Environmental and Resource Economics (2022) 83:911–935
https://doi.org/10.1007/s10640-022-00658-1

# The Policy Implications of the Dasgupta Review: Land Use Change and Biodiversity

## Invited Paper for the Special Issue on "The Economics of Biodiversity: Building on the Dasgupta Review" in *Environmental and Resource Economics*

**Edward B. Barbier**[1]

Accepted: 6 February 2022 / Published online: 19 April 2022


**Abstract**
The "Dasgupta Review" of the economics of biodiversity (Dasgupta 2021) identifies many factors that threaten the ecological sustainability of our economies. This article examines how two policy failures - the *underpricing* and *underfunding* of nature – influence global land use change and terrestrial biodiversity loss. If natural areas are priced too cheaply, then converting them to agriculture, forestry and other land uses is less costly than protecting or preserving habitats. Underfunding nature further reduces the incentives for conservation and restoration. The current global funding gap for biodiversity is just under $900 billion annually, and especially impacts developing countries. Ending the underpricing of natural landscape requires removing environmentally harmful subsidies and adopting policies that place an additional cost on the use of land and natural resources or on pollution. Overcoming the funding gap means expanding public and private sources of financing nature, particularly for poorer countries, such as biodiversity offsets, payments for ecosystem services, debt-for-nature swaps, green bonds, sustainable supply chains and international environmental agreements. Using the example of peatlands, the article shows how such a comprehensive global strategy can be built.

**Keywords** Biodiversity · Climate change · Dasgupta review · Ecosystem services · Land use change · Natural capital · Nature-based solutions · Tropical forests

**JEL classification** Q51 · Q54 · Q57

✉ Edward B. Barbier
Edward.barbier@colostate.edu

[1] Department of Economics, Colorado State University, 80523-1771 Fort Collins, CO, USA

## 1 Introduction

Underlying the "Dasgupta Review" of the economics of biodiversity (Dasgupta 2021) is a fundamental policy message. Averting the global biodiversity crisis will require humankind to rethink the relationship between economy and nature. Or, as Sir Partha notes in the Headline Messages accompanying his Review:

> "The solution starts with understanding and accepting a simple truth: our economies are embedded within Nature, not external to it."[1]

Unfortunately, as the Dasgupta Review documents, our economies continue to treat nature not only as an "external" source of resource stocks and pollution sinks but also as an essentially limitless one as well. Despite the increasing concern over global environmental risks, it has yet to translate into meaningful policy even though we have the tools to do so (Sterner et al. 2019).

Much of the Dasgupta Review is devoted to detailing the consequences of this inaction. It "highlights the serious, deep-rooted institutional and market failures that mean societies are failing to invest in the natural capital on which our ongoing prosperity depends, and are instead rapidly eroding that asset base, with growing economic costs and vulnerability to future disasters" (WWF UK 2021, p. 1).

The Dasgupta Review identifies many factors that threaten the ecological sustainability of our economies. The following article examines how two policy failures in particular - the *underpricing* and *underfunding* of nature – are critical to a major global environmental risk: land use change and terrestrial biodiversity loss.[2]

The main concern is the rapid conversion and degradation of natural habitats, such as forests, wetlands and grasslands. The principal threats are from agriculture, forestry, infrastructure, human settlements and other economic activities. The resulting dramatic decline in plant and animal species has led some scientists to warn of possible "biological annihilation" in coming decades (Cebellos et al. 2017).

The scale, speed and impacts of this destruction have been immense. Terrestrial ecological communities worldwide have lost more than 20% of their original biodiversity (Díaz et al. 2019). Natural ecosystems have declined by almost half over the past 50 years, and millions of terrestrial species are likely to become extinct by 2100 (IPBES 2019). Land use change is also a significant contributor to global warming, accounting for 14% of total carbon emissions on average over 2010 to 2019 (Friedlingstein et al. 2020). Land use pressure has reduced local biodiversity intactness - the average proportion of natural biodiversity remaining in local ecosystems - beyond safe limits across the majority of the world's land surface.[3] Even protected areas are not safe. As much as one third of global protected land is under intense human pressure (Jones et al. 2018).

[1] Quoted from p. 2 of *The Economics of Biodiversity: The Dasgupta Review – Headline Messages*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/957629/Dasgupta_Review_-_Headline_Messages.pdf

[2] The views expressed in this article, especially the role of underpricing and underfunding nature in perpetuating global environmental risks such as land use change and biodiversity loss, ocean and coastal decline, freshwater scarcity and climate change, are explored in more detail in Barbier (2022).

[3] Newbold et al. (2016) estimate that natural biodiversity remaining in local ecosystems exceeds safe limits across 58.1% of the world's land surface.

Reversing these trends will require a major transformation in how economies use land and nature, as called for by the Dasgupta Review. This article explores different policy initiatives, both globally and within countries, to address this critical problem.

After briefly summarizing key trends of land use change and biodiversity loss, the article explains how the underpricing of nature inhibits the creation of the incentives, institutions and innovations needed to change humankind's relationship with terrestrial ecosystems and biodiversity. Global biodiversity conservation is also plagued by underfunding, as the international community struggles to compensate developing countries for protecting valuable terrestrial habitats and restoring those that are degraded or converted. Overcoming such underfunding in the coming decades will be critical to halting the rapid decline in terrestrial natural capital.

The final part of this article looks more closely at policies to end the underpricing of natural landscape and the underfunding of nature. Collective action will require commitments not only by rich countries to assist poorer ones in protection and restoration efforts, but also by the private sector to invest in nature to reduce the risks from biodiversity and ecosystem loss. The example of peatlands is used to illustrate how such a comprehensive global strategy could be constructed.

## 2 Key Trends

The growing crisis posed by land use change and biodiversity loss is captured by three global trends (see Fig. 1).

One indicator used to track "the degradation of nature" is the Living Planet Index (LPI), which covers thousands of populations of mammals, birds, reptiles, amphibians and fish from around the world.[4] Over the past 50 years, the global LPI has been declining steadily, and it is now only 30% of its 1970 level.

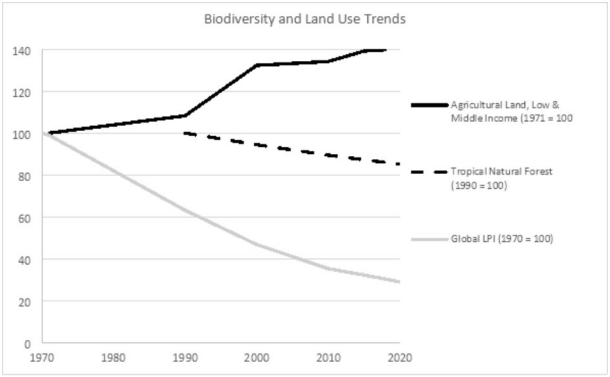


**Fig. 1** Key trends in land use change and biodiversity loss, 1970-2020

[4] The Living Planet Index (LPI) is a measure of the state of the world's biological diversity based on population trends of vertebrate species from terrestrial, freshwater and marine habitats. The current LPI comprises 4,801 species and 27,580 populations. All indices are weighted by species richness, giving species-rich taxonomic groups in terrestrial, marine and freshwater systems more weight than groups with fewer species. For more details, see WWF (2020) and WWF/ZSL https://livingplanetindex.org/data_portal.

Notes: Agricultural land refers to the share of land area that is arable, under permanent crops, and under permanent pastures. The agricultural land area trend over 1971-2018 is for low and middle-income countries, which are economies with 2019 per capita gross national income (GNI) of US$12,535 or less. These agricultural land data are from World Development Indicators, available at https://databank.worldbank.org/source/world-development-indicators. Natural forest is naturally regenerating forest, which is predominantly composed of trees established through natural regeneration. These tropical natural forest area data are from the Food and Agriculture Organization of the United Nations (FAO) Global Forest Resources Assessment (FRA) 2020, available at https://fra-data.fao.org/WO/fra2020/home/. Countries are defined as tropical following FAO FRA 2015 domain classification. In 2020, natural forest in tropical low and middle-income countries comprised 1,710 million hectares (ha), which is 99% of all tropical natural forest worldwide and 46% of all global natural forest. The global Living Planet Index (LPI) over 1970-2020 represents 20,811 populations of 4,392 species of mammals, birds, amphibians, reptiles and fish, available at WWF/ZSL https://livingplanetindex.org/data_portal. The base year for the LPI is 1970 (LPI = 100). The LPI from 2017 onwards is projected based on the 2010-2016 annual decline rate.

