions of carbon emissions. Sector specific guidance on how to rapidly decarbonise each sector while limiting the use of carbon offsets is one way to address these objectives.

Moreover, funding conservation through offsets on a project-by-project basis poses challenges for scaling up efforts to effectively address climate change mitigation. REDD+ programmes, for example, have shifted from small-scale, NGO-led projects that targeted small landholders to larger jurisdictional approaches that aim to address land-use changes outside of the forestry sector (Vonhedemann et al., 2020). Programmes are now increasingly being designed at the sub-national level which is seen to be a more strategic scale for REDD+ implementation and can support integration with other sectors such as traditional management initiatives and zero deforestation commitments (Vonhedemann et al., 2020). Landscape-level planning across legally defined jurisdictions and territories is urgently needed to achieve carbon emission reductions at scale. However, funding and the required political will at this level continues to be a challenge.

Approximately 15% of naturebased carbon offsets projects overlap with protected areas. Depicted here is Manu National Park, which is located within the Cordillera Azul (Peru) Protected Area. The Cordillera Azul PA has received more than 28 million carbon credits since its launch in 2008, although the programme has been criticised because it has been financially profitable but ineffective as a means of conservation. © RPBMedia / iStock.com



8.6.1 Potentially adverse impacts on ecosystems

Aside from the need to upscale and optimise climate change mitigation initiatives it is essential that they are well aligned with conservation objectives and do not exacerbate the biodiversity crisis. Although the prospect of runaway climate change is itself a threat to biodiversity, there are many mechanisms through which carbon emissions reduction projects and incentives schemes may cause adverse effects (reviewed in Shah, 2024). These may include effects on existing protected areas. Examples include effects on ecological connectivity that can be caused by infrastructure projects in the renewable energy sector (e.g. hydropower and wind farm development). These have been the subject of significant climate finance under international programmes such as the Clean Development Mechanism (CDM).

Additional issues may be caused by interventions that alter the risk of extreme events. For example, Veldman and colleagues (Veldman et al., 2019) highlighted the potential for increased fire risk associated with the afforestation of grasslands. Moreover, these interactions with natural hazards and risk may have consequences for both biodiversity and carbon storage. Similarly, even Natural Climate Solutions may exert adverse effects where high carbon sequestration rates are prioritised over natural ecosystem structure and function, as seen in forest management proposals that promote fast growing or young-growth conditions in an effort to sequester carbon at faster rates than old-growth or naturally diverse forests (Ameray et al., 2021).

These examples illustrate the essential need to evaluate the potential downsides of carbon mitigation projects and policies by identifying implications for biodiversity conservation both at the project site and in the wider landscape. Although existing PCAs make an important contribution to ensuring that these twin objectives are realised (i.e. decarbonisation and biodiversity conservation), it is also important to consider the shortcomings of existing protection mechanisms (e.g. limitations of effective size or extent of protection) and the future needs of nature. Carbon projects that are harmonious with natural ecosystem structure and function are likely to be advantageous.

Eucalyptus plantation in Brazil. This is an example of a carbon project with adverse effects on biodiversity. Although eucalyptus grows quickly and sequesters significant amounts of carbon in the early years, it is a nonnative species planted in vast monocultures with a negative impact on biodiversity. © Pedro Truffi / iStock.com



8.6.2 Leakage

Leakage is a specific issue that remains inherent to carbon credit systems. It occurs when a project reduces emissions in one place but then causes an increase in emissions elsewhere. For example, the reduction of logging in one place can increase logging in another area in order to meet timber demand. Similarly, leakage can affect the net gains for biodiversity that are realised from a given investment if losses occur at other sites. Carbon credits derived from restoration or improved protection also face issues of permanence and the risk of reversal (Pan et al., 2022). Other related issues with financing conservation through offsets is the equity concern around displacement and/or the lack of accessibility to resources that would enable Indigenous and local communities to govern and protect the land and waters. Displacement, livelihood restrictions and cultural impacts are some of the negative impacts that result from planning processes that lack participation and consent, which can infringe on human rights, and may intensify poverty and discrimination already faced by Indigenous communities (Hein, 2019; Townsend, Moola, & Craig, 2020).

