Microsoft

Investing in Nature for Sustainability

Corporate insights from science and practice

Center for Coastal Climate Resilience UC SANTA CRUZ

CIFOR

World Agroforestry

THE WILKES CENTER FOR CLIMATE SCIENCE & POLICY

SDA

Concordia

October 2024

Contents

Foreword

Nature is the foundation of sustainability and the global economy. Yet, we are witnessing its alarming decline. An estimated 75% of Earth's land surface has been altered from its natural state[1] while biodiversity loss is accelerating. These trends are weakening ecosystems' capacity to regulate climate and provide other important services like pollination, water filtration, and food production. The continued degradation of even just a few key ecosystem services could cost the global economy $2.7 trillion per year by 2030.[2] The UN Biodiversity Plan outlines a strategy to reverse nature loss and highlights the critical role that companies must play.

In 2020, Microsoft embarked on a journey to develop a corporate strategy for protecting and restoring ecosystems. We made commitments to be carbon negative, water positive, and zero waste. Recognizing the complexity of setting quantitative targets for ecosystems, we pledged to protect more land than we use while using our voice, tools, and investments to protect and restore ecosystems. Over the last four years, we have invested across all these areas and partnered with academia, civil society, governments, and other companies to evolve our approach through shared learning.

One of the most important insights along our journey is that nature, as a whole, is greater than the sum of its parts. Ecosystems are intricate networks of processes that provide humanity with indispensable life-supporting services. Disrupting any one single process in an ecosystem can undermine the system's ability to deliver multiple societal benefits. As a result, we recognize that durable nature-based carbon storage is not the function of trees alone, but of healthy ecosystems. Likewise, water replenishment is most effective when entire watershed ecosystems are healthy. Local communities and Indigenous peoples, long-standing stewards of these ecosystems, are essential partners in their protection and restoration. But companies are not empowered to invest holistically in nature to protect and enhance ecosystem health.

At Microsoft, we invest in ecosystem health through our holistic approach to nature-based carbon removal and water replenishment. We are also advancing AI tools and scientific understanding to better monitor ecosystem health. Meanwhile through our Climate Innovation Fund and policy efforts, we work to build markets that support the conservation of healthy ecosystems.

While we have made meaningful progress, our journey has not been without its challenges. We know there is more to do and more to learn. Many companies face significant hurdles—lacking sufficient knowledge, tools, and incentives to invest in ecosystem health.

In this paper, our sustainability team in partnership with leading scientists from around the world highlight the importance of investing in ecosystem health, share Microsoft experience, and offer insights from both science and practice for what is needed to maximize the sustainability impact of corporate nature-based investments and strengthen the broader enabling conditions for success. We hope these lessons can help inform a path forward to empower more companies to target their nature-based investments on ecosystem health.

By working together, we can ensure that nature—and with it, our economy and humanity—can thrive.

Melanie Nakagawa
CVP, Chief Sustainability Officer

Executive summary

Nature provides essential life-supporting services for people and the economy, but the ecosystems that provide these services are rapidly being degraded and lost. To avoid escalating risks to economic stability, human health, and the capacity to address the climate crisis, increased investments are urgently needed to protect and enhance ecosystem health.

Companies have an important role to play. They are increasingly investing in nature-based solutions such as carbon dioxide removal, water replenishment, or biodiversity conservation. The specific benefits of these investments hinge on the health of the whole ecosystems which provide these services. However, it is challenging for companies to consider ecosystem health holistically in investment decisions.

Microsoft collaborated with an international team of scientists to assess the opportunities and challenges of corporate investments in nature. This paper outlines the importance of investing in ecosystem health, shares Microsoft's experience, and offers insights from science and practice.

Key challenges for maximizing the sustainability benefits of companies' investments in nature are:

- Corporate investments in nature often narrowly target individual benefits (such as carbon or water), without considering the condition of or implications for the whole ecosystem.
- Investments that fail to consider the health of the whole ecosystem can undermine sustainability.
- Companies lack sufficient incentives, knowledge, and tools to prioritize ecosystem health.

Lessons for moving forward

1. **Build incentives to invest in ecosystem health.** Establish mechanisms that reward companies for investing in nature-based solutions that improve ecosystem health and ensure local community benefits and stewardship.
2. **Agree on science-based standards for the impacts of investments on ecosystem health.** Civil society and companies need to collaborate with scientists to agree on corporate standards for characterizing how sustainability investments affect ecosystem health.
3. **Make science accessible and build capacity to use it.** All actors in nature-based markets need to be able to use the best available science to evaluate ecological and social risks, design projects that enhance ecosystem health, and assess it effectively.
4. **Accept trade-offs as inevitable and aim to minimize them.** While not all sustainability benefits can be maximized at once, strategic planning can reduce negative impacts and optimize positive outcomes.
5. **Innovate to de-risk investment.** Nature-based investments face risks from the variability of natural systems; better tools are needed to understand, insure, and manage these risks.
6. **Expand blended finance.** Combining public and private capital can reduce financial risks to private investors and attract more investment into nature-based solutions.
7. **Invest beyond capital.** While funding is vital, projects and startups also need strategic support, including expertise, long-term demand signals, and market access.
8. **Use AI for speed, scale, and reliability.** AI can help companies prioritize ecosystem health by enabling cheaper, more effective measurement, trade-off analysis, and risk management.

Introduction

The world faces a convergence of environmental crises: climate change, biodiversity loss, and social inequality. Addressing these three crises requires a holistic approach to sustainability that prioritizes the health and integrity of our planet's ecosystems. The interconnections among these sustainability challenges are reflected in the 17 United Nations (UN) Sustainable Development Goals and are addressed in both the UN Framework Convention on Climate Change Paris Agreement and the Kunming-Montreal Global Biodiversity Framework. Underpinning each of these agreements is a clear scientific consensus: a thriving natural world is essential to achieving any of the global sustainability goals.

Companies are increasingly contributing to protecting and restoring the natural world. Many invest in nature to help meet their sustainability goals, for example to remove carbon from the atmosphere, replenish water, or protect biodiversity. Private sector investments in nature-based solutions (NbS)[3] increased from $26 billion annually in 2022 to almost $36 billion annually in 2023, accounting for 18% of global investments in NbS.[4,5] These numbers are expected to rise in the coming years as more initiatives call on companies to consider nature in their business reporting and planning.[6,7,8] Many initiatives have recently emerged. Some are voluntary, such as the Taskforce on Nature-related Financial Disclosures (TNFD), while others are regulatory, including the European Union's Corporate Sustainability Reporting Directive (CSRD) and Nature Restoration Law and the United Kingdom's Biodiversity Net Gain mandate.

It is encouraging to see corporate investments in nature increasing. But there is a problem: these investments are often focused on individual parts of an ecosystem—such as carbon, water, or biodiversity—in isolation, and frequently fail to address the aspirations and vulnerabilities of Indigenous and local communities. Nature and society, however, are not merely a collection of parts; they function as a set of interconnected systems, where each component plays a crucial role and is linked to others, all supporting the ecosystem services on which humanity depends (Figure 1). Investments that fail to consider the health of the entire ecosystem, and the communities that depend on it, risk destabilizing these ecosystems and jeopardizing their provision of services vital to humanity.

Ecosystem health[3] refers to how well an ecosystem supports and maintains native populations of species and key ecological processes such as energy flow, nutrient cycling, and organic matter movement. Ecosystem health underpins ecosystem services including pollination, water purification, and heat risk reduction. Ecosystem health is also known as ecosystem integrity or ecosystem functioning.[9]

Ecosystem health exists on a spectrum. Healthy ecosystems have robust populations of native species, have few unmanaged threats and minimal reductions in size or extent, and support strong ecological processes. Less healthy ecosystems may have been significantly affected by human activity, lost native species, and have poorly functioning ecological processes, but may still provide some services like carbon sequestration. Unhealthy ecosystems are severely degraded or intensely managed, and as a result have lost their natural structure and ability to reliably deliver their full suite of ecosystem services. Investments in nature are most effective when focused on protecting or enhancing ecosystem health.

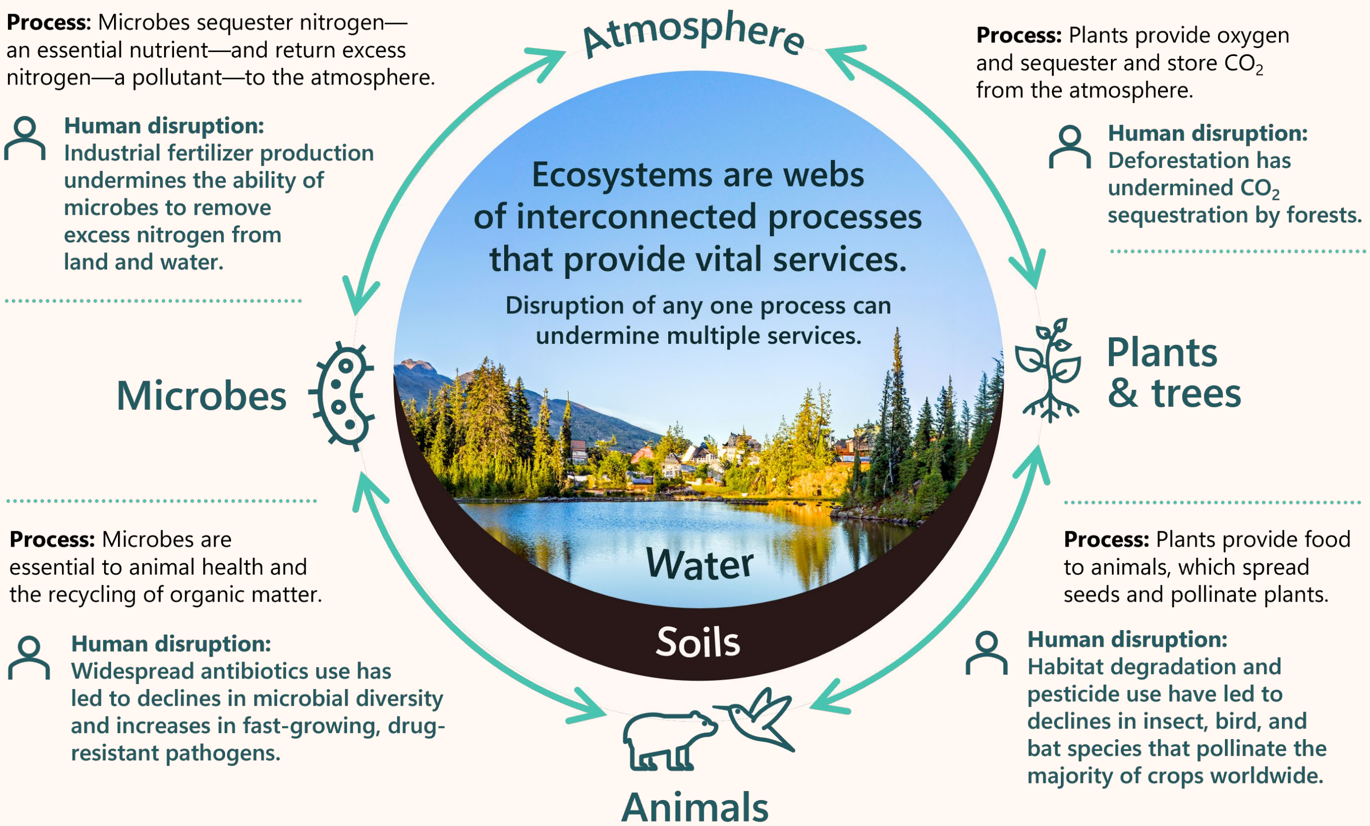

Figure 1: Illustrative ecological processes that provide vital services to humanity. When nature's ecosystems are healthy, they maintain essential ecological processes, sustain biodiversity, and collectively provide numerous benefits to humans, such as clean air, water, food, and climate stability. Note that these are just a few examples of ecological processes that exist in nature, and the ways in which humans disrupt them.[10,11,12,13,14]

A growing number of global initiatives now highlight that to advance sustainability goals, nature-based investments need to holistically consider ecosystem health and the needs of Indigenous and local communities. These initiatives include International Union for the Conservation of Nature's Global Standard for Nature-based Solutions,[15] UN Decade on Restoration, The Global Biodiversity Standard manual, and the Coalition for Private Investment in Conservation. Yet, companies often lack the incentives, knowledge, and tools needed to target investments to enhance ecosystem health and support Indigenous and local communities.

Over the last four years, Microsoft has worked to build a holistic strategy for investing in nature. While progress has been made, it has not been easy. To learn from this experience and from the best available science, Microsoft's environmental sustainability team collaborated with an international group of leading researchers and practitioners to assess the opportunities and challenges of corporate investments in nature. In this paper, we review the importance of investments in nature for sustainability, discuss the challenges that companies face, share Microsoft's experience, and offer lessons learned from science and practice to help inform a way forward.

Nature is the foundation of sustainability and the economy

Nature is the bedrock upon which sustainability is built. The health and vitality of natural ecosystems underpin the stability and resilience of the world's economies and the well-being of communities. There are many examples of how a thriving natural world is fundamental to achieving sustainable development goals and ensuring a prosperous future for all. Here are a few.