For terrestrial ecosystems, much biodiversity loss is occurring in developing countries, where agricultural land expansion continues to occur at the expense of natural forest, especially in tropical regions (see Fig. 1). Tropical forests are one of the most biologically rich and ecologically important biomes on Earth. Nearly all the world's tropical natural forest is located in low and middle-income countries. Since 1990, these countries have lost 15% of their forests. Over the past five decades, land for agricultural production in developing economies has increased by 40%, with much of the expansion occurring since 1990. Additional causes of rapid land use change and biodiversity loss in developing countries are forestry, mining and other extractive activities.[5]

Thus, our economies are hardly "embedded in nature" as the Dasgupta Review maintains they need to be. To halt and possibly reverse terrestrial land use change, ecosystem decline and biodiversity loss requires addressing the principle causes underlying these trends. As the remainder of this article discusses, two key drivers are the persistent underpricing of natural landscape and the chronic global underfunding of nature.

## 3 Underpricing Natural Landscape

The Dasgupta Review notes that ecosystems are an important source of "wealth" as they support economies and boost the welfare of people. Individuals also value nature for its own intrinsic worth. The traditions, culture and way of life of many local communities and indigenous people are intimately connected with their surrounding environment. Consequently, ecosystems should be viewed as highly valuable capital assets to humankind, because they produce a very wide range of beneficial ecosystem goods and services – often called *ecosystem services* for short.

These ecological values and benefits may be irreversibly lost when we degrade or convert nature. The fact that we ignore the rising cost of ecosystem loss signals that there is

[5] See, for example, Barbier (2019), Busch and Ferretti-Gallon (2017) and Leblois et al. (2017) for recent reviews of the causes of tropical land use change.

something fundamentally wrong in the economics of managing our increasingly fragile terrestrial landscape. As the Dasgupta Review points out, "biodiversity should not be assigned a value of zero at the point of decision" (Groom and Trusk 2021, p. 20), yet that is exactly what our current markets and institutions allow to happen.

I refer to this main flaw in our economies as the *underpricing of nature* – or more specifically in the case of terrestrial ecosystem and biodiversity decline - the *underpricing of natural landscape* (Barbier 2022). Modern economies are squandering valuable natural and ecological capital and failing to act on rising global environmental risks. This is because the ecosystem services provided by natural habitats are not routinely reflected in markets. Instead, most ecosystem goods and services are available for free. We do not have to pay for them, as healthy ecosystems provide their valuable benefits to us through their natural structure and functioning. This is certainly the problem for much of the world's remaining natural landscape.

But the problem is even worse. Not only do we not pay for the ecological degradation caused by land use change, but often we subsidize the economic activities that lead to this destruction. As the Dasgupta Review points out, we are not just pricing ecosystems and their services too cheaply, we are actually giving them a "negative price", which is tantamount to paying some economic activities to destroy nature:

> "The current structure of market prices works against our common future; the biosphere is precious but priced cheaply, if it is priced at all. Worse, owing to a wide range of government subsidies, some services come with a negative price." (Dasgupta 2021, p. 234).

Governments currently spend a lot on damaging nature. Environmentally harmful subsidies to agriculture alone amount to around $116 billion per year, which is about the same amount spent globally by the public and private sector on nature conservation and protection (OECD 2020a). Forestry subsidies that adversely impact terrestrial ecosystems are an additional $55 billion annually (Deutz et al. 2020). Governments also provide environmentally beneficial subsidies to nature, but they currently average only about $0.89 billion per year (OECD 2019).

Consequently, the paramount challenge for decoupling our economies from ecological decline arising from land use change is to end the underpricing of natural landscape. Only then will our institutions, incentives and innovations reflect the growing ecological and natural resource scarcity that is caused by continuing land use change. Until we accept the need to remove perverse subsidies that encourage destructive land use practices that harm the environment and to implement policies to correct the cheap cost of converting natural habitats, we cannot begin to address the problem of excessive global land use change that is behind the continuing loss and degradation of our terrestrial ecological capital.

Taking the scarcity of terrestrial ecosystems and biodiversity into account will induce changes in our use of valuable natural landscapes, and encourage less conversion and more conservation and restoration. Ending the underpricing of natural landscape is particularly crucial to encouraging the most important innovations needed for decoupling destructive land use change and development – the sustainable intensification of existing land uses and the reduction in food and agricultural waste.

Intensification of agriculture, forestry and other land uses, reducing waste and adopting sustainability practices will be essential to "bending the curve" of global ecological decline and biodiversity loss.[6] Boosting the productivity and sustainability of land-use systems in low and middle-income countries is especially a priority, if we want to reduce conversion of the world's remaining forests, wetlands and other natural habitat. According to Tilman et al. (2011), if current trends of agricultural intensification in wealthier nations and the pattern of land clearing in poorer nations were to continue, one billion additional hectares (ha) of land would be cleared globally for crops by 2050. On the other hand, greater agricultural intensification in all countries would mean only 250,000 million more hectares of land cleared.

**Table 1** Global underfunding of nature

| Category | Amount per year | Description and source |
|---|---|---|
| **1. Funding from all sources** | **$78.3–$90.7 billion** | OECD (2020a). |
| Public domestic finance | $67.8 billion | Average annual spending over 2015–2017 by 81 countries. |
| Public international finance | $3.9–$9.3 billion | Bilateral and multilateral official development assistance and concessional flows. |
| Private sector finance | $6.6–$13.6 billion | Average annual spending over 2015–2017 on biodiversity offsets, sustainable commodities, forest carbon finance, payments for ecosystem services, water quality trading and offsets, philanthropic spending, private contributions to conservation NGOs, and private finance leveraged by bilateral and multilateral public development finance ($41-$155 million annually). |
| **2. Funding needs** | **$969.6 billion** | |
| Costs of tropical natural climate solutions (NCS) | $618 billion | Author's estimates based on 35 tropical countries with cost-effective natural climate solutions and median cost of 5.5% of GDP (Griscom et al. 2020). |
| Costs of restoring degraded landscape | $350 billion | Costs of restoring 350 million hectares of degraded forest and agricultural land (Ding et al. 2019). |
| Costs of reducing pandemic risk | $9.6 billion | Direct forest protection payments to reduce tropical deforestation in areas at highest risk of wildlife-human disease spillover (Dobson et al. 2020). |
| **Funding gap (2.–1.)** | **$878.9–$891.3 billion** | |

[6] See, for example, Ellis et al. (2013), Leclère et al. (2020), Mace et al. (2018), Mehrabi et al. (2018), Springmann et al. (2018) and Tilman et al. (2011).

Ending the underpricing of natural landscape would go a long way towards fostering greater agricultural intensification and decoupling our economies from land use change, ecological decline and biodiversity loss. In addition, simply because many low and middle-income economies are highly dependent on their land and natural resources does not mean that they should underprice their economically and ecologically valuable natural landscape. Rather than help their economies develop and end poverty, such underpricing actually works against sustainable and inclusive development. Government policies that promote and subsidize agriculture, forestry, mining and other primary production activities encourage further land use conversion and natural resource overexploitation. This in turn impacts the long-run economic performance of economies.[7]

## 4 Underfunding of Nature

Ending the underpricing of natural landscape in all countries, including low and middle-income countries, is vital to reducing global loss of terrestrial ecological capital and biodiversity. The other imperative is to end the *underfunding of nature* worldwide.

Table 1 summarizes the extent of the current underfunding problem.

Global financing for nature conservation and protection from all sources is around $78 to $91 billion each year (see Table 1). It includes domestic spending by 81 countries ($68 billion) and private expenditure ($6.6 to $13.6 billion). The latter comprises biodiversity offsets, sustainable commodities, forest carbon finance, payments for ecosystem services, water quality trading and offsets, philanthropic spending, private contributions to conservation non-governmental organizations (NGOs), and private finance leveraged by bilateral and multilateral public development finance. International public finance for nature, in the form of bilateral and multilateral assistance to low and middle-income countries, is $3.9 to $9.3 billion each year.