8.6.3 Volatility of market prices

A further challenge for the development of carbon offset programmes involves the large quantities of carbon credits that are often generated per unit area (e.g. of PCAs), which then lead to an over-supply of carbon credits in the market which lowers the price of credits (Dixon et al., 2008). This ultimately reduces the overall efforts of reducing carbon emissions from industries and energy sectors and incentivises further use of offsets rather than directly reducing emissions, since lower priced credits present a more cost-effective option for businesses. Private entities seeking lower priced credits for the cheapest emissions reduction option results in the uneven distribution of projects, and projects that have been chosen for the wrong reasons. Companies may also be inclined to invest in PCAs to get carbon offset credits, instead of investing in technologies for reducing their own carbon emissions. For this reason, ETSs do not allow (or allow up to limited extent) credits from carbon offset programmes, since their primary goal is to cap carbon emissions to promote a transition to low-carbon business models and practices (International Carbon Action Partnership, 2022).

The quality and integrity of carbon offset projects depend on the degree to which inherent challenges to the offset market can be addressed, of which no simple formula for resolving them could be readily applied universally. Given the surge of interest in voluntary carbon markets, there is an even greater need to overcome concerns about carbon markets leading to greenwashing and over-crediting.

8.7 Non-market financial mechanisms

8.7.1 Project Finance for Permanence (PFP)

Project Finance for Permanence (PFPs) is a biodiversity finance mechanism that has also been used to link protected areas, climate change adaptation and mitigation (see Case Study 8.2 on the Great Bear Rainforest). PFP is often focused on the creation and management of strict nature reserves (IUCN Category 1a), wilderness areas (IUCN Category 1b), and governance by Indigenous peoples and local communities (Dudley, Stolton, & Shadie, 2013). In the PFP model, philanthropic organisations provide permanent investments in terrestrial and marine protection in exchange for a guarantee of the permanence of conservation and influence on decision-making (Blackwatters et al., 2023). A key feature of PFPs is that decisions are made by a board, which usually includes representatives of the foundation, as well as government, stakeholders and Indigenous groups. This ensures that the philanthropic investments are not subject to policy interference if government priorities change (Beer, 2022). PFPs have been used to finance biodiversity conservation and protected areas in developing countries (e.g. Palau, Fiji, Chile, Amazon Basin, Mongolia) (Beer, 2022; Blackwatters et al., 2023; The Nature Conservancy, 2024) and developed countries (e.g. Canada) (Government of Canada, 2024). The PFP model is not a market-based mechanism. Rather, from the perspective of philanthropic organisations, the approach is 'dollars' for 'policy influence'.

Case Study 8.2

Great Bear Rainforest (GBR) Project Finance for Permanence (PFP)



Submitted by

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Name of PCA and location

Great Bear Rainforest, Canada



Figure 8.2 Great Bear Rainforest Area. © Coast Funds, 2024.

IUCN governance type

Government/Indigenous/Private

The project

The GBR includes 6.4 million hectares of western North America's coastal temperate rainforest. Coastal temperate rainforest is rare globally, covering 0.1% of the Earth's land surface. A quarter of the world's unlogged coastal temperate rainforest is in the Great Bear Rainforest. Ecosystem components include bears, wolves, salmon, large ancient trees; inconspicuous species such as mosses, lichen, fungi, a rich soil fauna; and six million migratory birds (Price, Roburn, & MacKinnon, 2009). It is also one of the most carbondense ecosystems on the planet (DellaSala, 2018).