Climate mitigation goals cannot be met without healthy ecosystems. To keep global warming well below 2 °C, the target set in the Paris Agreement, rapid reductions in greenhouse gas emissions are needed.[16] Without nature's services, the emissions reduction task would be much greater. Ecological processes on land absorb about a quarter of the carbon dioxide that human activities emit each year.[11] A roughly equal amount of carbon is removed by physical and biological processes in the ocean.[11] However, as ecosystems are degraded or destroyed, their large reservoirs of carbon are released to the atmosphere, amplifying the climate crisis. Forests and soils alone hold two to three times more carbon than the atmosphere itself.[17] Through the restoration and protection of ecosystems, such as forests and wetlands, additional carbon dioxide removal and emissions reductions can be achieved. Scientists estimate that protecting and restoring nature could make a substantial contribution to climate mitigation efforts, but only a fraction of this potential is being realized today.[18]

Sustainable water supplies require healthy ecosystems. Imagine a world without readily available clean water—this harsh reality exists today for many people,[19] and is closer than we think for many others. Rivers, lakes, and aquifers serve as critical sources of freshwater, crucial for human existence and economic activities. Nature plays a triple role in ensuring water security: as a source (rivers, lakes, groundwater), a filter (soils, plants, microbes remove pollutants), and a regulator (wetlands and forests mitigate floods and droughts). Replacing nature's water services with industrial processes, such as desalination or conventional water treatment, would be vastly more expensive.[20]

According to a recent study, over 4 billion people still lack reliable access to safe drinking water,[21] more than double previous estimates,[22] highlighting the urgent need for sustainable water management solutions. Achieving the goal of universal access to clean water and sanitation will require enhancing the natural ecosystem services that provide drought resilience and protect water quality, alongside more sustainable water management practices. Major cities and corporations are increasingly investing in nature-based solutions to address water quality and security challenges.[23,24,25,26]

A sustainable, thriving global economy requires healthy ecosystems. The global economy relies on nature's flows of goods and services. This includes the raw materials crucial for construction (timber, minerals), manufacturing (metals, fibers), and pharmaceuticals (plant-based medicines), as well as essential services like pollination, water filtration, and climate regulation—key components of global supply chains.[27,28]

Although the full economic contributions of nature are poorly quantified, the World Bank's recent report, *The Economic Case for Nature,* estimates that by 2030, the global economy could suffer $2.7 trillion in losses due to the collapse of a few natural services, with low-income countries losing approximately 10% of their annual GDP.[29] These predictions are based on cautious assumptions, and only capture nature's contributions to a limited number of sectors, and thus underestimate the true economic risks posed by declining nature.[29,30]

Beyond its direct contributions, nature also mitigates societal risks, including natural disasters and the threat of pandemics.[31,32,33] Over the past two decades, floods and droughts have affected 1.8 billion people and caused over $775 billion in damages.[34] Protecting and restoring rivers, wetlands, and watersheds can mitigate these impacts by regulating water flow and replenishing supplies.

Business leaders are increasingly aware of these risks. The World Economic Forum's most recent global risk survey ranks extreme weather, biodiversity loss and ecosystem collapse, and natural resource shortages as the greatest sources of risk over a decade-long horizon,[34] outpacing concerns like cyber insecurity, interstate armed conflict, and societal polarization.

Circular economies depend on healthy ecosystems. Ecosystem processes are foundational to recycling water and waste. For example, ecosystems like forests and green spaces in urban areas process water by absorbing runoff, filtering particulates, and converting dissolved pollutants to less harmful forms via microbial activity, reducing water treatment costs and preventing sewers from overflowing and contaminating rivers during storms. Plants and microbes further help clean contaminated soils, creating habitat for animals and increasing property values.

In addition, natural processes turn waste material into valuable resources and give us new ideas for products that prevent waste at the source. Composting converts food waste into nutrient-rich soil amendments, reducing landfill burden and boosting soil health. Nature-inspired production methods, like using biodegradable materials derived from plants and growing foods and trees together in agroforestry systems, can create products that generate less waste and pollution.

Circular economies also inherently support healthy ecosystems. By keeping materials in circulation for longer, economies also reduce the need to extract and refine new materials from nature. Recycling paper and glass reduces the need to harvest more trees and sand, and reduces the energy used and carbon released in processing these materials into new products.

Biodiversity is the foundation of healthy ecosystems. Biodiversity encompasses the vast array of species from towering trees to microscopic organisms. This genetic diversity has enabled these species to adapt to different or changing environmental conditions in a diverse range of ecosystems, from the deep sea to tropical rainforests and deserts (Figure 2). The complex interactions within and among ecosystems together shape the planet and our lives.

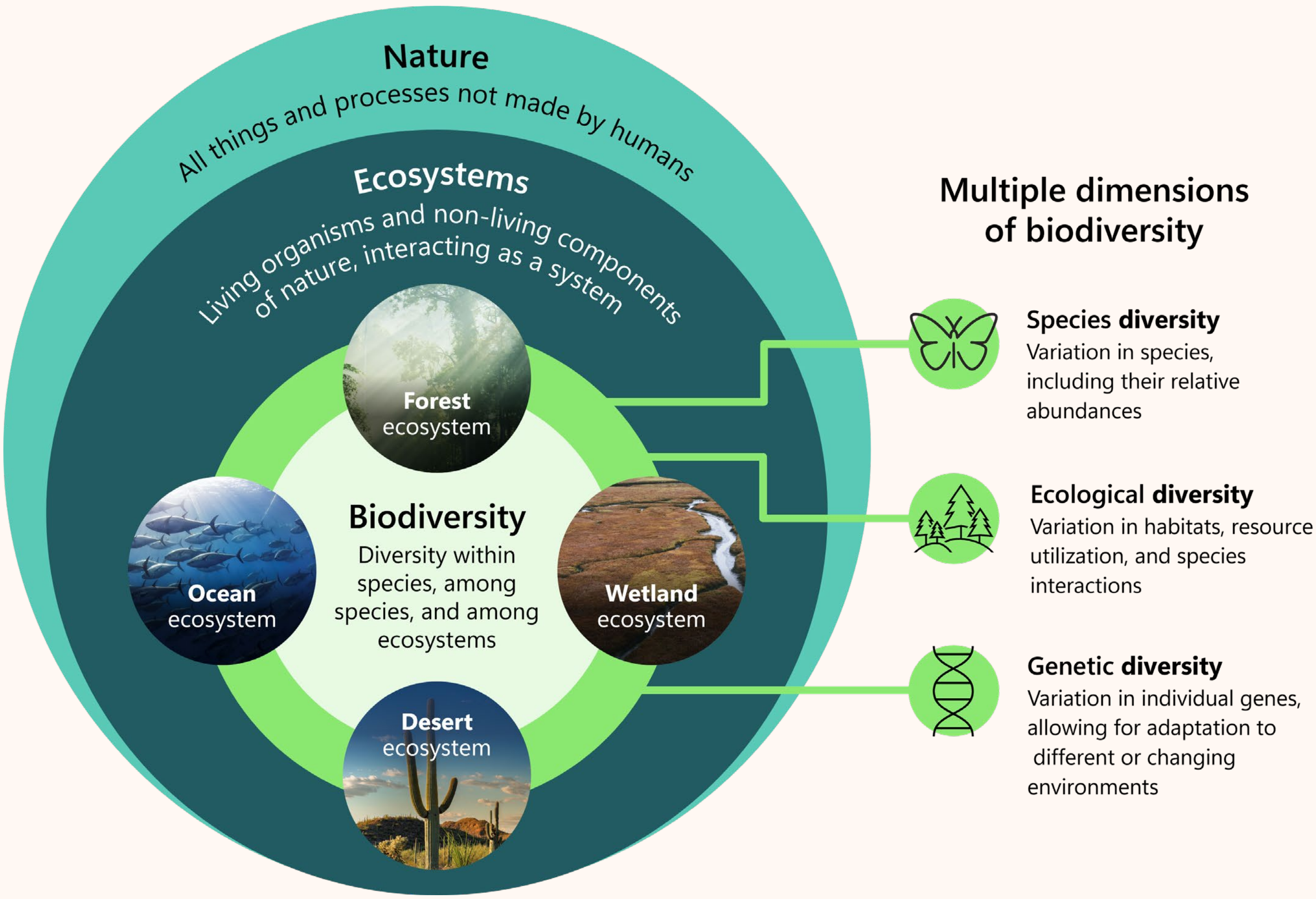

Figure 2: Definitions and relationships—nature, ecosystems, and biodiversity. Nature consists of a diverse range of ecosystems, all interconnected through the flow of energy, resources, and species. Biodiversity encompasses the variety of ecosystem types, species (including microbes), and genetic diversity. While biodiversity is a crucial indicator of ecosystem health, it is not the only one; other factors, such as ecosystem resilience, connectivity, functioning of ecological processes, and provision of services, also play essential roles in determining overall health.

Biodiversity is being lost at alarming rates. Scientists estimate that 1 million species are currently at the brink of extinction.[9,35] For example, coral reef ecosystems are being degraded by ocean heatwaves, ocean acidification, and low-oxygen dead zones, leading to the loss of habitat and food webs for countless marine organisms.

Biodiversity loss is most often recognized in the decline of key species, like bees, which are disappearing due to habitat loss, pesticides, monocultures, disease, and other stressors.[36,37] Their decline threatens food security, as bees pollinate many crops, including almonds, apples, avocado, cotton, and canola. Reduced populations of bees and other pollinator species lead to lower crop yields and higher production costs.[12,38,39]

The loss of biodiversity can also have broader cascading effects on nature's services to people. For example, the loss of forest species, from trees to soil microbial communities, directly affects the rate of natural carbon sequestration. Forest ecosystems with more of their native species are more effective in capturing and storing carbon dioxide from the atmosphere, contributing significantly to climate regulation.[40] Without species diversity, forests lose their resilience to disturbances and their capacity to sequester carbon declines.[41] Protecting biodiversity is therefore essential not only for maintaining ecosystem health but also for enhancing natural climate mitigation through carbon sequestration.

Biodiversity loss in any form (such as loss of genetic diversity, species, or ecosystems) undermines all ecosystem services, from pollination and climate regulation to soil fertility, water purification, flood risk reduction, heat stress regulation, and many others which are critical for business operations and economic stability.[42] Protecting biodiversity is therefore not only a conservation imperative but is also essential for ensuring resilient supply chains, a stable climate, as well as food and water security.

While investing in nature is only one of the critical actions needed to achieve global sustainability goals, it is an essential one. We cannot have a thriving planet and thriving people without a thriving natural world.

Nature-based solutions are actions taken to protect, manage, or restore natural or modified ecosystems in ways that address societal challenges.[3]

The importance of protecting and restoring ecosystem health

↗

"[Nature-based solutions] are derived as goods and services from ecosystems, therefore strongly depend on the health of an ecosystem."
—IUCN[15]

Companies are increasingly investing in nature to help meet their sustainability goals, seeking credit for a quantified amount of carbon reduced or removed, water replenished, or biodiversity protected. If these investments are not designed to support whole ecosystem health, they can undermine sustainability goals by reducing ecological and community resilience and contribute to long-term degradation of ecosystems and their services.[43]

Science indicates that holistic nature-based investments, which seek to protect and restore the health of ecosystems, are more likely to provide resilient services.[44] Consider the purchase of carbon credits through an investment in planting trees. While trees can be an important nature-based climate solution, the kind of tree, where it is planted, and what other species are present matter a great deal for climate outcomes. Non-native trees are often used because they might grow quickly and store more carbon in the short term.[45,46] However, native trees are often better suited to local conditions, so are likely to withstand local stresses. For example, the Kamagong tree, native to the Philippines, has deep root systems that help it withstand damage from typhoon winds better than shallow-rooted non-native trees.[47] Similarly, the Philippines-native Molave tree has high drought tolerance and pest-resistant leaves, unlike fast-growing non-native species.[48]

Planting non-native trees, selected only for their capacity to store carbon in the near term, can also damage local soils and water supplies,[49] degrading the habitat of native plants and animals and undermining the survival of the trees themselves.[50] Tree plantations meant to stabilize the climate can also acidify soils and increase wildfires,[51] causing air pollution and increasing health risks.

The greatest climate benefits from investments in trees are likely to come from growing many kinds of native plants together, rather than a plantation composed of only one or two species of trees.[52] Biodiversity can be a key factor in an ecosystem's resilience to disturbances such as drought,[53] pests,[54] and wildfire.[55] Relatedly, biodiversity also can be a key factor in helping restored ecosystems adapt to the changing climate (see Box 1).[56]

The ability of Indigenous peoples and local communities to derive livelihoods from biodiverse forest ecosystems is key to their buy-in as essential partners for the long-term success and reliability of nature-based solutions.[45] Indigenous peoples' and local communities' lands hold about 34% of what's known as irrecoverable carbon, carbon stored in ecosystems that if released to the atmosphere could not be replaced by 2050.[57]

Box 1: Information and supplies needed to restore native, biodiverse, and resilient ecosystems

Restoring healthy forests in a changing climate requires selecting the right tree species, for the right place, for the right purpose. However, finding appropriate species and sourcing seedlings for large-scale planting can be challenging. Better tools for identifying which species to plant are critical, as is building supplies of diverse native seedlings.