Just under $100 billion a year to fund nature sounds like a lot. But it isn't. Table 1 lists three important "funding needs" for global conservation: reducing the greenhouse gas emissions contributed by land use change, restoring degraded landscapes, and reducing the risks of future disease outbreaks caused by wildlife habitat loss. Together, these funding needs require a total annual investment of around $970 billion.

As mentioned previously, land use change contributes around 14% of global greenhouse gas emissions (Friedlingstein et al. 2020). It may be even a larger share in poorer economies. As Bowen and Fankhauser (2011, p. 157) note, "the most important source of greenhouse gas emissions in low-income countries remains, by some distance, *land-use change and forestry*. Together it accounts for 50% of low-income country emissions." Greenhouse gas emissions from land use change in tropical developing economies can be reduced significantly through natural climate solutions (NCS), which conserve, restore and improve land management to protect biodiversity and ecosystem services (Griscom et al. 2020). As indicated in Table 1, the additional funding needed to implement cost-effective NCS in 35 tropical low and middle-income countries that show potential for such approaches could be well over $600 billion per year.

[7] Since the landmark study by Mehlum et al. (2006), there has been a growing economics literature examining this interaction; e.g., for reviews, see Badeeb et al. (2017), Barbier (2019), Havranek et al. (2016), Papyrakis (2017) and van der Ploeg (2011).

The costs of restoring globally 350 million hectares of degraded forest and agricultural land amounts to around $350 billion annually (see Table 1). However, public funding for such activities is only $41 billion per year, and private investment about $10 billion. The annual shortfall in global funding of landscape restoration is therefore about $300 billion. Yet, for every dollar invested in restoring degraded forest, anywhere from $7 to $30 in economic benefits are generated (Ding et al. 2019).

Nearly two thirds of emerging infectious diseases spread from animals to humans, and three-quarters of them originate in wildlife (Cunningham et al. 2017 and Jones et al. 2008). An important cause is the reduction in natural habitat, which increases the likelihood of disease spillovers between infected animals (Barbier 2021; Cunningham et al. 2017; Faust et al. 2018; Gibb et al. 2020). If we want to prevent future pandemics from wildlife-borne diseases, such as COVID-19, we must also reduce exploitation and protect our natural habitat. The estimated price tag for reducing deforestation of tropical habitats with highest risk of virus spillover from wildlife to humans is just under $10 billion per year (see Table 1).

As a consequence, there is a very large *biodiversity funding gap* between current sources and investment needs. As Table 1 indicates, this gap in funding amounts to just under $900 billion annually. Although this estimate of the biodiversity funding gap is a ballpark figure and should be treated with caution, it is largely in line with other estimates.

For example, UNEP (2021) finds that approximately $133 billion per year is invested in *nature-based solutions*, which are broadly defined as actions to protect, sustainably manage, and restore natural or modified ecosystems, while also addressing societal challenges, such as food security, climate change, water security, human health, disaster risk, social and economic development. UNEP (2021) assesses that 86% ($115 billion) of the annual funding for nature-based solutions is from public sources, and 14% ($18 billion) from private sources. The report excludes investments in the marine environment, but does include mangroves. UNEP (2021) maintains that, if the world is to meet its climate change and biodiversity targets, annual funding for nature-based solutions needs to increase three-fold by 2030 and four-fold by 2050, or around $536 billion per year. However, unlike Table 1, this estimate does not include restoration of 350 million ha of degraded agricultural and forest land (Ding et al. 2019) or protecting tropical forest with high wildlife disease spillover (Dobson et al. 2020).

Similarly, Deutz et al. (2020) find that, as of 2019, current spending on global biodiversity conservation (terrestrial and marine) is between $124 and $143 billion per year, against a total estimated biodiversity protection need of between $722 and $967 billion per year. This leaves a current biodiversity financing gap of between US$ 598 billion and US$ 824 billion per year. However, unlike Table 1, the estimates of Deutz et al. (2020) do not include the costs of restoring degraded agricultural and forest land (Ding et al. 2019 ; Griscom et al. 2020; UNEP 2021) or protecting tropical forests with diseases spillover (Dobson et al. 2020).

Regardless, depending on the estimates used, the global biodiversity funding gap is still substantial. It is between $500 billion and $900 billion per year. Moreover, this global shortfall disproportionately impacts protection and conservation in low and middle-income countries. Most of the world's remaining terrestrial biodiversity and natural landscape are in these economies, and over three-quarters of species are found in the tropics (Barlow et al. 2018). Currently, the international community provides around $4 to $9 billion each year to assist these countries in their effort to protect and conserve nature, with perhaps an

additional $500 million from private finance mobilized by international aid agencies (see Table 1). But such global funding for developing countries is woefully inadequate to prevent habitat loss and over-exploitation, and is a major reason why the world is not preserving sufficient natural landscape and biodiversity.

Private sources of funding biodiversity are also insufficient, especially given the considerable benefits of biodiversity and ecosystem services in supporting market activities. Private sector finance – even including philanthropic and NGO support – is $6.6 to $13.6 billion each year (see Table 1). In comparison, the World Economic Forum analyzed 163 industry sectors and their supply chains, and found that $44 trillion of global value added is moderately or highly dependent on nature and its services (WEF 2020). This amounts to over half of the world's GDP. Even if these benefits are over-estimated by a magnitude of ten or even a hundred, they suggest that nature is grossly underpriced and underfunded by the private sector.

## 5 Ending Underpricing

A key step in ending the underpricing of natural landscape is to remove environmentally harmful subsidies. Curtailing such subsidies in agriculture and forestry could control inefficient and unsustainable land use, as well as excessive conversion and degradation of natural landscape. As indicated earlier, environmentally harmful subsidies in agriculture amount to around $116 billion annually, which is about the same amount spend each year on nature globally (OECD 2020a). In other words, if we removed all environmentally harmful subsidies in agriculture, and devoted the released funds to natural landscape protection instead, we would double the financing for nature worldwide. Similarly, if we reallocate the $55 billion in environmentally harmful forestry subsidies (Deutz et al. 2020), we could increase global conservation of natural landscape even further.

There may also be equity gains. Reviews of input subsidy programs in Sub-Saharan Africa indicate that they have largely failed to achieve the objectives of widespread agricultural intensification and more sustainable land use, while also largely benefiting mainly larger and wealthier farmers rather than poor smallholders (Holden 2019; Jayne et al. 2018). As pointed out by Holden (2019, p. 516), "The fundamental reason for this is that they have been captured by elites who are able to reap the lion's share of the benefits and at the same time gain political support from the rural masses that hope to benefit from the subsidies."

A better approach to increase agricultural intensification and reduce deforestation in Africa and other developing regions is to remove agricultural input subsidies and invest the savings in targeted investments to enhance sustainable land use among poor rural smallholders. Smallholder agriculture in most remote and marginal agricultural areas of Africa, Asia and Latin America is still a low development priority. Yet, targeting policies and investments to improve smallholder agriculture, land distribution and livelihoods in marginal environments could be a significant catalyst for green transformation in many low and middle-income economies. In these countries, about 70 to 80% of farms are smaller than 2 hectares, and they occupy about 30 to 40% of available agricultural land (Lowder et al. 2016). Investments and policies that support sustainable smallholder land use and liveli-

hood diversification not only reduce poverty but also encourage environmental protection and land regeneration, especially in remote land-abundant areas.[8]

Investments and policies that improve and diversify the livelihoods of smallholders can indirectly spur conservation when smallholders see additional value from protecting and restoring natural areas and from afforestation on their own lands. For example, much of the decline in deforestation trends in Latin America can also be attributable to the "woodland green revolution", which has arisen through the cultivation of non-timber forest products, timber and tree-based crops by smallholders and their protection of the surrounding natural landscape (Hecht 2014).