In 2006, after over 10 years of collaborations with First Nations, governments, environmental organisations, forest companies and private funders, the Great Bear Rainforest Agreement was signed. In 2008, with CAN 120 million secured - half from the British Columbia and Canadian governments and half from a consortium of six private foundations - the Coast Funds was established to implement the agreement. It serves as the independent fund administrator, characteristic of all PFPs. Its ninemember Board of Directors is nominated by participating First Nations, private foundations and the Government of British Columbia. The Coast Funds currently manages the Conservation Endowment Fund, a permanent trust that spends income from the trust fund on conservation management, science and stewardship jobs for First Nations. A Marine Stewardship Fund has been added to the Conservation Endowment for the Great Bear Sea PFP, created in 2024.

The hallmarks of the original Agreement were:

- Creation of a network of new and existing protected areas within the GBR that protects a critical core of ecologically and culturally significant areas from logging and other industrial uses;
- Replacement of conventional forestry with principles and goals of Ecosystem-based Management (EbM), which focuses first on the values required to sustain healthy ecosystems, rather than focusing on resource extraction;
- A new government-to-government relationship between Coastal First Nations and British Columbia, in which shared decision-making and collaboration with stakeholders is essential;
- A conservation economy for First Nation communities.

Over the years the management of the Great Bear Rainforest evolved, culminating in the 2016 Great Bear Rainforest Land-Use Order and the 2017 Great Bear Rainforest Forest Management Act. The order and subsequent legislation improved ecological integrity by increasing the amount of protected old-growth forest from 50% to 70%, creating eight new special forest management areas covering 295,000 ha, which are offlimits to logging, and ceasing commercial grizzly bear hunting in traditional territories of nine of the 27 First Nations participating in the GBR.

Successes

The GBR decision added 1.3 million hectares of protected areas and 297,000 hectares of "biodiversity areas" in which logging, but not mining, is excluded. The total area protected from logging in the GBR is over 2 million hectares, or 33% of the area - similar to the proportion of protection in other areas of global interest such as Costa Rica (25% protection) and the Great Barrier Reef (33% protection) (Price, Roburn, & MacKinnon, 2009).

Although the concept of Ecosystem-based Management is well-developed and has been used since the early 2000s in many different ecosystems, its implementation in the GBR includes some novel aspects such as:

increased control of land-use decisions by Indigenous people; establishment of management targets using ecological thresholds and natural variability; a commitment to independent science to guide land-use decision-making; and commitment to a new "conservation economy" that would support healthy ecosystems and healthy communities.

Following the success of the GBR, Canada has fully embraced the PFP model. In 2022 the Canadian government announced four new PFP projects, with CAN 800 million of financing, for Indigenous-led PFP conservation initiatives: the Great Bear Sea (northern shelf bioregion of British Columbia); Qikiqtani Region in Nunavut; Hudson Bay Lowlands, Western Hudson Bay and Southwestern James Bay in Ontario and Nunavut; and Northwest Territories. As of June 2024, the Great Bear Sea project was finalised and includes 28,000 km² of Marine Protected Areas (MPAs) or about 30% of the region (Fisheries and Oceans Canada, 2024). All of these PFP projects support Canada's commitment to protecting 30% of land, sea and inland waters and restoration of degraded ecosystems by 2030 (CBD, 2022), as well as Canada's commitments to reduce its GHG emissions by 40–45% from 2005 levels by 2030 (Government of Canada, 2021).



The Great Bear Rainforest, Canada, was one of the first examples of a Project Finance for Permanence (PFP). The photo is of a bald eagle perched on a large spruce tree. © DanielLacy / iStock.com

8.8 Future directions

Disagreements on the potential for Natural Climate Solutions still exist in the scientific community, as studies have found some estimates to be overly optimistic or simply incorrect (Seddon et al., 2021). While the protection of the carbon stored in intact terrestrial, coastal and marine ecosystems remains critical, overreliance on protection and conservation as a carbon offset poses risks around distractions and substitution for the urgent need for aggressive and rapid GHG emissions reduction. Persistent high levels of over-crediting as well as estimates of leakage, additionality and emissions reductions are, more broadly, highly uncertain.