The Center for International Forestry Research and World Agroforestry (CIFOR-ICRAF) has developed the Tree Globally Observed Environmental Ranges database (TreeGOER), which documents 51 environmental variables related to the observed occurrences of over 48,000 tree species, enabling land managers and researchers to identify which tree species will grow and thrive under current and future climate conditions. TreeGOER is complemented by the Dendrochronology (tree-ring dating) Lab, which reconstructs the past performance of trees in terms of their drought tolerance, growth dynamics, and productivity and water use efficiency. TreeGOER has been accessed over 5 million times by users around the world.

CIFOR-ICRAF has also partnered with the African Forest Landscape Restoration Initiative and the African Union and Africa Development Bank to build genebanks supplying the seeds for dozens of tree species. These tools allow users to explore the impact of climate conditions on tree species and better target planting the right trees in the right place to support restoration and climate change adaptation.

Acacia tree seedling nursery in Yangambi, Democratic Republic of Congo. (© Axel Fassio/CIFOR-ICRAF)

Local and Indigenous communities have invaluable knowledge about healthy ecosystems and can provide insights essential for the effective design and implementation of NbS.[58] Their active participation can help ensure that NbS projects are culturally appropriate, equitably beneficial, and sustainably maintained over time. By engaging or supporting local communities, companies can enhance the resilience and effectiveness of their NbS investments, ensuring that these projects provide lasting benefits.[59,60]

Community members collaborate with CIFOR-ICRAF to protect carbon-rich tropical peatlands in Quistococha, Peru. (© Junior Raborg/CIFOR-ICRAF)

Corporate guidelines are beginning to highlight the importance of approaching investments in NbS from a holistic perspective, rather than focusing only on a single service. For example, the 2024 report *Natural Climate Solutions for the Voluntary Carbon Market: An Investor Guide for Companies and Financial Institutions* emphasizes the importance of biodiversity and ecosystem health as integral parts of high-integrity NbS for climate.[61] Even with broad guidelines emerging, companies can face challenges investing effectively in the protection and restoration of healthy ecosystems, due to limitations in science, data, and tools.

Fortunately, these challenges are beginning to be addressed. For example, international research institutions, such as the Center for International Forestry Research and World Agroforestry (CIFOR-ICRAF), are working with multi-stakeholder groups to build science, tools, and programs for a pipeline of NbS that succeed in storing carbon, increasing biodiversity, securing jobs, and improving livelihoods.[62] The Wilkes Center for Climate Science and Policy at the University of Utah has developed science-based tools that can help companies assess the climate-related risks to nature-based solutions for carbon (see Box 2), and is developing alternative models for corporate nature-based sustainability crediting.[63]

Box 2: Tools for assessing risks to nature-based solutions

Robust estimates of risks are crucial to successfully scaling high-quality NbS. In particular, NbS projects with a climate mitigation goal need to last over 50–100 years or more, depending on the goals and claims made by the investment.[63] Risks to NbS for climate mitigation include human-system risks (such as social, governance, economic, financial) and nature-related risks (such as wildfire, drought, hurricane, pests).

While enormous uncertainty remains about the future of the global land carbon sink, it is increasingly possible to quantify regional and global patterns in disturbance risk. A major goal is to determine the durability of ecosystem carbon stocks over decades to centuries. Various approaches, from big data and machine learning to Earth system models, have been used to quantify these risks. Detailed carbon durability and risk maps have been produced for US forests with global forests risk profiles in progress. Policy-ready datasets that quantify the buffer pool size needed, based on risk assessments, in NbS protocols and programs are under development and expected soon.

Key near-term needs for carbon risk assessment broadly include better characterization of individual disturbance risks, better data on the human-system risks, how and where biodiversity and ecosystem health affect natural risk profiles, and open-source tools for stakeholder use that incorporate the best-available science. Similar advances are needed to understand and quantify risks to other benefits from NbS.

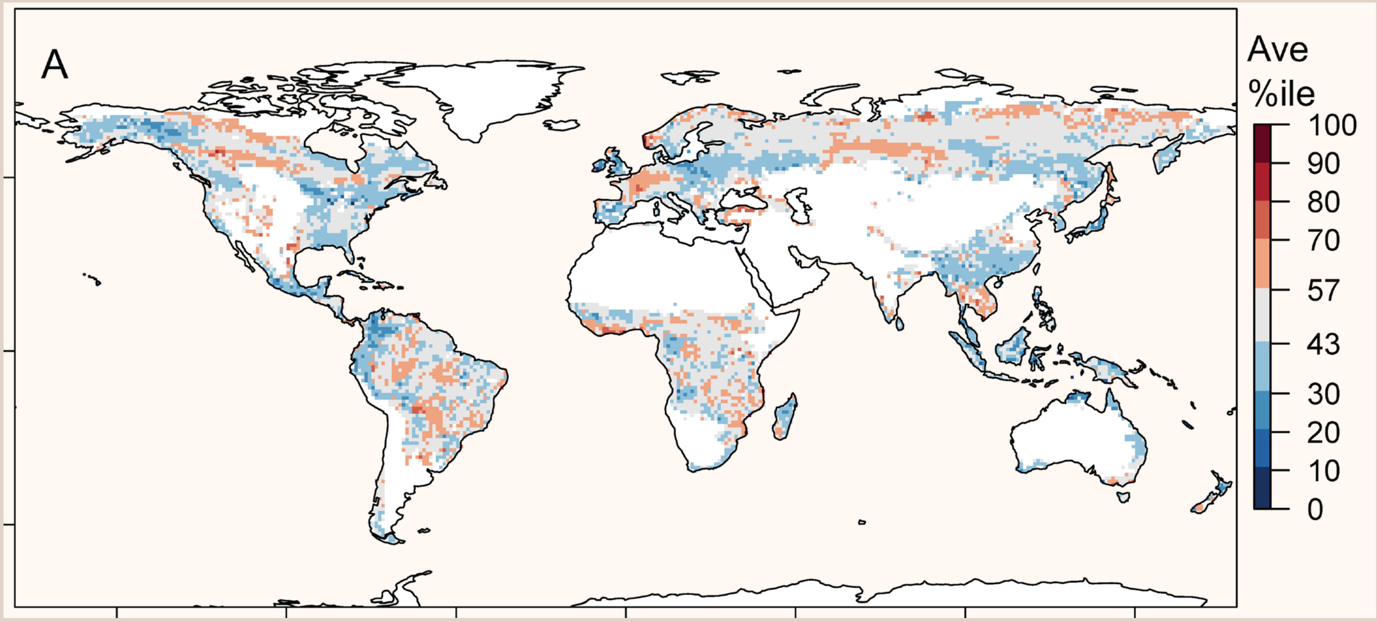

Figure 3: Comparisons and syntheses across different climate risk axes. Average percentile of risk combined across all metrics where zero percentile is lowest climate risk and 100 percentile is highest climate risk, averaged across all datasets that covered a given grid cell, across seven carbon risk datasets.[63]

Microsoft's approach to investing to protect and restore ecosystem health

By 2030, Microsoft is committed to being carbon negative, water positive, and zero waste, while also protecting ecosystems and conserving more land than it uses. Our approach to meeting these goals involves a range of strategies, including reducing resource consumption through efficiencies and innovations, sourcing zero-carbon energy, using zero-water cooling for datacenters, and designing for circularity.

In addition to these core shifts in operations, Microsoft is investing in nature to remove carbon from the atmosphere, replenish water in water-stressed basins, and protect land for ecological conservation. These efforts involve developing programs and partnerships focused on ecosystem health. Given that there is not a common standard for identifying the ecosystem health impacts of investments, it remains challenging for Microsoft and other companies to direct their resources towards NbS projects that prioritize it.

Key challenges include: (1) uncertainty in how to best assess, track, and predict ecosystem health; (2) a limited supply of nature-based project providers with the resources and expertise to holistically manage ecosystem health; and (3) securing long-term commitments from stakeholders to ensure ongoing stewardship and lasting benefits.

Investing directly in nature

Microsoft aims to take a holistic ecosystem approach to land conservation, water replenishment, and carbon removal. Overcoming challenges has required extensive research, partnerships, and innovation.

Over the last four years, Microsoft has met over 60% of its volumetric water replenishment goals with nature-based solutions.[26] Microsoft recognizes that water challenges are not just about water (see Box 3).

Solving water challenges also involves considering greenhouse gas emissions, biodiversity, and human health and livelihoods. As a result, progress is measured by tracking water replenished relative to targets, while also evaluating the project's value to the community and its impact on watershed health. Because no corporate-sector standards are currently available for tracking the benefits of water replenishment projects, Microsoft is supporting a collaboration to develop methods for systematically assessing the aquatic and terrestrial biodiversity benefits of NbS investments made in watersheds for water replenishment.[64] The collaborating organizations include the Pacific Institute, the CEO Water Mandate of the United Nations Global Compact, LimnoTech, The Nature Conservancy, and Second Nature Ecology and Design.

Box 3: Investing in enhancing watershed health

For Microsoft, meeting its water replenishment target is about more than a volume of water; it is about prioritizing and addressing the broader needs of an entire watershed and the people that inhabit it. That is why the company sees the value of assessing ecosystem co-benefits of replenishment projects wherever possible, including water quality improvement, biodiversity protection, and carbon storage. For example, Microsoft has partnered with global environmental NGO Conservation International (CI) and the Ecological Restoration Lab at the National Autonomous University of Mexico to restore the Xochimilco wetland ecosystem, a UNESCO World Heritage Site.[65] This ecosystem is the last natural remnant of the Valley of Mexico lagoon system, which has been severely affected by the expansion of Mexico City, leading to water scarcity and pollution. Wetlands naturally replenish water and reduce pollution by absorbing, filtering, and storing precipitation and runoff, critically important to water- and climate-stressed communities like Xochimilco.[66] Actions in Xochimilco focus on restoring watercourses, re-establishing native wetland vegetation, and employing biofilters to improve water quality.

Xochimilco was targeted by Microsoft because—in addition to its capacity to replenish upwards of 1 trillion gallons of water, to be confirmed following the project's completion—the wetland is home to 11% of Mexico's biodiversity, including the endangered axolotl salamander, a biological indicator of water quality.[26,67] Although it is too soon to tell what the restoration of Xochimilco will mean for these ecosystem services, wetland restoration projects typically increase biodiversity and ecosystem service provision by up to 30%.[68] Another ecosystem service provided by freshwater wetlands, globally, is the sequestration and storage of 20–30% of all soil carbon,[69,70,71] despite occupying only 5–8% of the earth's land surface.[72] Still another important service provided by wetland ecosystems is food; the Xochimilco project is also bringing back chinampas, artificial islands for growing crops dating from the Aztec period. Efforts by Microsoft and Conservation International therefore add up to more than gallons of water, but a high-integrity ecosystem in the heart of Mexico City.

Endangered Axolotl salamander inhabiting Mexico City's Xochimilco wetlands. (© Robert Roehl)

Microsoft has also developed partnerships to identify critical ecosystems in water-stressed regions where targeted investments can restore healthy environments. For example, through the Texas Water Action Collaborative facilitated by Texan by Nature, Microsoft and four other corporate funders were matched with a Texas Longleaf Team project that is a public-private partnership dedicated to restoring longleaf pine forests in the Trinity River Basin of east Texas. The native longleaf pine is vital to this ecosystem, filtering and storing freshwater, sequestering carbon, and supporting biodiversity. It also plays a key role in ecological resilience, thriving in harsh weather conditions and providing habitat for threatened and endangered species.

Microsoft also takes a holistic approach to its nature-based investments to achieve its carbon removal goals. In these investments, Microsoft seeks out partners and projects that can contribute to restoring local and regional ecological integrity of ecosystems, both in North America and the tropics.

Sockeye salmon in the Klamath River. (© Adobe Stock)

For example, Microsoft contributed to the Western Rivers Conservancy's Blue Creek Forest Project in the Klamath River watershed of California. This project not only helps build forest carbon stocks but also is helping to establish the Blue Creek Forest and Salmon Sanctuary, which will protect 47,000 acres of temperate rainforest. In addition, proceeds from the sale of carbon credits have assisted Western Rivers Conservancy in acquiring and returning to the Yurok Tribe some of their ancestral territory.

In South America's Atlantic Forest—one of the world's most threatened ecosystems, having suffered a staggering 88% loss of its original vegetation[73]—Microsoft has partnered with re.green to regenerate forest on degraded pasture land in Brazil. This project will restore these lands with over 10 million trees, which will remove carbon from the atmosphere and store it for decades. And because Microsoft understands that healthy ecosystems are important for higher-durability carbon removal, it is working with re.green to use native species, enhance biodiversity, monitor ecological health, and support local communities (see Box 4).