In addition to eliminating environmentally harmful subsidies it may also be necessary to tax pesticides, fertilizers, forest products and timber harvests that place an additional cost on the use of land and natural resources or on environmentally damaging pollution. Such taxes can help ensure that agriculture, forestry and other land uses are not excessively degrading the environment, over-exploiting natural resources and unnecessarily converting ecosystems. In addition, the revenues raised from these taxes can be channeled into the conservation, restoration and sustainable use of natural landscape and ecosystems.

Since 1980, such *biodiversity-relevant taxes* have been rising steadily in 59 countries. However, these taxes are still too small to have a significant impact on the underpricing of nature. They generate only about $7.5 billion a year in revenue, equivalent to around 1% of the total revenue from all environmentally relevant taxes (OECD 2020b). In comparison, environmentally harmful agricultural subsidies are fifteen times greater (OECD 2020a).

Increasing use of biodiversity-relevant taxes to deter excessive loss of ecological capital is clearly a priority. But more innovative policies are also required.

One possibility is a *tropical carbon tax* (Barbier et al. 2020). This is a levy placed on fossil fuel imports and consumption in tropical countries, with some of the proceeds invested in natural climate solutions (NCS) aimed at conserving, restoring and improving land management to protect biodiversity and ecosystem services. NCS are a relatively inexpensive way of reducing tropical land use change, which is not only a major cause of global biodiversity loss but an important source of greenhouse gas emissions. For example, cost-effective tropical NCS can mitigate 6,560 $10^6$ tonnes of $CO_2e$ in the coming decades at less than $100 per $10^3$ tonnes of $CO_2e$, which is about one quarter of emissions from all tropical countries (Griscom et al. 2020).

Costa Rica and Colombia have already adopted a tropical carbon tax strategy. If 12 other megadiverse countries roll out a policy similar to Colombia's, they could raise $1.8 billion each year between them to invest in natural habitats that benefit the climate (Barbier et al. 2020). A more ambitious policy of taxation and revenue allocation could yield nearly $13 billion each year for natural climate solutions. Such investments could also mitigate substantial greenhouse gas emissions in temperature countries as well. For example, the United States could abate 299 million tonnes $CO_2e$ of greenhouse gas emissions annually through cost-effective NCS, which would also provide other benefits, such as air and water filtration, flood control, soil conservation and wildlife habitats (Fargione et al. 2018). Most importantly, investing in NCS places a value on nature and its services, and sends a market signal that ecological capital is a valuable economic asset that is worth holding onto rather than converting to other land uses.

[8] See, for example, Barbier and Hochard (2019), Hecht (2014), Holden (2019), Huang (2018), Larson et al. (2016) and Pingali (2012).

Pricing natural landscape appropriately may also be important for decoupling agricultural and rural development from continued land expansion and deforestation. But instead, most countries have attempted to control land use change through more direct policies, such as imposing environmental regulations and limiting forest conversion, with mixed results.

Even though there are signs that environmental restrictions can limit excessive agricultural land expansion, their effectiveness remains limited as long as forests and other natural landscape are undervalued compared to agricultural uses. For example, in the Brazilian Amazon, appreciation of land values due to soy expansion has contributed to significant deforestation and conversion of other natural habitat, because these areas are treated as if they have no other value. Cattle ranching is still pervasive, and although it is a relatively low-value land use with limited land productivity, rangeland expansion continues to generate substantial deforestation because natural forest is considered worth even less (Cardoso da Silva et al. 2017; Holland et al. 2016; Richards 2015; Richards et al. 2014).

In an attempt to control tropical deforestation from primary product industries, in 2011 Indonesia implemented a moratorium on new concessions for oil palm plantations, timber plantations and logging activity on primary forests and peatlands. In the first few years after its implementation, the moratorium did reduce deforestation. But the policy would have been more effective if it was combined with price-based instruments, such as carbon payments, payments for ecosystem services, taxes on deforestations or certified environmentally sustainable products, "all of which attempt to raise the private value of maintaining land as forest relative to converting land to agriculture" (Busch et al. 2015, p. 1331).

## 6 Overcoming the Funding Gap

If the rest of the world does substantially increase its funding of conservation investments in poorer countries, it could have a major impact on saving ecosystems and biodiversity. The key question is what collective action is needed globally to ensure that such investments in nature occur?

One avenue is for wealthier countries not only to increase the amount of their own domestic spending on nature conservation but also to devote substantially more bilateral and multilateral assistance to poorer countries.

Increasing domestic conservation investments can provide much needed economic benefits, including jobs, which should be an important consideration as major economies recover from the COVID-19 pandemic. For example, ecosystem restoration in the United States provides direct employment for 126,000 workers and generates $9.5 billion in economic output annually, while creating a further 95,000 indirect jobs and $15 billion in household spending (BenDor et al. 2015; OECD 2020b).

The returns to increased conservation investment in developing countries could be even greater. In 16 low and middle-income countries, for every dollar spent in conservation, almost seven dollars more are generated in the economy after five years (Batini et al. 2021). The authors attribute these high returns to three factors. First, conversation spending sponsored by donors supplements domestic resources in developing countries rather than crowds them out. Second, conservation actions in these countries are highly labor-intensive and create jobs. Finally, as discussed earlier, conservation of natural landscape protects ecosys-

tem services that support the economic livelihoods of the rural poor, including water, food, fodder, resource harvests and protection from extreme events.

One way that richer countries could fund more conservation in poorer economies is to step up their investments in biodiversity offsets and payments for ecosystem services.

*Biodiversity offsets* are conservation actions, such as protecting threatened forests or restoring wetlands, which are intended to compensate for unavoidable losses to natural habitats caused by other investments in the economy. The objective is to ensure at least a no net loss of biodiversity and, where possible, a net gain. Globally, about $5 billion is spent annually on biodiversity offsets (OECD 2020b). However, much of these offsets occur domestically within wealthier economies. Richer countries and multilateral agencies need to increase their assistance to low and middle-income countries for funding biodiversity offsets.

*Payments for ecosystem services* are market transactions, usually direct cash or credit payments, made by those who benefit from ecosystem services to landowners who have agreed to provide these services through specific actions, such as habitat conservation or restoration. The type of ecosystem services generated include watershed protection, carbon sequestration, water quality benefits, biodiversity conservation and wildlife habitat benefits. Ten large, publicly funded payments for ecosystem services programs account for around $10 billion of global funding annually. In addition, private schemes that pay for watershed protection services provide financing of around $15 million each year (OECD 2020a and 2020b).

There is plenty of scope to expand public and private payments for ecosystem services, and especially to fund more projects in developing countries. Such schemes should focus on tropical countries where natural climate solutions are most cost-effective and to reduce tropical deforestation in areas at highest risk of wildlife-human disease spillover (see Table 1). Tropical countries that benefit most from the extra spending on biodiversity conservation should also be a priority (see Table 2).

The COVID-19 pandemic has caused rising debt levels and budget cuts in low and middle-income countries. As a possible win-win strategy for addressing the climate and debt crises, lender countries could offer lower interest rates and principal repayments in return for increasing biodiversity and natural area protection in borrowing countries, in exchange for the latter delivering on additional conservation actions and investments. The basic idea of such *debt-for-nature swaps* involves restructuring or cancelling some of a nation's foreign debt in exchange for investment in greater conservation of natural areas.

Such deals have existed since the late 1980s. Since 1990, debt-for-nature swaps by the United States cancelled approximately $1.8 billion owed by 21 low- and middle-income countries. The swaps generated $400 million for conservation. Debt-for-nature swaps carried out by all other high-income countries totaled $1 billion of debt cancelled and generated about $500 million for conservation. Evidence suggests that the US bilateral debt-for-nature deals have been associated with lower rates of forest loss in borrowing countries.[9]

[9] Sommer et al. (2020). However, Cassimon et al. (2011) find that debt-for-nature swaps have also typically displayed a number of shortcomings: they often fail to deliver additional resources to the debtor country or to the government budget; often fail to deliver more resources for conservation purposes; often have a negligible effect on overall debt burdens; and are often in conflict with principles of alignment with government policy and institutions.

If debt-for-nature swaps are to be effective in closing the funding gap for global nature conservation, clearly more deals need to be made and key shortcomings addressed. One option is to expand the range of conservation actions to include a commitment by participating low and middle-income countries to ending the underpricing of natural landscape. By undertaking subsidy reforms and pricing land conversion in exchange for debt relief, these countries will be re-establishing their credit worthiness with financial investors and markets. This could potentially be a win-win strategy for addressing both the debt crisis and underfunding of nature faced by many developing countries.