Resolving equity issues at global, national and local scales is essential for ensuring that adequate funding is provided for the protection of the world's ecosystems to support climate change mitigation efforts, which consequently is interconnected with the world's capacity to adapt to climate change and ability to halt and reverse biodiversity loss. Improvements in carbon mitigation finance mechanisms could address some of the gaps and risks associated with funding PCAs.

8.8.1 Carbon credits specifically for PCAs

Currently, the price for carbon credits generated through nature-based carbon offset programmes is the same as carbon credits generated from other offset or emission reduction programmes. This system incentivises commercial entities to choose comparatively cheaper carbon credits from nature-based carbon offset programmes rather than reducing emissions directly. A relatively higher price, and obligatory purchase limit, could be set for carbon credits generated through nature-based carbon offset programmes. This could include restrictions on the use of offsets to entities that cannot immediately reduce emissions directly.

8.8.2 Allocation of carbon revenue towards PCA financing

National governments could allocate more carbon tax revenues to PCA implementation and management as well as sustained PCA operations and monitoring. This also assumes that increased financing from tax revenues will be additional to ongoing funding from national budgets and international donations for PCAs. However, careful consideration for improved management of PCAs will be needed as the monitoring of ecosystem health is not common practice for completed carbon offset programmes targeted at PCAs. Regular reporting on carbon accounting of a carbon offset programme can ensure the efficiency of ecosystem management activities undertaken in the project area. Governments can impose carbon accounting requirements for PCAs in receipt of additional funds from carbon taxes and revenues.

8.8.3 Improved credibility of carbon offsets

Research has demonstrated that offsets have not been effective at rapidly reducing GHG emissions, partly because of overestimates in accounting for the emissions reductions from nature (Badgley et al., 2022; Cames et al., 2016; Hyams & Fawcett, 2013). Continuous improvements in monitoring, measurements and verification systems, to make them more robust, is urgent. This includes insistence that both above and below-ground carbon be measured in all ecosystems.

8.8.4 Expansion of ecosystems eligible for carbon offsets

In addition to the ongoing efforts of carbon offset programmes in PCAs in forests, similar carbon offset programmes can be adopted in PCAs in other ecosystems such as grasslands, wetland and marine areas. Such programmes will enhance management of PCAs as well as continuous monitoring of carbon emission and sequestration in the PCAs.

8.8.5 Safeguarding against adverse effects from climate mitigation activities

Financing must respect and adhere to strong safeguards that ensure better transparency and accountability, effective anti-corruption measures, free, prior and informed consent (FPIC) standards and a normative approach for conducting transactions and business across all sectors. Secured property rights to common resources are one way, among others, to govern common resources from private to public. Regulation and policy around the planning and implementation of funding programmes and mechanisms could ensure explicit respect for rights and title of Indigenous peoples and communities as well as adherence to the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP).

8.8.6 Seeking co-benefits for biodiversity and climate change

There is also a need to better track and monitor the risks and opportunities for synergies with climate and biodiversity funding in order to expedite action on the dual crises.

Carbon-dense rainforest in Madagascar. Some of the primary forests in Madagascar, such as the Makira Natural Park Project, have been funded through verified carbon credits. Over 30 years 38 million tons of CO₂e will be avoided through this project. © Jakub Zajic / iStock.com



Chapter 9

Future directions for climate change mitigation in protected areas

Shane Orchard and Risa B. Smith

Protected and conserved areas (PCAs) play vital roles in climate change mitigation by protecting ecosystem components that sequester carbon dioxide from the atmosphere and protecting carbon stored in above and below-ground reservoirs. Tools are readily available to quantify the contributions of PCAs to climate change mitigation and many practitioners are already making use of these tools, as evidenced by the case studies included in this report.