In Panama, Microsoft recently partnered with Rubicon Carbon and Carbon Streaming Corporation to fund a 28,000-acre forest restoration project designed by ecological restoration company Ponterra. This project will restore a unique tropical forest by planting over 6 million trees from over 75 native species in a formerly forested area degraded by decades of cattle ranching. The team chose to work with Ponterra in part because of its holistic mission to restore biodiversity and uplift local communities by designing and operating high-integrity nature restoration projects. Ponterra employs ecologists, naturalists, and other scientists to design restoration projects that support rich biodiversity recovery. Ponterra's team of naturalists and data scientists measure the population of plants and animals still alive at the beginning of the project, and then track over time the return to the project area of plants, birds, bats and other mammals, as well as insects and other invertebrates.

By providing upfront financing along with a long-term offtake commitment, Microsoft is also supporting the entry of smaller companies into this nascent nature-based market through offtake agreements. Offtake involves one company buying a large percentage of available carbon credits, reducing the price and cash-flow risk for smaller investors. These efforts address two key constraints on the carbon market today: the limited availability of high-quality and high-durability carbon credits, and of market capital.[74,75] Thus, in both Brazil and Panama, Microsoft is looking to do more than remove its own carbon dioxide from the atmosphere—it is supporting an emerging business model that can help incentivize holistic restoration of nature.

In these projects, as well as others around the world, Microsoft's partnerships with scientists, local communities, NGOs, and governments are critical to ensuring that the restoration projects support the development of healthy ecosystems as well as local communities.

Box 4: Investing holistically to restore tropical rainforests

Microsoft recognizes the importance of investing in healthy ecosystems to achieve its carbon dioxide removal goals.[76] This is why Microsoft's carbon dioxide removal team has partnered with re.green in Brazil to replant over 40,000 acres of cattle pastures that were slashed and burned from the Mata Atlântica (Atlantic Forest). re.green brings a holistic view to restoring this tropical rainforest by regenerating the nutrient-starved soils of denuded pasturelands, re-planting them with native rainforest tree species, and in the process creating habitat patches colonized by wildlife from intact forest. Microsoft-sponsored restoration of the Atlantic Forest with re.green will sequester and store over 3 million tons of carbon dioxide equivalents during its first 15 years alone.[77]

Science-based assessments of nature-based solutions are critical to knowing when and where investments should be made.[78] To that end, re.green is assessing the implications of the composition of its tree species for resilience, biodiversity, carbon storage, and local communities. re.green ecologists recognize that a more diverse tree community can store more carbon and is more resilient to disturbances like droughts and fires, which are being intensified by climate change.[52,79] These projects can also incorporate trees that are critically endangered, and trees that supply communities with sustainable forest products like Brazil nuts. In this way, restoration increases biodiversity and generates a revenue stream to local communities whose buy-in is critical to the success of the project.

re.green restoration plot adjacent to Brazil's intact Atlantic Forest. (© Miguel Moraes/re.green)

Investing in enabling conditions

For corporate investment to fill its crucial role in protecting and restoring nature, conditions need to change so that investments are easier, less costly to make, and maximize impact. Microsoft is working to help create these enabling conditions by co-developing and enhancing access to AI-enabled tools for improving measurement, advancing the science to support evidence-based policies and standards, and building markets for high-integrity nature-based solutions.

Co-developing AI-enabled solutions

AI and advanced Earth observation technologies are becoming vital tools for measuring, understanding, and protecting nature. They can help assess ecosystem health by integrating diverse data on species, biomass, productivity, and habitat connectivity across space and time. By processing vast amounts of data from diverse sources like sounds, images, text, and sensors, AI technologies can enable faster, cheaper, and more accurate ecological analysis on local to global scales.

Microsoft partners with public and private sector organizations to apply AI and advanced Earth observations to measure and understand nature's complexity at a scale and speed that was impossible even just a few years ago. For example, Microsoft is partnering with companies like BeeOdiversity to utilize AI and bees for monitoring biodiversity. BeeOdiversity uses AI to analyze pollen collected by bees, providing insights into ecosystem health and biodiversity changes. This approach helps identify environmental factors like invasive species, heavy metals, and pesticides, enabling targeted actions to improve ecosystem health.

The Microsoft AI for Good Lab has partnered with scientists to build new AI-enabled camera traps and bioacoustics technologies that enable the analysis of sounds and images of the natural world, providing unique insights into the state of biodiversity and the health of ecosystems.

As these technologies advance, the AI for Good team is working to make them accessible to ecosystem monitoring practitioners. For example, while automated deep-learning methods for wildlife monitoring are becoming more common, they remain complex and require specialized knowledge. To overcome this, Microsoft developed Pytorch-Wildlife, a user-friendly AI tool for animal detection and classification in images and videos.[80] Microsoft has partnered with Universidad de los Andes in Colombia to train and deploy this and other models for species recognition in the Amazon Rainforest, and with the Agency for Regulation and Control for Biosecurity and Quarantine of the Galapagos Islands to detect invasive opossums in the Galapagos Islands. The team plans to expand its capabilities to address a broader range of environmental challenges. The AI for Good team is also working with partners to apply these advanced technologies for ecosystem monitoring and assessment (see Box 5).

As biodiversity measurement becomes mainstream in sustainability reporting, Microsoft is collaborating with partners to guide the use of AI and advanced technologies for meeting reporting requirements. For example, Microsoft worked with Planet Labs, the Natural Capital Project, the Gund Institute for the Environment, and others to develop a white paper—*Accelerating Biodiversity and Ecosystem Reporting*—that outlines how AI and Earth observations can help companies efficiently meet emerging regulations, such as the EU's CSRD and the Task Force for Nature-related Financial Disclosures (TNFD).

Box 5: AI for ecosystem assessment, monitoring, and protection

The Microsoft AI for Good team has partnered with the Universidad de los Andes, Instituto Sinchi, the Alexander von Humboldt Institute in Colombia, IDEAM, and Planet Labs to assess and monitor biodiversity and ecosystem change in the Amazon.[81] This effort, Project Guacamaya, tasks a suite of algorithms with processing large amounts of multi-modal data continuously collected by automated camera traps, bioacoustics receivers, and satellites. Previously, a handful of experts painstakingly reviewed years of backlogged images and sound recordings to identify species. Instead, algorithms now quickly and efficiently compare historical and contemporary observations as they are made to databases on the cloud with minimal manual validation, identifying native species, non-native species, and even entirely unknown species. The algorithms used for camera trap (Pytorch Wildlife) and bioacoustics data (Microsoft/CLAP) are publicly available and have so far been downloaded by tens of thousands of users.[80]

Ecosystem disturbances like wildfires, unauthorized roads, illegal deforestation, and unlawful mining are also being assessed and monitored by Project Guacamaya's algorithms. The use of AI to rapidly assess and monitor biodiversity and ecosystem change is enabling Colombian authorities, scientific organizations, and other stakeholders to better protect the world's largest rainforest from human encroachment and monitor climate impacts.

Camera trap image from the Amazon rainforest. (© Project Guacamaya/Microsoft)

Another area where AI is providing valuable insights is in understanding trade-offs and identifying synergies between restoration and nature-based investments. This is particularly relevant in the context of the Global Biodiversity Framework's ambitious 30x30 goals, which aim to restore 30% of degraded ecosystems and protect 30% of the world's land and oceans by 2030. As countries like Canada work toward these targets, determining which areas to prioritize for protection and restoration requires careful consideration of both biodiversity conservation and the provision of ecosystem services. To help inform these complex decisions, researchers from the Sustainability in the Digital Age at Concordia University, in collaboration with Microsoft, have used AI to assess trade-offs and identify synergies of alternative protection and restoration scenarios (see Box 6).

Box 6: Using AI to identify and quantify trade-offs of nature-based solutions

In line with the Global Biodiversity Framework, Canada aims to restore 30% of degraded ecosystems and protect 30% of its land by 2030. A critical question is: which 30% of terrestrial ecosystems? A collaboration between Sustainability in the Digital Age at Concordia University and Microsoft is using AI to assess these trade-offs and identify synergies between biodiversity protection, ecological intactness, carbon storage, and water. The analysis suggests that maximizing the protection of threatened biodiversity and irrecoverable carbon in forests results in a comprehensive pathway to improve biodiversity, climate change mitigation, and water outcomes. Restoration in agricultural lands, focusing on restoring intactness and improving water management, also shows potentially significant biodiversity benefits. This AI-driven approach can help guide decision-making for cost-effective and synergistic pathways to achieve biodiversity, emissions, and water targets. Effectively aligning these NbS priorities will require coordination at different government levels, including Indigenous governments, and integrating investments from the public and private sectors.

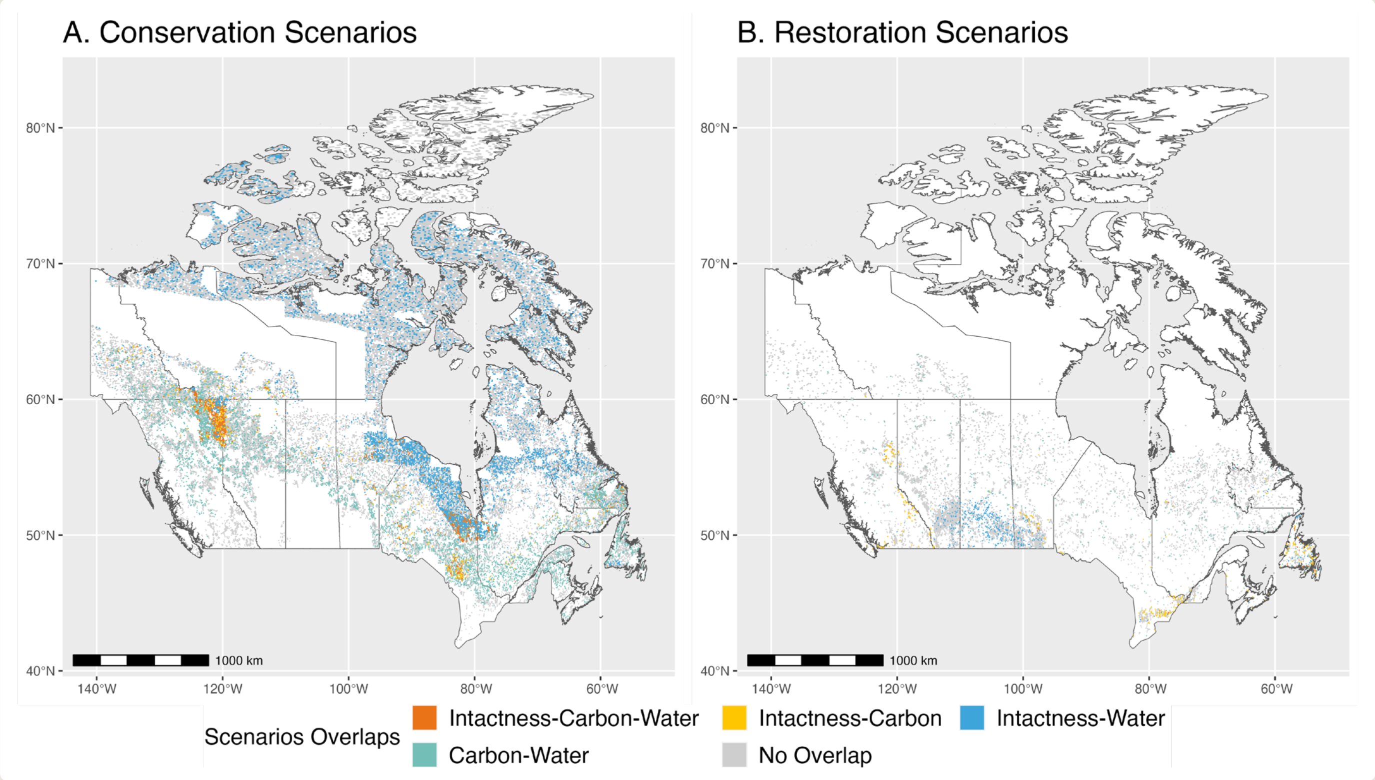

Figure 4: Spatial distribution of conservation and restoration priority scenarios overlaps to align 30x30 targets with co-benefits in Canada.[82]

Advancing science

While much can be done today to enhance the health of ecosystems, many open science questions remain, particularly about how to detect, attribute, and account for ecological changes and evaluate trade-offs. Advancing science in support of practical solutions often requires collaboration across disciplines and sectors. Microsoft works with a wide range of environmental and social scientists, engineers, and sustainability policy practitioners to help build and inform science-based solutions. Here are a couple of examples.