Another way to close the funding gap is to expand the use of *green bonds* for biodiversity and sustainable land use investments. These are debt instruments where the proceeds are used exclusively to finance or refinance projects with environmental benefits. First issued in by the European Investment Bank in 2007 and the World Bank in 2008, green bonds reached a market value of $258 billion in 2019. The Luxembourg Stock Exchange established the first dedicated Green Exchange (LGX) that includes trading in green bonds in 2016.[10] The issuers of green bonds are typically local and national governments, corporations and multilateral development agencies and banks.

While the global market for green bonds is growing, their focus is mainly on renewable energy, energy efficiency, green transport and other climate change mitigation investments. Green bonds are rarely used to finance biodiversity conservation and sustainable land use. Climate change, energy and transport have accounted for around 80% of green bonds; land use projects only 3% (Chahine and Liagre 2020).

The main issuer of green bonds for investments in low and middle-income economies is the World Bank. Since 2008, the Bank has issued green bonds to raise $17 billion for eligible projects worldwide. Of these commitments, nearly $12 billion in green bond proceeds have been disbursed to support 106 projects in 31 developing countries. But 63% of the projects funded have been for renewable energy, energy efficiency and clean transportation. Only 15% have been allocated to agriculture, land use, forests and ecological resources and 4% to biodiversity, with a total allocation of just over $1.6 billion (World Bank 2020).

If greens bonds are to catalyze more biodiversity and sustainable land use investments, especially in developing countries, several limitations need to be overcome. Two key challenges are the relatively small scale of many conservation projects compared to clean energy and transport investments, and as a result, the perceived relative low returns and significant risk of investing in biodiversity and sustainable land use. The average value of issued green bonds is $150 million, but individual conservation projects in low and middle-income countries are unlikely to reach such a scale, unless they are bundled into larger investment opportunities (Chahine and Liagre 2020).

Developing country governments, working with multilateral agencies issuing green bonds, local governments and NGOS, could identify and combine individual natural landscape projects from various localities and regions into a single nation-wide investment portfolio. A green bond could then be issued for the entire portfolio of projects, and then disbursed to individual regional and local investments.

[10] Chahine and Liagre (2020) and World Bank (2020). Note that, as traded assets, the market valuation of green bonds does not necessarily reflect the amount of money raised by issuers of green bonds to finance environmental projects. As Chahine and Liagre (2020, p. 1) comment about the rapid expansion in the market value of green bonds in recent years: "A lot of this growth has been captured by different stock exchanges where Green Bonds are listed."

Green bonds could also be issued to support other scalable conservation actions, such as a country-wide program of payments for ecosystem services, biodiversity offsets, ecological restoration, or for expanding protected areas, their policing and monitoring. A good example is Mexico's recently completed $350 million Forests and Climate Change program, which was partially funded by the issuance of a World Bank green bond. The project supported rural communities' sustainable management of forests, generated additional income for these communities from forest products and services, and significantly reduced greenhouse gas emissions from deforestation and forest degradation (World Bank 2020).

But if we really want to end the underfunding of global biodiversity, the corporate world needs to step up. This is especially important for key sectors dependent on terrestrial natural landscape, such as forestry and agricultural industries.

One way is for these industries to transform their supply chains, many of which are environmentally destructive. Between 2000 and 2012, beef, soy, forest products (timber and pulp) and palm oil accounted for over 1 million $km^2$ of tropical forest loss (40% of global deforestation), including forested peatlands, with 31% of this loss attributed to exports and supply chains to the European Union and China (Haupt et al. 2020). On the other hand, consumer, shareholder and investor pressure is motivating companies to invest in making their supply chains more sustainable. One estimate indicates that corporate sustainable supply chains globally are allocating $5.5 to $8.2 billion annually toward biodiversity conservation (Deutz et al. 2020). This needs to continue and expand.

Agricultural and forestry sectors stand to gain significantly from greater participation and investments in global biodiversity conservation (Barbier et al. 2018). By spending $15 to $30 billion annually to protect natural forests worldwide, the forest products industry would attain its own industry sustainable forest management goals and boost profits. Agriculture also has an incentive to protect habitats of wild pollinators, who along with managed populations enhance global crop production by $235 billion to $577 billion each year. One way to catalyze on such investments is through formal international agreements that allow formal participation by leading corporations in forestry, agricultural and other sectors that benefit from conservation. In exchange for committing to the agreement, the corporations would have to commit funding to conserve natural areas and sustainable land use globally. The resulting increase in industry revenues and profits could provide $25-50 billion annually for global conservation, which would help close the funding gap (Barbier et al. 2018).

In sum, we have to scale up and align finance for biodiversity and natural landscape conservation from all sources, public and private. For example, it is estimated that we need at least three if not four times the amount of current annual spending on natural-based solutions, if the world is to meet its climate change, biodiversity and land degradation targets (UNEP 2021). Actions by individual governments and businesses are important, but this must be a collective effort. As many businesses worldwide are the main beneficiaries from nature and its services, it is time for major corporations to do their part.

## 7 A Comprehensive Global Policy Strategy: Peatlands

Ending the underpricing and underfunding of natural landscape requires a comprehensive policy strategy, which will include both public and private initiatives and substantial assistance to poorer countries. Any strategy also needs to overcome the market, institutional

**Table 2** Carbon mitigation potential and costs of peatland conservation and restoration in tropical countries at cost-effective levels (<–US$100 per tonne of $CO_2$e)

| | Peatland conservation | | Peatland restoration | | Total | |
|---|---|---|---|---|---|---|
| Country | Annual carbon mitigation $MtCO_2e$/year | Annual cost US$M/year[a] | Annual carbon mitigation $MtCO_2e$/year | Annual cost US$M/year[a] | Annual carbon mitigation $MtCO_2e$/year | Annual cost US$M/year[a] |
| Indonesia | 462.82 | 23,141.0 | 174.65 | 8,732.5 | 637.47 | 31,873.5 |
| Malaysia | 51.31 | 2,565.5 | 16.77 | 838.5 | 68.08 | 3,404.0 |
| Papua New Guinea | 24.5 | 1,225.0 | 6.98 | 349.0 | 31.48 | 1,574.0 |
| Uganda | 7.92 | 396.0 | 6.98 | 349.0 | 14.9 | 745.0 |
| Brazil | 1.58 | 79.0 | 4.2 | 210.0 | 5.78 | 289.0 |
| Dem Rep of Congo | 0.85 | 42.5 | 0.84 | 42.0 | 1.69 | 84.5 |
| Peru | 0.05 | 2.5 | 0.14 | 7.0 | 0.19 | 9.5 |
| Republic of Congo | 0.01 | 0.5 | 0.01 | 0.5 | 0.02 | 1.0 |
| **Total 8 countries** | **549.0** | **27,452.0** | **210.6** | **10,528.5** | **759.6** | **37,980.5** |
| Global share (%) | (97%) | (97%) | (90%) | (90%) | (95%) | (95%) |
| **Other countries** | **17.2** | **861.0** | **23.6** | **1,179.5** | **40.8** | **2,040.5** |
| ***Global total*** | ***566*** | ***28,313*** | ***234*** | ***11,708*** | ***800*** | ***40,021*** |

*Notes*: [a] Following Griscom et al. (2020), annual cost estimate is US$50 per tonne of carbon dioxide equivalent ($tCO_2e$) multiplied by annual cost-effective mitigation, which is an approximation of the area under the marginal cost curve up to the cost-effective level of mitigation. Peatland conservation and restoration is considered cost-effective mitigation if it costs less than US$100 per tonne of carbon dioxide equivalent ($tCO_2e$) mitigated. M = mega or million ($10^6$). Estimates are for 77 tropical countries

*Source*: Based on Griscom et al. (2020)

and incentive barriers preventing the implementation of conservation and restoration of key habitats in host countries. To illustrate further, the example of a comprehensive global policy for peatlands is explored.[11]

A peatland is "an area with or without vegetation with a naturally accumulated peat layer at the surface" (Joosten and Clarke 2002, p. 24). Peat is partially decayed plant material that accumulates under waterlogged conditions over long time periods. Commonly called peat swamp forests, fens, bogs or mires, they represent 50 to 70% of global wetlands and cover over four million square kilometers ($km^2$) or 3% of the land area of the planet (Humpenöder et al. 2020; Joosten and Clarke 2002 and Xu et al. 2018b).