However, new approaches will be necessary to accelerate the deployment of climate change mitigation into PCA management and policy. It will be particularly important to ensure that area-based conservation can address emerging issues (Woodley, Jarvis & Rhodes, 2021). For example, it is unavoidable that climate change will impact PCAs due to the lag effects of past emissions (IPCC, 2023). Increases in the intensity and distribution of natural disturbances (Folke et al., 2004; Scheffer et al., 2001; Schiel et al., 2021), range shifts in species and ecosystems (Hovick et al., 2016; Krause-Jensen & Duarte, 2014), exceedance of climate tipping points (Armstrong McKay et al., 2022), expansion of invasive species (Hellmann et al., 2008), the creation of novel ecosystems (Hobbs, Higgs, & Hall, 2013) and human impacts that may further degrade ecosystems adjacent to protected areas are occurring. The management of PCA networks will have to be nimble and adaptable. PCA boundaries may need to be more flexible to include areas beyond the historical range of species and address connectivity between existing sites which will become more critical (Cashion et al., 2020). Ensuring the long-term permanence of ecosystem carbon will become more critical, the identification and protection of climate refugia more pressing, and the protection and long-term management of restored ecosystems more important. From this standpoint it is clear that current PCA networks must themselves adapt if they are to remain effective into the future (Baron et al., 2009).

A motivating factor for the current interest in assessing the climate mitigation potential of PCAs is the ability to make use of climate financing. Strict adherence to scientifically defensible accounting principles will be critical to ensure the credibility of carbon accounting and to avoid instances of greenwashing through the use of carbon credits. This requires the creation of carbon credit verification systems that are more stringent than the ones in current use in many climate finance and development sectors (Orchard et al., 2025; Shah, 2024).

Publicly available information is at the heart of credible climate mitigation analyses. Many of those who submitted case studies to this report identified the lack of publicly available data sources as a hindrance to providing the best analyses. A push to ensure that key information is collected and readily available is essential and will likely require investments by public institutions. The further development of decision-support tools used in conservation planning exercises to include the climate mitigation aspects of future range projections is another area of opportunity that could help to optimise the climate change mitigation benefits of PCA networks (Kukkala & Moilanen, 2013; Lawler, White, & Master, 2003; Margules & Pressey, 2000).

Case study compendium

Case Study No.	Title	Country	Governance	Terrestrial (TE) or Coastal blue carbon ecosystem (CBCE)	Page No.			
Chapter 2 Policy to support climate change mitigation in protected areas								
2.1	Climate mitigation benefits of PCAs	Tanzania	National/ International	TE (forest)	8			
2.2	Is climate-smart conservation feasible in Europe? Spatial relations of protected areas, soil carbon, and land values.	Europe	Private/Government/ Indigenous	TE	13			
2.3	China's national blue carbon accounting system Fig. 2.3 The spatial distribution of blue carbon in the coastal wetlands of China	China	National	CBCE (mangrove, salt marsh, seagrass)	18			
2.4	Amazon Regional Protected Areas Program (ARPA): Large enough and key in conserving the Brazilian Amazon	Brazil	Private/Government (state & national)/ civil society	TE (forest)	21			
2.5	Climate-focused forest management in the Whaelghinbran conservation forest, Wabanaki protected and restored forests	Canada	Community/ Indigenous	TE (forest)	23			
Chapter 3 Ecosystems with high value for carbon and biodiversity								
3.1	The capacity of the Dja Wildlife Reserve to store carbon	Cameroon	Government	TE (forest)	32			
3.2	Orla Maritima da Bala de Sepetiba Environmental Protection Area	Rio de Janeiro, Brazil	Government (sub- national)	CBCE (mangrove)	39			
3.3	Carbon and hydrology management of the Great Dismal Swamp National Wildlife Refuge	USA	Government (sub- national)	TE (wetland)	41			
Chapt	er 4 Methodology for quantifying carbon s	sinks and sto	ores					
4.1	Estimation of carbon storage in National Parks of Korea	Republic of Korea	Government	TE (mixed) & CBCE (tidal flats, mud flats, seagrass)	52			
4.2	Blue carbon in Nusa Penida MPA	Indonesia	Government	CBCE (mangrove, seagrass)	54			
4.3	Parks Canada's Carbon Atlas: Assessing Carbon Dynamics in Ecosystems in National Parks	Canada	Government	TE (forest)	57			
4.4	Economic valuation of carbon storage and sequestration in Retezat National Park	Romania	Government	TE (various)	59			
4.5	Habitat restoration in Cairngorms Special Area of Conservation (SAC)	United Kingdom	Various	TE	60			
4.6	Impact of protected areas on avoided blue carbon emissions	Indonesia	Government and others	CBCE (mangrove)	62			
4.7	Soil organic carbon stock under semi-deciduous tropical forests: Téné Protected Forest	Oumé Côte d'Ivoire	Private and Government	TE (forest)	64			
4.8	Assessing, protecting and restoring blue carbon in Greater Farallones and Cordell Bank National Marine Sanctuaries	United States	Government	CBCE (bull kelp, baleen whales, seagrass, salt marsh)	66			
4.9	Protected Natural Areas "Las Esmeralda" Conservation and Production in Native Forests in South America	Argentina	Private	TE (forest, grassland, wetland, agriculture)	69			