Accounting and reporting. Standards for corporate greenhouse gas accounting have evolved over decades, becoming more rigorous as carbon accounting grows mainstream and mandatory. Despite this progress, many science-based questions remain. Microsoft collaborates with global scientists to advance the science behind carbon accounting. For example, Microsoft partnered with the Stanford University's Woods Institute for the Environment to convene an international team of scientists and practitioners to outline the opportunities and challenges of developing reliable, global greenhouse gas accounting.[83]

A critical question in carbon accounting is the climate value of carbon stored temporarily in nature. Unlike technological solutions like direct air capture and storage (DACS), some nature-based carbon credits are less durable, as stored carbon can be re-released by disturbances like wildfires. This risk of reversal has led some to question the value of these credits, potentially discouraging investment. Microsoft scientists partnered with researchers at Concordia and Simon Fraser universities to model the climate value of low-durability nature-based carbon storage. Their climate models demonstrated that even temporary storage can help reduce peak warming if combined with deep decarbonization.[75] They also proposed a method for integrating temporary nature-based carbon storage into effective climate strategies.[84]

Monitoring and assessment. The Microsoft AI for Good Lab collaborates with governments and universities to help build a better understanding of species distribution and movement using advanced Earth observation and analytics. For example, it has partnered with the US National Oceanographic and Atmospheric Administration (NOAA) to use AI-based tools for accelerating biodiversity surveys and developed algorithms to analyze bioacoustics data,[85,86,87] aiding in the detection of endangered Cook Inlet beluga whales.[88] The team has also collaborated with researchers from around the world to improve understanding of animal behavior, such as the social structures of giraffes in the African savanna.[89] This knowledge is vital for conserving endangered species like the beluga and keystone species like giraffes, which can provide signals of broader ecosystem changes.[90]

While species tracking is improving, understanding biodiversity loss at a global scale remains challenging due to limited coordination and data integration. Global-scale biodiversity monitoring is crucial for conservation. To help address this, Microsoft collaborated with an international team led by researchers from McGill University and GEO BON to outline the needs for a global biodiversity observing system (GBiOS). The proposed system aims to standardize and coordinate monitoring efforts worldwide, guiding effective conservation actions and policies.[91]

Building markets

Building robust nature-based markets that explicitly target the protection and restoration of ecosystem health (and other socio-economic co-benefits) will be crucial for increasing the scale and effectiveness of corporate investments for a thriving natural world. Nature-based markets are at various stages of development. The carbon market is the largest for corporate investors, nature-based water replenishment is still emerging, and biodiversity markets are just beginning to appear.

Most nature-based markets from which corporate investors purchase sustainability credits do not explicitly consider ecosystem health as a factor in the quality of a credit.

The Microsoft Climate Innovation Fund (CIF) is helping to build a robust market for nature-based solutions that enhance ecological health by investing in companies focused on ecosystem measurement, reporting, and verification (see Box 7).

Box 7: Building nature-based markets—regenerative agriculture

Microsoft is catalyzing funding and technical expertise to overcome barriers to nature-positive agriculture with Farmland LP, an investment fund that has converted over 6,000 acres of conventional farmland to organic farmland. Converting conventional farmland to organic farmland can be an important nature-positive action that builds ecosystem health by increasing biodiversity, landscape connectivity, and resilience, and enhanced ecosystem services. Regenerative agricultural practices such as cover cropping, crop rotation, planting hedge and tree rows, and livestock pasturing all increase soil, pollinator, and plant biodiversity. The resulting landscape of diverse hedges, trees, and organic polycultures creates a mosaic of connected habitats and wildlife migration corridors.[92] Different parts of this landscape are resilient to different disturbances such as pests, droughts, and flooding. This ecosystem can provide multiple services—such as aquifer recharge,[93] effective nutrient cycling,[94] and even carbon sequestration and storage[95]—in addition to organic produce.

Farmland LP takes investments from companies like Microsoft to acquire conventional farmland, which is then converted to organic farmland using its technical expertise and regenerative agricultural practices. The properties are managed by a 55-person internal farm management team to ensure long-term sustainability and productivity. Together with the USDA, Delta Institute, and Earth Economics, Farmland LP has valued the ecosystem services provided by its converted organic farmland at $21.4 million over five years; this represents a 7.3% ecosystem service gain on top of a 10.5% net economic gain for investors, annually. The "double bottom line" of organic agriculture scaled by Farmland LP and Microsoft therefore stands to ameliorate historical trade-offs between farmland productivity and ecosystem integrity.

Farmland LP's internal farm management team uses blueberries as a cover crop. (@ Getty Images)

The CIF collaborates with Microsoft teams to understand the factors that constrain the markets for carbon removal and water replenishment and focuses on companies that work to remove those constraints. For example, Microsoft's CDR team recognizes the value of investing in soil health to sequester carbon, safeguard livelihoods, and provide essential nutrients. But quantifying improvements in soil health is difficult and expensive.

To help address these challenges, the CIF invested in companies like Yard Stick PBC, which pairs in-ground measurements with machine learning to quantify soil organic carbon as a key metric of soil health more accurately and affordably than traditional methods (see Box 8). This lowers costs for project developers and provides customers with better insight into credit quality. CIF also invests in companies like Vibrant Planet PBC, which provides AI-enabled services to assess land conditions, mitigate risk, and enhance provision of ecosystem services. The CDR team continues to work with leading soil projects to improve measurement rigor.

Box 8: Improving measurement, reporting, and verification—soil organic carbon

Accurate, comparable measurements of soil organic carbon are a critical metric and first step towards understanding efficacy of some nature-based solutions, such as forest restoration, wetland restoration, and regenerative agriculture.[96] Current protocols for quantifying soil organic carbon are varied and each relies on cumbersome, manual soil collection processes and lengthy laboratory analyses, all with their own biases and uncertainties.[97] Moreover, most have been developed for Northern temperate croplands that are not broadly representative of ecosystems globally. There is a need for a standardized and more efficient approach to soil organic carbon quantification. Microsoft has invested in Yard Stick PBC to do just that.

Yard Stick PBC offers high-quality digital soil organic carbon measurements with a compact and innovative field-based sensor. This sensor uses a spectroscopy camera equipped with a sapphire lens to measure how organic carbon reflects light in soils, correlates this reflectance to concentration, and then stores these geolocated data in the cloud. Yard Stick's approach is 90% less expensive than traditional laboratory methods and has so far been successfully scaled to croplands and rangelands, two globally extensive and vitally important ecosystems. The scaling of this technology will enable users to collect soil organic carbon data, establish baselines, and track the progress of nature-based solutions at a speed, scale, and interoperability never before possible.

Soil organic carbon being measured in the field with Yard Stick's innovative sensor. (© Yard Stick PBC)

Microsoft is also focused on building demand for nature-based credits that prioritize ecosystem health. As a founding member of the Symbiosis Coalition, Microsoft is working with Google, Meta, and Salesforce to scale nature-based climate solutions that align with its own criteria for high-quality CDR by prioritizing five key attributes—ecological integrity, community benefits, durability, conservative accounting, and transparency—while using the members' collective demand to reduce transaction costs and learn how to conduct effective diligence. The Coalition also seeks to integrate new technology and research to better measure outcomes, equitably engage with Indigenous peoples and local communities, and balance carbon sequestration benefits with other environmental co-benefits.

Finally, Microsoft is using its voice to support policies and standards to establish the institutional structures needed for effective nature-based investments. For example, Microsoft engaged on the EU Biodiversity Strategy for 2030 in Europe, advocated for policies such as the Great American Outdoors Act, and provided support for the State of Washington protocols on high-quality nature-based carbon removal.

Lessons for the future

↗

In the coming years, corporate investments in nature are likely to play an increasingly important role in achieving global sustainability goals. To maximize the positive sustainability impact of these investments and avoid potential detrimental effects, several key aspects of nature-based markets and corporate investment structures must evolve. Drawing on Microsoft's practical experience as a corporate investor and on the latest insights from science, we share lessons for the future on what is needed to enable and support companies to maximize the sustainability impacts of their investments in nature.

Lesson 1: Build incentives to invest in ecosystem health

Companies need stronger incentives to prioritize healthy ecosystems in their investments in nature for sustainability.

Sustainability investments that maintain healthy ecosystems or improve the health of degraded ecosystems should be prioritized, and those that invest in unhealthy ecosystems or leave them worse off should be avoided. Yet, ecosystem health is rarely considered explicitly when companies purchase units of nature-based benefits, whether credits for a ton of carbon or a volume of water replenishment. The current accounting system is binary: a unit of credit either has full value or none at all, which means credits are treated as interchangeable commodities. This system incentivizes some companies to choose the cheapest credits, regardless of the ecosystem condition and actual outcomes, and creates a race to the bottom, potentially rewarding projects that undermine ecosystem health.[98,99]

To shift this dynamic, stronger incentives are needed. Reputational risks, physical risks, and emerging market mechanisms are beginning to encourage companies to more fully characterize the sustainability impact of different nature-based investments. Standards are increasingly being used to characterize the social and other environmental co-benefits of carbon credits.[100,101] Frameworks are being developed to credit multiple benefits of NbS by "stacking" or "bundling" credits.[64,102,103] Stacking involves offering multiple credits from the same ecosystem reflecting different services (for example, carbon removal and water replenishment credits from a wetland), while bundling involves offering a single credit that aggregates all ecosystem services.[104] Restoration units have also been proposed as a means of assessing more broadly the value of nature-based carbon credits.[105] Typically, carbon credits that are bundled with biodiversity and community credits are sold for a premium, which in 2023 was $4 per metric ton of carbon dioxide equivalents.[100] Meanwhile, rating agencies are beginning to differentiate carbon credit quality, including other environmental and social co-benefits.[106]

Another option proposed is to shift away from a compensation system that directly ties each credit a company procures to a unit of its residual footprint (for example, a ton of carbon or a volume of water). An alternative to this is a contribution model. In a contribution model applied to climate mitigation, companies contribute to a pool of funds that could support the restoration of healthy ecosystem with the goal of removing carbon dioxide from the atmosphere, rather than claiming direct carbon offset or compensation credits.[107] This is similar to conservation mitigation banking, where companies contribute to a pool of funds that supports broader conservation efforts, such as protection or restoration of a wetland or watershed. Mitigation banks combine scientific expertise, public sector guidelines, and private sector funding to undertake larger projects to protect or restore ecosystem health than are practical for individual compensatory efforts.[108] For example, companies that bear some responsibility for the degradation of rivers across the US Pacific Northwest have contributed funds to largescale watershed restoration efforts that mitigate pollutants, re-establish wetlands, reshape riverbanks, and create habitat.[109,110] Both compensation and contribution models can be effective, but they each depend on the underlying scientific and ecological integrity of the projects that receive investment. Smaller buyers or organizations that lack technical or procurement resourcing to interrogate the quality of nature-based projects may choose to pursue a contribution model to pool their limited financial resources.

Even as new frameworks for more holistic nature-based crediting are emerging, there is still no agreed-upon standard for rewarding companies for nature-based sustainability investments that document positive impacts on the health of ecosystems. Without standards for rewarding companies for credit quality based on ecosystem health, companies will struggle to justify the extra effort and funding needed to consider the broader quality of their investments.

Lesson 2: Agree on science-based standards for the impacts of investments on ecosystem health

Civil society and companies need to collaborate with scientists to agree on standards for characterizing how investments through nature-based markets affect ecosystem health.

There is no broadly accepted standard for characterizing ecosystem health, and little has been done to translate existing science to inform investments. Yet, ecosystem health can determine the quality of the sustainability benefits of nature-based investments. Those investments that are supported by healthy ecosystems are more likely to return the desired sustainability benefits, be less vulnerable to loss (that is, more durable) and trade-offs (such as loss of other benefits), and may provide broader ecosystem and societal benefits. In the carbon and water markets it is often assumed that all units are equivalent, that a carbon credit or unit of volumetric water benefit (VWB) are fungible quantities. But they are not. Depending on their design, location, and implementation, nature-based investments can differ tremendously in the extent to which they deliver intended outcomes,[111] their durability,[41,112] and whether they undermine or offer additional ecosystem and socioeconomic benefits.[113]

Although there is an extensive body of scientific literature on ecosystem health, there is no universally accepted definition[90,91] nor standard for understanding how investments affect ecosystem health. However, guidelines have been developed to help practitioners assess characteristics of ecosystem health, such as Ecosystem Integrity Index,[114] IUCN's Red List of Ecosystems, and the UN System of Environmental Economic Accounting. Common characteristics considered when assessing ecosystem health include resilience, connectivity, functioning of ecological processes, and species composition.

For nature-based solutions, the IUCN developed a global standard, which includes ecosystem health as a key criterion for success.[6] In addition, guidance has been developed by UNEP-WCMC, the Capitals Coalition, and partners to help companies assess ecosystem health or condition in different decision-making contexts and consistently document impacts on ecosystem condition.[115]

These advances and tools have not yet been sufficiently integrated into the corporate nature-based solutions markets. Companies will likely be slow to integrate ecosystem health in their procurement of sustainability credits until broadly accepted standards are adopted.

Lesson 3: Make science accessible and build capacity to use it

The best available science must be accessible and usable to guide corporate investments in nature and reliably assess impacts on ecosystem health and sustainability.

While extensive science exists to guide ecosystem health restoration,[116,117,118] it is not easily accessible to corporate sustainability investors. New tools and initiatives are needed to provide companies with access to the best science-based guidance on where and how to invest in nature for maximum sustainability benefits. Additionally, tools are needed to assess trade-offs, such as when carbon removal projects lead to detrimental unintended consequences for water and biodiversity. Another trade-off occurs when native tree restoration is planned for areas where the soil is bright or often snow-covered. In these areas, although planting dark forests can contribute to biodiversity, it may also lead to a net increase in planet warming by reducing albedo and absorbing heat.[119]

Capacity building is also needed for project developers, buyers, and auditors involved corporate nature-based markets. Successful investments in ecosystem health require these actors to navigate the time-consuming due-diligence process with expertise in local ecology and community needs. Carbon markets already face a shortage of qualified auditors and data managers,[120] and this gap will likely widen as NbS criteria expand to include broader ecosystem health measures. Universities can help close this expertise gap by offering programs, degrees, and certificates in systems thinking, nature and carbon accounting, and social and environmental sciences, such as the Bachelor's of Indigenous Land Stewardship program at the University of British Columbia.