Peatlands are especially vital for combatting the climate crisis. If undisturbed, peat layers are an effective permanent store of carbon. Consequently, peatlands are one of the most carbon-dense terrestrial ecosystems globally, storing twice as much carbon as the world's forests (Leifeld and Menichetti 2018). In addition, peatlands provide habitat for many unique and threatened species, support water cycles, control pollution and sediments, are a source of locally harvested products, and serve as an inspiration for art, religion, and other

[11] See Barbier and Burgess (2021) for further details on such a global strategy for ending the underpricing and undervaluing of peatlands.

cultural values (Barbier and Burgess 2021; Bullock et al. 2012; Glenk and Martin-Ortega 2018; Martin-Ortega et al. 2014).

But global peatlands are in serious decline, especially in tropical developing countries. Around 11-15% of these ecosystems have been drained for agriculture, grazing, peat mining and forestry, and a further 5-10% are degraded through vegetation removal or alteration (Humpenöder et al. 2020; Leifeld and Menichetti 2018; Leifeld et al. 2019). Peatland decline has slowed somewhat in temperate and boreal regions, but the loss of tropical peatlands continues at a high rate. If unchecked, the area of peatland converted in tropical regions could increase to around 300,000 square kilometers ($km^2$) by 2050 (Leifeld et al. 2019). This is almost double today's drained peatland area in the tropics.

This continuing global loss of peatlands is a classic example of the underpricing and underfunding of nature (Barbier and Burgess 2021). The principal cause for the mismanagement of global peatlands is that their economic contributions are *undervalued*. Commercial activities and policies that degrade and convert these high-carbon ecosystems often ignore or fail to account adequately for their benefits to society. In addition, global peatland conservation and restoration suffer from chronic *underinvestment*. The current public and private funding of peatlands falls well short of what is needed to save such valuable ecosystems.

Although the economic and environmental benefits of peatlands are often considerable, the cost of restoring degraded or drained peatlands can be high, especially in tropical regions (Hansson and Dargusch 2018). To rewet 40% of drained peatlands by 2050, annual global investments in peatland restoration must rise from nearly US$19 billion annually to US$31 billion by 2030, to US$39 billion by 2040, and then in excess of US$46 billion by 2050 (Barbier and Burgess 2021).

An alternative indication of the funds needed is to estimate how much it would cost to conserve and restore tropical peatlands as a nature-based solution for greenhouse gas mitigation. Table 2 provides one such estimate for 79 tropical countries.

Investing in cost-effective tropical peatland conservation and restoration for carbon mitigation would reduce global greenhouse gas emissions by 800 million tonnes per year. That is more than the annul emissions of Germany, or just under 3% of the global total.[12] As Table 2 indicates, attaining this mitigation potential requires an annual investment of US$40 billion per year in tropical peatland conservation and restoration (US$28.3 billion for conservation and US$11.7 billion for restoration).

The estimates in Table 2 illustrate the current challenge of underinvestment in global tropical peatland restoration and conservation. This is especially urgent for the eight countries that could potentially account for 97% of the carbon mitigation from investing in tropical peatlands – Indonesia, Malaysia, Papua New Guinea, Uganda, Brazil, Democratic Republic of Congo, Peru and Republic of Congo.

For example, currently Indonesia has around US$200 million in domestic and international funds for annual spending on peatland restoration. This sounds considerable, but given the high costs of tropical restoration, such funds will be sufficient to restore only 1,000 $km^2$ of peatlands annually, which is well below what is needed. Budiharta et al. (2018) estimate that offsetting the carbon emissions attributable to the existing 46,000 $km^2$ of industrial oil-palm plantations in Kalimantan, Indonesia requires restoring 4,000 to 16,000 $km^2$ of degraded peatlands, including failed agricultural projects, at a cost of US$0.7–2.9 billion. Offsetting biodiversity losses would require at least 47,000 $km^2$of degraded areas to be

[12] See https://www.ucsusa.org/resources/each-countrys-share-co2-emissions.

restored at a cost of US$7.7 billion. To realize these targets, as well as to achieve the carbon mitigation potential estimated in Table 2, Indonesia will require much more funding for conserving and restoring its peatlands. The same is true for many other tropical countries.

In addition, existing funding for all nature-based solutions, including peatlands, is heavily reliant on public sources of financing. Around 86% of global nature-based solutions comes from either domestic government funds, bilateral and multilateral assistance or other public funds (UNEP 2021).[13] Peatlands may be even more dependent on domestic and international public financing. Consequently, the challenge for ending the underinvestment in global peatlands is not only to increase the scale of funding but also to find new sources, especially through additional private sector financing.

However, as these irrecoverable stores of carbon are disappearing quickly, the bill for saving peatlands will only rise further if we fail to invest now. The opportunity cost of delaying action on peatland conservation and restoration as part of a greenhouse gas mitigation strategy could be substantial (Glenk et al. 2021). Although some governments are beginning to recognize the economic importance of peatlands and are adopting better policies for their conservation, restoration and sustainable management, averting the worldwide crisis of mismanaging peatlands requires addressing the problems of undervaluing and underinvestment as the basis for a global strategy for promoting peatlands as a nature-based solution. Such a strategy requires three key elements (Barbier and Burgess 2021).

First, all countries with significant peatland areas should ensure that the values provided by these ecosystems are adequately taken into account in the land use decisions that inflict damages, degrade or destroy peatlands. They should adopt policies, regulations and other actions needed to improve conservation, restoration and sustainable management of their peatlands. These actions should include prohibiting additional loss of peatlands, removing subsidies that are harmful to peatlands, using market-based incentives and regulations to control peatland damages, and allocating any revenues generated or saved from subsidy and pricing reforms to improve peatland conservation, restoration and sustainable management.

Second, wealthy countries that contain peatlands should adopt these actions unequivocally. But many low and middle-income countries, especially those with significant tropical peatlands, may need technical and financial assistance in undertaking some of these policies, especially for restoring degraded peatlands. The international community should provide adequate financial and technical support to low and middle-income countries that adopt policies and actions for improved peatland conservation, restoration and sustainable management.

This additional support can be provided by a consortium of donors, including public-private partnerships, and should be conditional on verifiable policies and actions by recipient countries that have developed long-term policy and management plans for peatlands. Such an approach has been espoused by the REDD+ framework, where potential recipient countries have to demonstrate their "REDD readiness" by first creating a national strategy or action plan for reducing emissions from forest degradation and depletion and guaranteeing accurate and transparent monitoring, reporting and verifying of results-based actions.

In a similar way, countries seeking assistance from the international community for peatlands as a nature-based solution should demonstrate their "sustainable peatlands readiness" by:

[13] This is true for biodiversity funding in general, as Table 1 illustrates. See also OECD (2020a), which estimates that around 85% of global financing for nature conservation and protection is via public funds.

- Devising a national strategy of policy actions for conservation, restoration and sustainable management of peatlands.
- Establishing accurate and transparent monitoring, reporting and verifying of results-based actions under the national strategy.

Third, in a post-COVID world of limited financial resources, there is a need to develop new potential sources of private and public funding of peatlands globally. As discussed previously, there are a whole range of possible options, including biodiversity offsets, payments for ecosystems services, voluntary carbon markets, REDD+, debt-for-nature swaps and green bonds. In addition, the agricultural, forestry, mining, food and beverage, and other global industries must invest in making their supply chains "peatland friendly" by ensuring that they result in no additional loss of peatlands and by partnering with public programs to rewet and restore degraded peatlands.