Case Study No.	Title	Country	Governance	Terrestrial (TE) or Coastal blue carbon ecosystem (CBCE)	Page No.				
Chapter 5 Methodology for quantifying biodiversity									
5.1	Climate co-benefits of tiger conservation	India	Government	TE (various)	76				
5.2	Kahuzi-Biega National Park: Employing carbon accounting to support biodiversity conservation	Democratic Republic of Congo	Government	TE (peatland, forest)	81				
Chapter 6 Identifying hotspots for carbon-density and biodiversity									
6.1	Climate co-benefit of biodiversity conservation in Kazakhstan's Steppe	Kazakhstan	Government (sub- national)	TE (steppe)	88				
6.2	Integrating carbon stocks and landscape connectivity for nature-based climate solutions in Ontario	Canada	Private and Government	TE (landscape connectivity)	94				
Chapter 7 Role of restoration to enhance climate change mitigation in protected areas									
7.1	Restoration of peatlands in protected area network	Finland	Government	TE (peatland)	102				
7.2	Management of secondary vegetation around Calakmul Biosphere Reserve	Mexico	Government	TE (forest)	103				
7.3	The role of protected areas in the maintenance and recovery of carbon stocks in mangroves	Guanabara Bay, Brazil	Government (various levels)	CBCE (mangrove)	106				
7.4	Peniup restoration project in Gondwana Link	Australia	Government	TE (forest)	109				
Chapter 8 Financing protected areas for climate change mitigation									
8.1	REDD+ improved forest ecosystem conservation in PCAs	Cambodia	Government and community	TE (forest)	115				
8.2	Great Bear Rainforest and Project Finance for Permanence	Canada	Government/ Indigenous/Private	TE and CBCE	122				

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PROTECTED AREA AND OECM DEFINITIONS, MANAGEMENT CATEGORIES AND GOVERNANCE TYPES

IUCN defines a protected area as:

A clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values.

The definition is expanded by six management categories (one with a sub-division), summarised below.

la Strict nature reserve: Strictly protected for biodiversity and also possibly geological / geomorphological features, where human visitation, use and impacts are controlled and limited to ensure protection of the conservation values.

Ib Wilderness area: Usually large unmodified or slightly modified areas, retaining their natural character and influence, without permanent or significant human habitation, protected and managed to preserve their natural condition.

Il National park: Large natural or near-natural areas protecting large-scale ecological processes with characteristic species and ecosystems, which also have environmentally and culturally compatible spiritual, scientific, educational, recreational and visitor opportunities.

III Natural monument or feature: Areas set aside to protect a specific natural monument, which can be a landform, sea mount, marine cavern, geological feature such as a cave, or a living feature such as an ancient grove.

IV Habitat/species management area: Areas to protect particular species or habitats, where management reflects this priority. Many will need regular, active interventions to meet the needs of particular species or habitats, but this is not a requirement of the category.

V Protected landscape or seascape: Where the interaction of people and nature over time has produced a distinct character with significant ecological, biological, cultural and scenic value: and where safeguarding the integrity of this interaction is vital to protecting and sustaining the area and its associated nature conservation and other values.