Lesson 4: Accept trade-offs as inevitable and aim to minimize them

Not all ecological and social benefits can be maximized at once, but strategic planning can reduce negative impacts and optimize positive sustainability outcomes.

While some investments in healthy ecosystems can return multiple sustainability benefits, others regularly create trade-offs.[121,122,123,124] Science indicates that healthy ecosystems provide the most robust long-term environmental benefits; however, because there is no single metric defining ecosystem health, a range of ecological conditions could qualify as healthy, and these could vary among different types of ecosystems. Consequently, a company that approaches its nature investments through the lens of enhancing ecosystem health while pursuing a specific sustainability benefit (such as carbon, water, or biodiversity) will likely face trade-offs. For instance, projects that prioritize carbon sequestration might yield lower biodiversity benefits than those explicitly seeking to maximize biodiversity—yet both systems could be characterized as healthy under different definitions.

Trade-offs also arise in species selection. Specifically, plants with fast growth rates are generally less tolerant of stress.[125,126,127] The implication is that focusing on fast-growing species may reduce the forest's overall resilience. This can lead to tensions between achieving long-term ecosystem resilience goals and meeting the immediate community economic needs. For example, while native species are typically preferred for their ecological benefits, fast-growing non-native species can offer important short-term economic and carbon sequestration value. Research suggests that well-designed systems combining native forests with plantations of non-native species can, in some cases, provide both ecological and community benefits.[128,129] Effectively balancing multiple priorities requires assessing trade-offs and identifying ways to optimize benefits, as well as implementing long-term monitoring to ensure objectives are met and unintended consequences are avoided.[15]

Lesson 5: Innovate to de-risk investments

Comprehensive strategies are needed to reduce risks to nature-based investments.

Natural systems are inherently variable, and in many cases, human actions are increasing that variability. Disturbances from weather, pests, diseases, and human activities can undermine the ability of ecosystems to provide the services or goods that people rely on. Risk assessments of corporate nature-based investments are currently in their infancy and are not generally based on rigorous science, especially for carbon credits. Investments that prioritize ecological health tend to be more resilient to disturbances than those narrowly focused on single outcomes;[130] however, these resilience benefits are rarely captured in risk assessments.

A wide range of insurance and public support programs exist to protect people and public infrastructure from natural hazards and provide resources for rebuilding when losses do occur. Similar insurance schemes are emerging for NbS. For example, in Mexico[131] and Hawaii,[132] new insurance products have been created to de-risk investments in coral reef ecosystems. After Hurricane Delta damaged Mexico's Mesoamerican Barrier Reef in 2020, a policy paid $800,000 to expedite reef restoration and recovery, crucial for the coastal businesses and surrounding areas that depend on them.[133]

Insurance is just one tool for de-risking nature-based investments; others are emerging. For example, nature-based carbon storage investments face risks from fires, logging, drought, and pests, which can cause the release of greenhouse gases back to the atmosphere. To mitigate these risks, many investments include a "buffer pool" that provides a backup reserve of carbon storage. However, buffer pools are often too small for the climate and disturbance risks they face[130] and are rarely based on peer-reviewed, systematic risk assessments that consider climate change impacts. A major challenge to determining an adequate buffer pool size is assessing environmental risk (for example, wildfires, sea-level rise, drought, pests, and pathogens) over the 40–100 year timescales required for climate benefits.[63,134] Updating buffer pool methods with rigorous, consistent, and open-source scientific data is urgently needed.

Lesson 6: Expand blended finance

Innovative blended-financing mechanisms are needed to manage high upfront costs and improve long-term returns.

Sustainability investments in nature that prioritize ecosystem health often require greater financial commitment than narrower projects that focus on a single objective. They also require "patient capital"—long-term investments with returns over extended periods. To attract sufficient capital to scale the NbS sector, these investments and the offtake agreements that underpin them should resemble infrastructure projects like renewable energy, transportation systems, and public buildings, which are also commonly funded through blended finance models.

Blended finance strategies, which combine public, private, and philanthropic funds, are increasingly used to finance NbS projects and markets.[107,135,136,137] These strategies can increase total capital by diversifying the investor base, including by attracting lower-risk investors by having higher-risk capital absorb early-stage uncertainties. This additional capital is essential for initiatives that prioritize ecosystem health, which often require more complex and longer-term investments.

Public-private partnerships can expand financing for science-based NbS. An example is the Resilient Landscapes Luxembourg NbS incubator, established by CIFOR-ICRAF in collaboration with the Grand Duchy of Luxembourg through its Resilient Landscapes program. In this partnership, the government provides upfront investments to bridge the maturity gap between grant-funded development initiatives and investment-driven scale-ups. The incubator develops essential elements for bankability, including business models, risk mitigation, and financing strategies. By capitalizing on CIFOR-ICRAF's multidisciplinary expertise, the incubator matures a pipeline of NbS projects into investment-ready deals, offering financial returns to impact-focused investors while ensuring science-based, verifiable social and environmental benefits.

Green bonds can also serve as a blended finance strategy. By issuing green bonds, organizations attract investors seeking both financial returns and environmental impact. For example, a recent World Bank outcome bond raised $225 million for Amazon reforestation, funding efforts to restore ecosystems and enhance biodiversity, and generating carbon credits for sale.[138]

Lesson 7: Invest beyond capital

Capital is crucial for building nature-based markets that advance ecosystem health, but projects and startups also need other types of support to succeed and scale.

For nature-based markets to enhance ecosystem health, multiple factors must align. Companies can be powerful partners beyond their initial investments. For example, by collaborating with technology companies, nature-based project practitioners can accelerate innovation, learning, and development. Partnering on go-to-market strategies and knowledge sharing can help startups navigate market entry and expansion, aligning their products with market needs. For example, Microsoft publishes its criteria for high-quality carbon removal and lessons learned for carbon and water projects,[139] which helps facilitate market development of high-quality NbS.

Another challenge where corporate investors can help is signaling demand for supply of diverse native-species planting material through their long-term support for habitat restoration. According to the Global Tree Assessment, approximately 30% of the 60,000 known tree species are threatened with extinction.[140] Insufficient investment and a broken chain in tree seed and seedling systems hinder the availability of quality planting material. Addressing these constraints through partnerships and investments in nature can signal the demand for a reliable supply of high-quality planting materials, critical for successful restoration projects.

Lesson 8: Use AI for speed, scale, and reliability

AI technologies can help companies prioritize ecosystem health in their sustainability investments by enabling cheaper and more effective measurement, trade-off analysis, and risk management.

Reliable and cost-effective measurement, reporting, and verification (MRV) are essential for the success and scalability of nature-based solutions. Traditional MRV methods for ecosystem health and nature-based credits are often manual and resource-intensive. AI offers transformative tools for tackling these challenges. By automating the collection and analysis of vast data from various sources, AI can significantly reduce the time and cost of MRV. AI can integrate data from soil and water sensors, camera traps, bioacoustics, and Earth observations to identify patterns and changes in ecosystem conditions, such as vegetation cover, carbon stocks, and biodiversity, with increasing accuracy.

Beyond MRV, AI can revolutionize decision-making by providing insights into complex trade-offs. By analyzing a wide array of datasets, AI models can identify potential synergies and conflicts among different ecosystem services, helping stakeholders make informed choices. For example, AI can help determine the optimal location for a reforestation project by considering factors such as carbon sequestration potential, biodiversity benefits, albedo and other climate impacts, and local community needs.

Recent advances in AI are also enhancing risk management. Risk assessment for NbS should aim for high spatial and temporal resolution aligned with the claims made by the investing company. Open-source, transparent, and easily accessible tools are critical for widespread adoption of AI for enhanced risk assessment.

The combination of AI and Earth observation technologies have improved prediction of weather-related risks at the timescale of weeks to months.[141] Longer-term climate forecasts are also improving, which could support more robust longer-term risk assessments (such as 10–50 years).[141,142,143] Targeted efforts are needed to combine new analytics tools with traditional process-based models to better characterize risk to NbS based on risk type, ecosystem type, and the health of the ecosystems where NbS projects are implemented.

Authors

Amy Luers, Ph.D.
Senior Global Director, Sustainability Science & Innovation, Microsoft

Heather Tallis, Ph.D.
Senior Fellow, Center for Coastal Climate Resilience, University of California at Santa Cruz

William Anderegg, Ph.D.
Professor & Director, Wilkes Center for Climate Science & Policy University of Utah

Erika Basham
Director Investments & Product Strategy, Microsoft

Libby Blanchard, Ph.D.
Postdoctoral Fellow, Wilkes Center for Climate Science & Policy University of Utah

Kaitlin Chuzi
Director, Integrated Technology & Biomimicry, Microsoft

Paulina Concha-Larrauri
Program Manager, Water Positive, Microsoft

Annie Guo
Senior Program Manager, Carbon Dioxide Removal, Microsoft

Allen Kim
Director, AI for Good, Microsoft

Damon Matthews, Ph.D.
Professor and Research Chair, Climate Science & Sustainability, Concordia University

Benjamin Miller, Ph.D.
Sustainability Scientist, Sustainability Science & Innovation, Microsoft

Camilo Alejo, Ph.D.
Postdoctoral Fellow, Climate Science & Sustainability, Concordia University

Eliza Roberts
Director, Water Positive, Microsoft

Katie Sierkes
Program Manager, Carbon Dioxide Removal, Microsoft

Eliane Ubalijoro, Ph.D.
Chief Executive Officer, CIFOR-ICRAF

Glossary

The following definitions are derived from the glossary of the Intergovernmental Panel of Biodiversity and Ecosystem Services.[3]

Biodiversity: Diversity within species, among species, and among ecosystems. Includes species diversity, ecological diversity, and genetic diversity.

- Species diversity: Variation in species, including their relative abundances.
- Ecological diversity: Variation in habitats, resource utilization, and species interactions.
- Genetic diversity: Variation in individual genes, allowing for adaptation to different or changing environments.

Circular economy: A regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling.

Ecological processes: The physical or biological processes that link organisms to their environments.

Ecosystem: Living organisms and non-living components of nature, all interacting as a system.

Ecosystem health: The extent to which an ecosystem supports and maintains native populations of species and key ecological processes such as energy flow, nutrient cycling, and organic matter movement. Ecosystem health underpins ecosystem services including pollination, water purification, and heat risk reduction. Ecosystem health is also known as ecosystem integrity or ecosystem functioning.

Ecosystem degradation: A long-term reduction in an ecosystem's structure, functionality, or capacity to provide benefits to people.

Ecosystem restoration: Policies and practices that are necessarily focused on recovery of a self-sustaining living system characteristic of past or least-disturbed landscapes.

Ecosystem service: A service that is provided by an ecosystem as an intrinsic property of its functionality (such as pollination, nutrient cycling, nitrogen fixation, fruit and seed dispersal).

Nature: All things and processes not made by humans.

Nature-based solutions: Actions that are taken to protect, manage, or restore natural or modified ecosystems in ways that address societal challenges.

Resilience: The level of disturbance that an ecosystem or society can undergo without crossing a threshold to a situation with different structure or outputs.

References

1. Brondizio, E.S., Settele, J., Díaz, S., & Ngo, H. T., eds. *Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. IPBES secretariat, Bonn, Germany (2019). https://doi.org/10.5281/zenodo.3831673.
2. Protecting Nature Could Avert Global Economy Losses of $2.7 Trillion Per Year. World Bank Group. https://www.worldbank.org/en/news/press-release/2021/07/01/protecting-nature-could-avert-global-economic-losses-of-usd2-7-trillion-per-year (2021).
3. Glossary. IPBES. https://www.ipbes.net/glossary (2022).
4. *State of Finance for Nature 2022*. UN Environment Programme. https://www.unep.org/resources/state-finance-nature-2022 (2022).
5. *State of Finance for Nature 2023*. UN Environment Programme. https://www.unep.org/resources/state-finance-nature-2023 (2023).
6. Private Funders of the New 'Protecting Our Planet Challenge' Announce $5 Billion Commitment to Protect and Conserve 30% of Planet by 2030. Bloomberg Philanthropies. https://www.bloomberg.org/press/private-funders-of-the-new-protecting-our-planet-challenge-announce-5-billion-commitment-to-protect-and-conserve-30-of-planet-by-2030/ (2021).
7. G20 leadership required to catalyze private capital inflow for nature-based solutions. UN Environment Programme. https://www.unep.org/news-and-stories/press-release/g20-leadership-required-catalyze-private-capital-inflow-nature-based (2022).
8. Climate Solutions Partnership: Nature-based Solutions (NBS). World Resources Institute. https://www.wri.org/initiatives/climate-solutions-partnership/nature-based-solutions.
9. Tollefson, J. Humans are driving one million species to extinction. *Nature* **569**, 171–171 (2019).
10. Hubau, W. *et al.* Asynchronous carbon sink saturation in African and Amazonian tropical forests. *Nature* **579**, 80–87 (2020).
11. Friedlingstein, P. *et al.* Global Carbon Budget 2023. *Earth Syst. Sci. Data* **15**, 5301–5369 (2023).
12. Dicks, L. V. *et al.* A global-scale expert assessment of drivers and risks associated with pollinator decline. *Nat. Ecol. Evol.* **5**, 1453–1461 (2021).
13. Peixoto, R.S. *et al.* Harnessing the microbiome to prevent global biodiversity loss. *Nat. Microbiol.* **7**, 1726–1735 (2022).
14. Erisman, J. *et al.* How a century of ammonia synthesis changed the world. *Nature Geosci.* **1**, 636–639 (2008).
15. IUCN Global Standard for Nature-based Solutions: first edition. IUCN. https://doi.org/10.2305/IUCN.CH.2020.08.en (2020).
16. Shukla, P.R. *et. al.*, eds. *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press,

Cambridge, UK and New York, NY, USA (2022). doi: 10.1017/9781009157926.001. https://www.ipcc.ch/report/ar6/wg3/.