For example, wealthier countries in cooperation with the private sector should encourage more use of biodiversity offsets for peatlands. Richer countries and multilateral agencies also need to increase their assistance to low and middle-income countries for funding biodiversity offsets, and to expand their use for peatlands. This could especially be important for tropical peatland restoration efforts, which are costly for most emerging and developing economies. For instance, as noted previously, offsetting the biodiversity impacts from existing oil palm plantations in Kalimantan, Indonesia would require rewetting at least 47,000 $km^2$ of degraded peatlands at a cost of US$7.7 billion (Budiharta et al. 2018).

There is also greater potential for expanding the use of payment of ecosystem services (PES) for conserving and restoring peatlands, especially for the water services that they provide. In many regions, peatlands are responsible for the supply of drinking and industrial water, filtration of toxic metals and pollution control, but only 28% of water supplying peatlands globally are protected (Martin-Ortega et al. 2014; Xu et al. 2018a). This is an important opportunity to expand PES schemes worldwide for watershed conservation and other water services to include peatlands. Already, water utilities and other public entities are engaged in paying for such services that enhance water availability and quality (Deutz et al. 2020; UNEP 2021), which could form the basis for establishing PES schemes for peatlands.

The scale and scope of REDD+ projects should be expanded to become a much more effective tool for peatland conservation and restoration, especially of forested peatlands in tropical countries. An initial start is for countries to incorporate forested peatlands in their REDD+ national strategies and emission reference levels. For example, in its national REDD+ strategy, the Republic of Congo mandates that agro-industrial concessions are not granted near wetlands or forests with high biodiversity value, and includes peatland carbon stocks in the country's forest reference emission levels for REDD+ credit assessment (Miles et al. 2017). In addition, countries implementing REDD+ projects for forested peatlands located in remote regions will need supplementary financial support for the development and implementation of measuring, reporting and verification of carbon stocks for results-based payments (Köhl et al. 2020).

Debt-for-nature swaps could also be designed to providing more global financing of peatland management, in the ways outlined above. For example, the deals could include a commitment by participating low and middle-income countries to remove subsidies and other forms of financial support to agricultural, forestry, mining and other economic activities that excessively degrade or convert peatlands. This not only signals a willingness to end

the undervaluing of peatlands but also reduces government spending, which is an important consideration in a post-pandemic world of rising debt.

Green bonds could also catalyze more peatland investments, especially in low and middle-income countries. As described previously, green bonds could be issued to support a single nation-wide peatland investment portfolio. Bonds could also be issued for other scalable peatland actions, such as a country-wide program of payments for ecosystem services, biodiversity offsets, ecological restoration, as in the case of Mexico's Forests and Climate Change Program. Green bonds could also be employed to expand peatland conservation areas, their policing and monitoring.

Corporate funding of peatlands conservation, restoration and sustainable management should play a greater role in ending the underfunding of global peatlands. There needs to be a concerted effort by the agricultural, forestry, mining and other global industries affecting peatlands to invest in improving the sustainability of their supply chains and also to safeguard that their activities result in no additional loss of peatlands.

For example, the *No Deforestation, No Peat, No Exploitation* (NDPE) initiative ensures that production does not involve any forest loss, conversion of peatlands or exploitation of indigenous communities or unjust labor practices. The NDPE approach is gaining ground with certain industries that have been environmentally harmful to peatlands, such as palm oil, but the outcome has been mixed. In Indonesia and Malaysia, NDPE policies cover 83% of palm oil refining capacity, which also includes their plantations and the plantations of any third-party suppliers. However, non-cooperating refiners continue to leak unsustainable palm oil into the market thus undermining the effectiveness of the policies (ten Kate et al. 2020). A survey of 79 of the world's most significant producers, processors and traders of palm oil found that, while 57 companies have committed to no planting on peat via NDPE, only 14 report on implementing the commitment. Similarly, 59 companies have committed to no burning of peat, but only 43 companies disclose details of fire management and monitoring practices.[14]

Voluntary contribution programs, such as the Roundtable on Sustainable Palm Oil (RSPO), have also encouraged more sustainable palm oil production, but not necessarily reduced peatland loss. Carlson et al. (2018) analyzed RSPO certified and non-certified oil palm plantations in Indonesia and found that certification had little noticeable impact on reducing forested peatland loss or active fires. Other voluntary programs, such as for carbon markets, could also be utilized to support funding of peatland conservation and restoration. One of the first programs to use carbon credits for peatland rewetting and restoration is MoorFutures in Germany. Their approach could be expanded to other countries in Europe and across the world, especially given the difficulty of raising funds for peatland restoration (Bonn et al. 2014; Günther et al. 2018). For example, Günther et al. (2018) estimates that more than half of carbon mitigation schemes over a range of peatland rewetting costs and vegetation scenarios were profitable when funded through a hypothetical carbon credit scheme (modeled on MoorFutures).

In addition to ensuring that their supply chains do not cause additional loss of intact peatlands, businesses should also engage with and actively support government efforts to reform and redirect subsidies away from activities that are harmful to peatlands. They should also proactively invest in sustainable supply chain development and support producers to tran-

[14] From https://bioenergyinternational.com/feedstock/many-palm-oil-companies-failing-to-meet-2020-zero-deforestation-targets.

sition to sustainable production practices that lead to no additional damage or conversion to peatlands. Those activities that were based on peatland conversion, such as palm oil production, could also take responsibility for previous carbon emissions and make financial contributions to future peatland restoration and carbon sequestration programs. Finally, businesses should also financially support and partner with public programs to rewet and restore degraded peatlands, including through the various innovative financial mechanisms discussed above - biodiversity offsets, payment for ecosystem services, voluntary carbon markets, REDD+, debt-for-nature swaps and green bonds.

## 8 Conclusions

The Dasgupta Review has pointed the way for ensuring that our economics are better "embedded in nature". But achieving this goal requires tackling the two principle causes of the current rapid loss of global terrestrial ecosystems and biodiversity: the *underpricing of natural landscape* and *the underfunding of nature*.

If natural areas are priced too cheaply, then converting them to agriculture, forestry and other land uses is less costly than protecting or preserving them. Underfunding nature further reduces the incentives for conserving and restoring ecosystems and habitats.

Decoupling development from excessive land use change and ecosystem loss is necessary to make our economies both more sustainable and inclusive. This outcome is crucial if we want to generate the incentives, innovations and governance necessary to transition to sustainable intensification of agriculture, forestry and other land uses, reduce food and waste, and ultimately, "bend the curve" of ecological and biodiversity decline.

Most of the world's remaining terrestrial biodiversity and natural landscape is in low and middle-income countries. Yet current global funding to support conservation efforts in these countries is woefully inadequate to prevent habitat loss and over-exploitation. This underinvestment is another reason why the world is not preserving sufficient natural areas.

If catastrophic global biodiversity decline is to be avoided, we need to rethink the international framework for cooperation, and at the same time, foster investment by those with the greatest ability and incentive to conserve biodiversity. And, if we want developing countries to conserve more natural areas, ecological capital and biodiversity that yield global benefits, then we have to devise more creative and innovative ways for helping them do so.

The good news is that we have at our disposal a growing number of financial instruments and mechanisms to spur collective action by rich countries to assist poorer ones in protection and restoration efforts, and by the private sector to invest in nature to reduce the risks posed by biodiversity and ecosystem loss. These include biodiversity offsets, payments for ecosystem services, debt-for-nature swaps, green bonds, sustainable supply chains and international environmental agreements. There are creative ways of to scale up and align finance for biodiversity and natural landscape conservation from all sources, public and private. Moreover, these mechanism should be used in conjunction with demonstrable policy reforms that end the underpricing of natural landscape.

The example of peatlands discussed in this article illustrates how a comprehensive global strategy for ending the underpricing and underfunding of nature can be devised by combining collective action with innovative financing and commitment to policy reforms in host countries. It also points to a rich resource agenda in environmental and resource economics.

First, we need more studies of how the underpricing of natural landscape is leading to the loss of important ecosystem services and values, especially in tropical developing economies. We also require analysis of the effects of policy reforms, from removal of environmentally harmful subsidies to the use of market-based instruments, on the conservation and restoration of valuable natural habitats and ecosystems. A related issue is the governance and institutional conditions for enhancing the effectiveness of and incentivizing the preservation and restoration of natural landscape.