VI Protected areas with sustainable use of natural resources: Areas which conserve ecosystems, together with associated cultural values and traditional natural resource management systems. Generally large, mainly in a natural condition, with a proportion under sustainable natural resource management and where low-level non-industrial natural resource use compatible with nature conservation is seen as one of the main aims.

The category should be based around the primary management objective(s), which should apply to at least three-quarters of the protected area – the 75 per cent rule.

The management categories are applied with a typology of governance types – a description of who holds authority and responsibility for the protected area. IUCN defines four governance types:

Type A. Governance by government: Federal or national ministry/agency in charge; sub-national ministry or agency in charge (e.g. at regional, provincial, municipal level); government-delegated management (e.g. to NGO).

Type B. Shared governance: Transboundary governance (formal and informal arrangements between two or more countries); collaborative governance (through various ways in which diverse actors and institutions work together); joint governance (pluralist board or other multi-party governing body).

Type C. Private governance: Conserved areas established and run by individual landowners; non-profit organisations (e.g. NGOs, universities) and for-profit organisations (e.g. corporate landowners).

Type D. Governance by Indigenous peoples and local communities: Indigenous peoples' conserved areas and territories – established and run by Indigenous peoples; community conserved areas – established and run by local communities.

The Convention on Biological Diversity defines an "other effective area-based conservation measure" (OECM) as:

A geographically defined area other than a Protected Area, which is governed and managed in ways that achieve positive and sustained long-term outcomes for the in situ conservation of biodiversity, with associated ecosystem functions and services and, where applicable, cultural, spiritual, socioeconomic, and other locally relevant values.

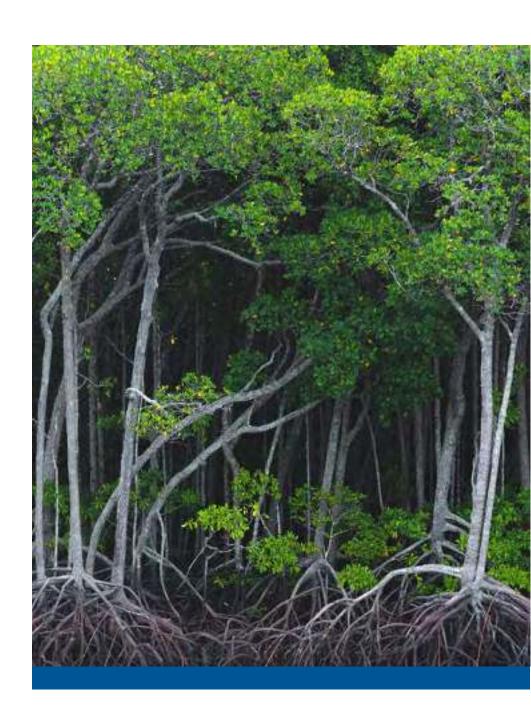
This covers three main cases:

- 1. **Ancillary conservation** areas delivering in-situ conservation as a by-product of management, even though biodiversity conservation is not an objective (e.g. some war grave sites).
- 2. **Secondary conservation** active conservation of an area where biodiversity outcomes are only a secondary management objective (e.g. some conservation corridors).
- 3. **Primary conservation** areas meeting the IUCN definition of a protected area, but where the governance authority (i.e. community, Indigenous peoples' group, religious group, private landowner or company) does not wish the area to be reported as a protected area.

For more information on the IUCN definition, categories and governance types, see Dudley (2008). *Guidelines for applying protected area management categories*, which can be downloaded at: https://doi.org/10.2305/IUCN.CH.2008.PAPS.2.en

For more on governance types, see Borrini-Feyerabend et al. (2013). *Governance of Protected Areas: From understanding to action*, which can be downloaded at https://portals.iucn.org/library/node/29138.

For more information on OECMs, see Jonas et al. (2023) Site-level tool for identifying other effective area-based conservation measures (OECMs): first edition, which can be downloaded at: https://portals.iucn.org/library/node/51296





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