17. Sanderman, J., Hengl, T. & Fiske, G. J. Soil carbon debt of 12,000 years of human land use. *Proc. Natl. Acad. Sci.* **114**, 9575–9580 (2017).

18. Griscom, B. W. *et al*. Natural climate solutions. *Proc. Natl. Acad. Sci.* **114**, 11645–11650 (2017).

19. *The United Nations World Water Development Report 2023: partnerships and cooperation for water; executive summary*. UNESCO World Water Assessment Programme. https://unesdoc.unesco.org/ark:/48223/pf0000384657 (2023).

20. Abell, R., *et al*. *Beyond the Source: The Environmental, Economic and Community Benefits of Source Water Protection*. The Nature Conservancy, Arlington, VA, USA (2017). https://www.nature.org/content/dam/tnc/nature/en/documents/Beyond_The_Source_Full_Report_FinalV4.pdf.

21. Greenwood, E., *et al*. Mapping safe drinking water use in low- and middle-income countries. *Science* **385**, 784-790 (2024). doi:10.1126/science.adh9578.

22. *Progress on Household Drinking Water, Sanitation and Hygiene 2000-2017—Special focus on Inequalities*. U.N. Children's Fund and World Health Organization. https://www.who.int/publications/i/item/9789241516235 (2019).

23. Medellín shows how nature-based solutions can keep people and planet cool. UN Environment Programme. https://www.unep.org/news-and-stories/story/medellin-shows-how-nature-based-solutions-can-keep-people-and-planet-cool (2019).

24. Hamel, P. *et al*. Mapping the benefits of nature in cities with the InVEST software. *Npj. Urban Sustain.* **1**, 1–9 (2021).

25. Holden, P. B. *et al*. Nature-based solutions in mountain catchments reduce impact of anthropogenic climate change on drought streamflow. *Commun. Earth Environ.* **3**, 1–12 (2022).

26. *Water replenishment: Our learnings on the journey to water positive*. Microsoft. https://aka.ms/MicrosoftWaterReplenishment (2023).

27. *Nature Risk Rising: Why the Crisis Engulfing Nature Matters for Business and the Economy*. World Economic Forum. https://www.weforum.org/publications/new-nature-economy-report-series/nature-risk-rising/ (2020).

28. Queiroz, C. *et al*. Investment in resilient food systems in the most vulnerable and fragile regions is critical. *Nat. Food* **2**, 546–551 (2021).

29. Johnson, J.A. *et al*. *The Economic Case for Nature—A Global Earth-economy Model to Assess Development Policy Pathways*. World Bank Group. https://www.worldbank.org/en/topic/environment/publication/the-economic-case-for-nature (2021).

30. Lewsey, F. Dasgupta Review: Nature's value must be included in economics to preserve biodiversity. University of Cambridge. https://www.cam.ac.uk/stories/dasguptareview (2021).

31. Everard, M., Johnston, P., Santillo, D. & Staddon, C. The role of ecosystems in mitigation and management of Covid-19 and other zoonoses. *Environ. Sci. Policy* **111**, 7–17 (2020).

32. Lawler, O. K. *et al*. The COVID-19 pandemic is intricately linked to biodiversity loss and ecosystem health. *Lancet Planet. Health* **5**, e840–e850 (2021).

33. Vicarelli, M. *et al*. On the cost-effectiveness of Nature-based Solutions for reducing disaster risk. *Sci. Total Environ.* **947**, 174524 (2024).

34. Vigerstol K., Karres, N., Kang, S., Lilly, N., & Massey-Bierman, M. *Accelerating Adaptation: the promise and limitations of Nature-based Solutions in the race to adapt to increasing floods and droughts*. The Nature Conservancy, Arlington, VA, USA (2023). https://www.nature.org/en-us/what-we-do/our-insights/perspectives/accelerating-adaptation-nature-based-solutions/.

35. Pimm, S. L. *et al*. The biodiversity of species and their rates of extinction, distribution, and protection. *Science* **344**, 1246752 (2014).

36. Ghisbain, G. *et al*. Projected decline in European bumblebee populations in the twenty-first century. *Nature* **628**, 337–341 (2024).

37. Kazenel, M. R., Wright, K. W., Griswold, T., Whitney, K. D. & Rudgers, J. A. Heat and desiccation tolerances predict bee abundance under climate change. *Nature* **628**, 342–348 (2024).

38. Klein, A-M. *et al*. Importance of pollinators in changing landscapes for world crops. *Proc. R. Soc. B.* **274**, 303–313 (2006). doi:10.1098/rspb.2006.3721.

39. Aizen, M. A. *et al*. Global agricultural productivity is threatened by increasing pollinator dependence without a parallel increase in crop diversification. *Glob. Change Biol.* **25**, 3516–3527 (2019).

40. Liang, J. *et al*. Positive biodiversity-productivity relationship predominant in global forests. *Science* **354**, aaf8957 (2016).

41. Anderegg, W. R. L. *et al*. Climate-driven risks to the climate mitigation potential of forests. *Science* **368**, eaaz7005 (2020).

42. Sukhdev, P. *et al*. *Mainstreaming the Economics of Nature: A Synthesis of the Approach, Conclusions and Recommendations of Teeb*. UN Environment Programme, Geneva (2010). https://www.unep.org/resources/report/economics-ecosystems-and-biodiversity-mainstreaming-economics-nature-synthesis.

43. Heilmayr, R., Echeverría, C. & Lambin, E. F. Impacts of Chilean forest subsidies on forest cover, carbon and biodiversity. *Nat. Sustain.* **3**, 701–709 (2020).

44. Feng, Y. *et al*. Multispecies forest plantations outyield monocultures across a broad range of conditions. *Science* **376**, 865–868 (2022).

45. Seddon, N. Harnessing the potential of nature-based solutions for mitigating and adapting to climate change. *Science* **376**, 1410–1416 (2022).

46. Brancalion, P. H. S. & Holl, K. D. Guidance for successful tree planting initiatives. *J. Appl. Ecol.* **57**, 2349–2361 (2020).

47. Caunda, M. J. Recultivating and embracing Philippine Native Trees over Exotic species. *Cebu Daily News*. https://cebudailynews.inquirer.net/569584/recultivating-and-embracing-philippine-native-trees-over-exotic-species (2024).

48. Journal, B. A glimpse to botanical garden: Case study in the environment and ecological niche of molave tree. *BOHR Publ.* (2023).

49. Moyano, J. *et al.* Unintended consequences of planting native and non-native trees in treeless ecosystems to mitigate climate change. *Journal of Ecology* **00**, 1-12 (2024).

50. Veldman, J. W. *et al.* Where Tree Planting and Forest Expansion are Bad for Biodiversity and Ecosystem Services. *BioScience* **65**, 1011–1018 (2015).

51. Aguirre-Gutiérrez, J., Stevens, N. & Berenguer, E. Valuing the functionality of tropical ecosystems beyond carbon. *Trends Ecol. Evol.* **38**, 1109–1111 (2023).

52. Weiskopf, S. R. *et al.* Biodiversity loss reduces global terrestrial carbon storage. *Nat. Commun.* **15**, 4354 (2024).

53. Isbell, F. *et al.* Biodiversity increases the resistance of ecosystem productivity to climate extremes. *Nature* **526**, 574–577 (2015).

54. Oliver, T. H. *et al.* Declining resilience of ecosystem functions under biodiversity loss. *Nat. Commun.* **6**, 10122 (2015).

55. McLauchlan, K. K. *et al.* Fire as a fundamental ecological process: Research advances and frontiers. *J. Ecol.* **108**, 2047–2069 (2020).

56. Thorogood, R. *et al.* Understanding and applying biological resilience, from genes to ecosystems. *Npj. Biodivers.* **2**, 1–13 (2023).

57. Noon, M. L. *et al.* Mapping the irrecoverable carbon in Earth's ecosystems. *Nat. Sustain.* **5**, 37–46 (2022).

58. Sze, J. S., Carrasco, L. R., Childs, D. & Edwards, D. P. Reduced deforestation and degradation in Indigenous Lands pan-tropically. *Nat. Sustain.* **5**, 123–130 (2022).

59. Cottrell, C. Avoiding a new era in biopiracy: Including indigenous and local knowledge in nature-based solutions to climate change. *Environ. Sci. Policy* **135**, 162–168 (2022).

60. Vogel, B., Yumagulova, L., McBean, G. & Charles Norris, K. A. Indigenous-Led Nature-Based Solutions for the Climate Crisis: Insights from Canada. *Sustainability* **14**, 6725 (2022).

61. *Nature-based Climate Solutions for the Voluntary Carbon Market—An Investor Guide for Corporates and Financial Institutions*. Natural Climate Solutions Alliance. https://www.wbcsd.org/resources/natural-climate-solutions-for-the-voluntary-carbon-market-an-investor-guide-for-companies-and-financial-institutions/ (2024).

62. *Delivering Nature-based Solution Outcomes by Addressing Policy, Institutional and Monitoring Gaps in Forest and Landscape Restoration*. Kenya-U.K. Pact, CIFOR-ICRAF, World Agroforestry, U.N. Food and Agricultural Organization, Africa Wildlife Foundation. https://www.cifor-icraf.org/nature-based-solution-for-forest-and-landscape-restoration/ (2023).

63. Anderegg, W. R. L. *et al.* A climate risk analysis of Earth's forests in the 21st century. *Science* **377**, 1099–1103 (2022).

64. Brill, G. *et al. Benefit Accounting of Nature-Based Solutions for Watersheds: Guide*. United Nations CEO Water Mandate and Pacific Institute, Oakland, California (2021). https://pacinst.org/publication/benefit-accounting-nbs-guide/.

65. Historic Centre of Mexico City and Xochimilco. UNESCO World Heritage Convention. https://whc.unesco.org/en/list/412/.

66. Wagner, J., Mega, E. R., Sengupta, S. & Rodríguez, C. Mexico City Has Long Thirsted for Water. The Crisis Is Worsening. *The New York Times* (2024). https://www.nytimes.com/2024/05/18/world/americas/mexico-city-water.html.

67. Vance, E. Biology's beloved amphibian—the axolotl—is racing towards extinction. *Nature* **551**, 286–289 (2017).

68. Meli, P., Benayas, J. M. R., Balvanera, P. & Ramos, M. M. Restoration Enhances Wetland Biodiversity and Ecosystem Service Supply, but Results Are Context-Dependent: A Meta-Analysis. *PLOS ONE* **9**, e93507 (2014).

69. Lal, R. Carbon sequestration. *Philos. Trans. R. Soc. B Biol. Sci.* **363**, 815–830 (2007).

70. Kayranli, B., Scholz, M., Mustafa, A. & Hedmark, Å. Carbon Storage and Fluxes within Freshwater Wetlands: a Critical Review. *Wetlands* **30**, 111–124 (2010).

71. Nahlik, A. M. & Fennessy, M. S. Carbon storage in US wetlands. *Nat. Commun.* **7**, 13835 (2016).

72. Mitsch, W. J., Gosselink, J. G., Zhang, L., & Anderson, C. J. *Wetland Ecosystems*. John Wiley & Sons (2009). https://www.wiley.com/en-us/Wetland+Ecosystems-p-9780470286302.

73. Ribeiro, M. C., Metzger, J. P., Martensen, A. C., Ponzoni, F. J. & Hirota, M. M. The Brazilian Atlantic Forest: How much is left, and how is the remaining forest distributed? Implications for conservation. *Biol. Conserv.* **142**, 1141–1153 (2009).

74. Morales, M. Inside Microsoft's Panama tropical forest carbon offtake deal. *Trellis*. https://trellis.net/article/inside-microsofts-panama-tropical-forest-carbon-offtake-deal/ (2024).

75. Matthews, H. D. *et al*. Temporary nature-based carbon removal can lower peak warming in a well-below 2 °C scenario. *Commun. Earth Environ.* **3**, 65 (2022). https://doi.org/10.1038/s43247-022-00391-z.

76. *Microsoft Carbon Removal—Observations from our third year*. Microsoft. https://aka.ms/FY23CarbonRemovalLessonsLearned (2023).

77. re.green signs a landmark forest restoration project with Microsoft. re.green. https://re.green/en/historias/re-green-signs-a-landmark-forest-restoration-project-with-microsoft/ (2024).

78. Novick, K. A. *et al*. We need a solid scientific basis for nature-based climate solutions in the United States. *Proc. Natl. Acad. Sci.* **121**, e2318505121 (2024).

79. Mori, A. S. *et al*. Biodiversity–productivity relationships are key to nature-based climate solutions. *Nat. Clim. Change* **11**, 543–550 (2021).

80. Hernandez, A. *et al*. Pytorch-Wildlife: A Collaborative Deep Learning Framework for Conservation. Preprint at http://arxiv.org/abs/2405.12930 (2024).

81. AI may hold a key to the preservation of the Amazon rainforest. Microsoft. https://news.microsoft.com/source/latam/features/ai/amazon-ai-rainforest-deforestation/?lang=en (2023).

82. Alejo. Prioritizing Nature-based Solutions through Reinforcement Learning to align Canada's 30x30 targets with climate and water co-benefits. In prep.

83. Luers, A. et al. Make greenhouse-gas accounting reliable — build interoperable systems. *Nature* **607**, 653–656 (2022).

84. Matthews, H. D. *et al.* Temporary nature-based carbon removal can lower peak warming in a well-below 2 °C scenario. *Commun. Earth Environ.* **3**, 1–8 (2022).

85. Robinson, C., Ortiz, A., Hughey, L., Stabach, J. A. & Ferres, J. M. L. Detecting Cattle and Elk in the Wild from Space. Preprint at http://arxiv.org/abs/2106.15448 (2021).

86. Zhong, M. *et al.* Acoustic detection of regionally rare bird species through deep convolutional neural networks. *Ecol. Inform.* **64**, 101333 (2021).

87. Khan, C. B. *et al.* A Biologist's Guide to the Galaxy: Leveraging Artificial Intelligence and Very High-Resolution Satellite Imagery to Monitor Marine Mammals from Space. *J. Mar. Sci. Eng.* **11**, 595 (2023).

88. Zhong, M. *et al.* Beluga whale acoustic signal classification using deep learning neural network models. *J. Acoust. Soc. Am.* **147**, 1834–1841 (2020).

89. Lavista Ferres, J. M. *et al.* Social connectedness and movements among communities of giraffes vary by sex and age class. *Anim. Behav.* **180**, 315–328 (2021).

90. Lee, D. E. & Bond, M. L. Precision, accuracy, and costs of survey methods for giraffe *Giraffa camelopardalis*. *J. Mammal.* **97**, 940–948 (2016).

91. Gonzalez, A. *et al.* A global biodiversity observing system to unite monitoring and guide action. *Nat. Ecol. Evol.* **7**, 1947–1952 (2023).

92. Can farming in wildlife corridors benefit people and biodiversity? World Wildlife Fund. https://www.worldwildlife.org/stories/can-farming-in-wildlife-corridors-benefit-people-and-biodiversity (2023).

93. Grinshpan, M., Furman, A., Dahlke, H. E., Raveh, E. & Weisbrod, N. From managed aquifer recharge to soil aquifer treatment on agricultural soils: Concepts and challenges. *Agric. Water Manag.* **255**, 106991 (2021).

94. Wood, S. A. *et al.* Functional traits in agriculture: agrobiodiversity and ecosystem services. *Trends Ecol. Evol.* **30**, 531–539 (2015).

95. Yang, Y., Tilman, D., Furey, G. & Lehman, C. Soil carbon sequestration accelerated by restoration of grassland biodiversity. *Nat. Commun.* **10**, 718 (2019).

96. Bossio, D. A. *et al.* The role of soil carbon in natural climate solutions. *Nat. Sustain.* **3**, 391–398 (2020).

97. Davis, M. R. *et al.* Review of Soil Organic Carbon Measurement Protocols: A US and Brazil Comparison and Recommendation. *Sustainability* **10**, 53 (2018).

98. Swinfield, T., Shrikanth, S., Bull, J. W., Madhavapeddy, A. & zu Ermgassen, S. O. S. E. Nature-based credit markets at a crossroads. *Nat. Sustain.* (2024) https://doi.org/10.1038/s41893-024-01403-w.

99. Trencher, G., Nick, S., Carlson, J. & Johnson, M. Demand for low-quality offsets by major companies undermines climate integrity of the voluntary carbon market. *Nat. Commun.* **15**, 6863 (2024).

100. *2023 State of the Voluntary Carbon Markets Report*. Ecosystem Marketplace. https://www.ecosystemmarketplace.com/publications/state-of-the-voluntary-carbon-market-report-2023/ (2023).

101. Delacote, P. *et al.* Strong transparency required for carbon credit mechanisms. *Nat. Sustain.* **7**, 706–713 (2024).

102. *Innovative Finance for Nature and People*. Global Environment Facility. https://www.thegef.org/newsroom/publications/innovative-finance-nature-and-people (2023).

103. von Hase, A. & Cassin, J. *Theory and Practice of 'Stacking' and 'Bundling' Ecosystem Goods and Services: a Resource Paper*. Business and Biodiversity Offsets Programme (BBOP). Forest Trends, Washington, D.C. (2018). https://www.forest-trends.org/bbop_pubs/stacking_and_bundling/.

104. Robertson, M. *et al*. Stacking ecosystem services. *Front. Ecol. Environ.* **12**, 186–193 (2014).

105. Raynaud, P. & Sorret, T. *Standard for Global Restoration Efforts*. Ecosystem Restoration Standard. https://docs.ers.org/programme-v1.1.pdf (2024).

106. Faecks, B. & Dufrasne, G. *Rating the raters: Assessing the quality of carbon credit rating agencies*. Carbon Market Watch. https://carbonmarketwatch.org/publications/rating-the-raters-assessing-carbon-credit-rating-agencies/ (2023).

107. Blanchard, L.A. *et al*. Funding forests' climate potential without carbon offsets. *One Earth* **7** (7), P1147-1150 (2024).

108. Section 404 of the Clean Water Act: Federal Guidance for the Establishment, Use and Operation of Mitigation Banks. US EPA. https://www.epa.gov/cwa-404/federal-guidance-establishment-use-and-operation-mitigation-banks-0 (2015).

109. Innovative Partnerships Fast Track Polluted Portland Harbor Toward Restoration. NOAA Fisheries. https://www.fisheries.noaa.gov/feature-story/innovative-partnerships-fast-track-polluted-portland-harbor-toward-restoration (2022).

110. Coweeman River Wetland and Conservation Bank. State of Washington Department of Ecology. https://ecology.wa.gov/Water-Shorelines/Wetlands/Mitigation/Wetland-mitigation-banking/Mitigation-bank-projects/Coweeman-River.

111. West, T. A. P. *et al*. Action needed to make carbon offsets from forest conservation work for climate change mitigation. *Science* **381**, 873–877 (2023).

112. Kirschbaum, M. U. F. Temporary Carbon Sequestration Cannot Prevent Climate Change. *Mitig. Adapt. Strateg. Glob. Change* **11**, 1151–1164 (2006).

113. zu Ermgassen, S. O. S. E. *et al*. Evaluating the impact of biodiversity offsetting on native vegetation. *Glob. Change Biol.* **29**, 4397–4411 (2023).

114. Hill, S. L. L. *et al*. The Ecosystem Integrity Index: a novel measure of terrestrial ecosystem integrity with global coverage. 2022.08.21.504707 Preprint at https://doi.org/10.1101/2022.08.21.504707 (2022).

115. *Measuring Ecosystem Condition - A Primer for Business*. Capitals Coalition. https://capitalscoalition.org/publication/measuring-ecosystem-condition-a-primer-for-business/.

116. Lu, Y. *et al*. Ecosystem health towards sustainability. *Ecosyst. Health Sustain.* **1**, 1–15 (2015).

117. Hernández-Blanco, M. *et al*. Ecosystem health, ecosystem services, and the well-being of humans and the rest of nature. *Glob. Change Biol.* **28**, 5027–5040 (2022).

118. Strassburg, B. B. N. *et al*. Global priority areas for ecosystem restoration. *Nature* **586**, 724–729 (2020).

119. Hasler, N. *et al.* Accounting for albedo change to identify climate-positive tree cover restoration. *Nat. Commun.* **15**, 2275 (2024).

120. *Scaling Voluntary Carbon Markets: A Playbook for Corporate Action*. World Economic Forum. https://www.weforum.org/publications/scaling-voluntary-carbon-markets-a-playbook-for-corporate-action/ (2023).

121. Parrotta, J., Mansourian, S., Grima, N. & Wildburger, C., eds. Forests, Climate, Biodiversity and People: Assessing a Decade of REDD+. *IUFRO World Series* **40**. International Union of Forest Research Organizations, Vienna (2022). https://www.iufro.org/news/article/2022/05/04/world-series-vol-40-forests-climate-biodiversity-and-people-assessing-a-decade-of-redd/

122. Hajjar, R. *et al.* A global analysis of the social and environmental outcomes of community forests. *Nat. Sustain.* **4**, 216–224 (2021).

123. Chaplin-Kramer, R. *et al.* Mapping the planet's critical natural assets. *Nat. Ecol. Evol.* **7**, 51–61 (2022).

124. Yirdaw, E., Kanninen, M. & Monge, A. Synergies and Trade-Offs between Biodiversity and Carbon in Ecological Compensation. *Sustainability* **15**, 11930 (2023).

125. Wright, I. J. *et al.* The worldwide leaf economics spectrum. *Nature* **428**, 821–827 (2004).

126. Reich, P. B. The world-wide 'fast–slow' plant economics spectrum: a traits manifesto. *J. Ecol.* **102**, 275–301 (2014).

127. Díaz, S. *et al.* The global spectrum of plant form and function. *Nature* **529**, 167–171 (2016).

128. Paul, K. I. *et al.* Managing reforestation to sequester carbon, increase biodiversity potential and minimize loss of agricultural land. *Land Use Policy* **51**, 135–149 (2016).

129. Brancalion, P. H. S. *et al.* Exotic eucalypts: From demonized trees to allies of tropical forest restoration? *J. Appl. Ecol.* **57**, 55–66 (2020).

130. Lewis, S. L., Wheeler, C. E., Mitchard, E. T. A. & Koch, A. Restoring natural forests is the best way to remove atmospheric carbon. *Nature* **568**, 25–28 (2019).

131. Scotti, V. Mexico's Mesoamerican Barrier Reef is now being protected with insurance - here's how. World Economic Forum. https://www.weforum.org/agenda/2021/09/mesoamerican-coral-reef-mexico-using-insurance-to-protect-ecosystem/ (2021).

132. Major Upgrade to First U.S. Coral Reef Insurance Policy Increases Coverage and Enables More Robust Post-Storm Response. The Nature Conservancy. https://www.nature.org/en-us/newsroom/upgrade-to-first-us-coral-reef-insurance-policy/ (2024).

133. Swiss Re: Insuring Natural Capital to Protect Ecosystems and Communities. The Nature Conservancy. https://www.nature.org/en-us/about-us/who-we-are/how-we-work/working-with-companies/companies-investing-in-nature1/swiss-re/.

134. Badgley, G. *et al.* California's forest carbon offsets buffer pool is severely undercapitalized. *Front. For. Glob. Change* **5**, (2022).

135. Wu, C. *et al.* Uncertainty in US forest carbon storage potential due to climate risks. *Nat. Geosci.* **16**, 422–429 (2023).

136. Lankes, H. P. *Blended finance for scaling up climate and nature investments: Report of the One Planet Lab*. Grantham Research Institute on Climate Change and the Environment, London, England, UK (2021). https://www.lse.ac.uk/granthaminstitute/publication/blended-finance-for-scaling-up-climate-and-nature-investments/.

137. Allen, I. & Mulyana, F. Blended financing for carbon projects with great social impact. PricewaterhouseCoopers. https://www.pwc.com/id/en/media-centre/pwc-in-news/2024/english/blended-financing-for-carbon-projects-with-great-social-impact.html (2024).

138. New Model for Conservation Finance to Accelerate Reforestation Efforts in the Amazon. World Bank Group. https://www.worldbank.org/en/news/feature/2024/08/12/new-model-for-conservation-finance-to-accelerate-reforestation-efforts-in-the-amazon (2024).

139. *Criteria for High-quality Carbon Dioxide Removal—2024 Edition*. Microsoft. https://query.prod.cms.rt.microsoft.com/cms/api/am/binary/RWGG6f (2024).

140. *State of the World's Trees*. Botanic Gardens Conservation International. https://www.bgci.org/resources/bgci-tools-and-resources/state-of-the-worlds-trees/ (2021).

141. Lam, R. *et al*. Learning skillful medium-range global weather forecasting. *Science* **382**, 1416–1421 (2023).

142. Wong, C. DeepMind AI accurately forecasts weather—on a desktop computer. *Nature* (2023) https://doi.org/10.1038/d41586-023-03552-y.

143. Kochkov, D. *et al*. Neural general circulation models for weather and climate. *Nature* **632**, 1060-1066 (2024)