Second, the innovative financing and funding mechanisms for biodiversity outlined in this article need further study. We also need more analysis of the collective action and accompanying institutional reforms required to ensure that adequate financing of conservation and restoration occurs in host countries. In addition, more research is required for the specific mechanisms discussed here - biodiversity offsets, payment for ecosystem services, voluntary carbon markets, REDD+, debt-for-nature swaps and green bonds – especially on how they can be scaled up and employed to increase funding of natural landscape in tropical developing countries.

**Acknowledgements** I am grateful to Ingmar Schumacher for inviting me to write this article and for his helpful guidance. I have also benefited from the comments of an anonymous referee and from the many exchanges and conversations with Partha Dasgupta concerning his Review.

## References

Badeeb R, Abubakr HH, Lean, Jeremy Clark (2017) "The evolution of the natural resource curse thesis: A critical literature survey." *Resources Policy* 51:123-134

Barbier EB (2019) Natural Resources and Economic Development, 2nd edn. Cambridge University Press, New York and Cambridge

Barbier EB (2021) Habitat Loss and the Risk of Disease Outbreak. J Environ Econ Manag 108:102451

Barbier EB (2022) Economics for a Fragile Planet. Cambridge University Press, New York and Cambridge

Barbier EB, Joanne C, Burgess *Economics of Peatlands Conservation, Restoration, and Sustainable Management - A Policy Report for the Global Peatlands Initiative*.United Nations Environment Programme, Nairobi. https://wedocs.unep.org/bitstream/handle/20.500.11822/37262/PeatCRSM.pdf

Barbier EB, Hochard JP (2019) "Poverty-environment traps." *Environmental and Resource Economics* 74, no. 3 (2019): 1239-1271

Barbier EB, Joanne C, Burgess, Thomas J, Dean (2018) How to pay for saving biodiversity. Science 360(6388):486–488

Barbier EB, Lozano R Carlos Manuel Rodriguez and Sebastian Troëng. 2020. "Adopt a carbon tax to protect tropical countries" Nature 578:213–216

Barlow, Jos, Filipe França, Toby A. Gardner, Christina C. Hicks, Gareth D. Lennox, Erika Berenguer, Leandro Castello, Evan P. Economo, Joice Ferreira, Benoit Guénard, Cecília Gontijo Leal, et al. 2018. "The future of hyperdiverse tropical ecosystems." Nature 559:517–526.

Batini N, Di Serio M, Fragetta M, Melina G (2021) and Anthony Waldron. "Building Back Better: How Big are Green Multipliers?" *IMF Working Paper* WP/21/87. International Monetary Fund, Washington, D.C

BenDor Todd TW, Lester A, Livengood A, Davis, Yonavjak L (2015) Estimating the Size and Impact of the Ecological Restoration Economy. PLoS ONE 10(6):e0128339

Bonn A, Reed MS, Evans CD, Bain HJoostenC, Farmer J, Emmer I et al (2014) Investing in nature: Developing ecosystem service markets for peatland restoration. Ecosyst Serv 9:54–65

Bowen A, and Sam Fankhauser (2011) Low-Carbon Development for the Least Developed Countries. World Econ 12(1):145–162

Budiharta S, Meijaard E, Gaveau DLA, Struebig MJ, Wilting A, Kramer-Schadt S, Wilson KA (2018) "Restoration to offset the impacts of developments at a landscape scale reveals opportunities, challenges and tough choices." *Global Environmental Change* 52: 152-161

Bullock CH, Marchs J, Collier, Frank JC (2012) Peatlands, their public good value, and priorities for their future management – the example of Ireland. Land Use Policy 29(4):921–928

Busch J and Kalifi Ferretti-Gallon (2017) What Drives Deforestation and What Stops It? A Meta-*Analysis*. Rev Environ Econ Policy 11(1):3–23

Busch J, Engelmann KFerretti-GallonJ, Wright M, Austin KG, Stolle F, Turubanova S, Potapov PV, Margona B, Hansen MC, Baccini A (2015) "Reductions in emissions from deforestation from Indonesia's moratorium on new oil palm, timber, and logging concessions." *Proceedings of the National Academy of Sciences* 112:1328-1333

Cardoso da Silva, Jose Maria, Prasad S, Felizola Diniz-Filho JA (2017) The impact of deforestation, urbanization, public investment, and agriculture on human welfare in the Brazilian Amazon. Land Use Policy 65:135–142

Carlson KM, Heilmayr R, Gibbs HK, Noojipady P, Burns DN, Morton DC, Nathalie F, Walker GD, Paoli, and Claire Kremen (2018). "Effect of oil palm sustainability certification on deforestationfire in Indonesia." *Proceedings of the National Academy of Sciences* 115(1):121-126

Cassimon D, Prowse M and Dennis Essers (2011) The pitfalls and potential of debt-for-nature swaps: A US-Indonesia case study. Glob Environ Change 21:93–102

Ceballos G, Ehrlich PR (2017) Rodolfo Dirzo. "Biological annihilation via the ongoing sixth mass extinction signaled by vertebrate population losses and declines." *Proceedings of the National Academy of Sciences.* 114(30):E6089-E6096

Chahine P (2020) and Ludwig Liagre. *How can Green Bonds catalyse investments in biodiversity and sustainable land-use projects.* Global Landscapes Forum and Luxembourg Green Exchange. https://www.globallandscapesforum.org/wp-content/uploads/2020/10/How-can-Green-Bonds-catalyse-investments-in-biodiversity-and-sustainable-land-use-projects-v12_Final.pdf

Cunningham AA, Daszak P, James LN, Wood (2017) One Health, emerging infectious diseases and wildlife: two decades of progress? Philosophical Trans Royal Soc B:Biological Sci 372:20160167

Dasgupta P (2021) The Economics of Biodiversity: The Dasgupta Review. HM Treasury, London. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/962785/The_Economics_of_Biodiversity_The_Dasgupta_Review_Full_Report.pdf

Deutz A, Heal GM, Niu R, Swanson E, Townshend T, Zhu L, Delmar A, Meghji A, Sethi SA (2020) Financing Nature: Closing the global biodiversity financing gap. The Nature Conservancy, and the Cornell Atkinson Center for Sustainability. The Paulson Institute. https://www.paulsoninstitute.org/wp-content/uploads/2020/09/FINANCING-NATURE_Full-Report_Final-Version_091520.pdf & Tobin-de la Puente

Díaz S, Settele J, Brondizio ES, Hien T, Ngo J, Agard A, Arneth P, Balvanera KA, Brauman, Stuart HM, Buthchart, Kai MA, Chan et al (2019) Pervasive human-driven decline of life on Earth points to the need for transformative change. Science 366(6471):eaax3100

Ding H, Faruqi S, Wu A, Altamirano JC, Ortega A, Verdone M (2019) René Zamora Cristales, Robin Chazdon and Walter Vergara. *Roots of Prosperity: The Economics and Finance of Restoring Land.* World Resources Institute, Washington, D.C

Dobson AP, Stuart L, Pimm L, Hannah L, Kaufman JA, Ahumada AW, Ando, Aaron Bernstein, Jonah Busch, Peter Daszak, Jens Engelmann, et al (2020) "Ecology and economics for pandemic prevention." *Science* 369(6502): 379–381

Ellis, Erle C., Jed O. Kaplan, Doran Q. Fuller, Steve Vavrus, Kees Klein Goldewijk and Peter H. Verburg. 2013. "Used Planet: A Global History." *Proceedings of the National Academy of Science* 110(20):7978–7985

Fargione JE, Bassett S, Boucher T, Bridgham SD, Conant RT, Susan C, Cook-Patton PW, Ellis A, Falucci JW, Fourqurean, Trisha Gopalakrishna, et al (2018) "Natural climate solutions for the United States." *Science Advances* 4:eaat 1869

Faust CL, Hamish I, McCallum, Laura SP, Bloomfield NL, Gottdenker TR, Gillespie CJ, Torney AP Dobson and Raina K. Plowright. 2018. "Pathogen spillover during land conversion."Ecology Letters 21(4):471–483

Friedlingstein P, Jones MO'SullivanMW, Robbie M, Andrew J, Hauck A, Olsen GP, Peters, Wouter Peters, Julia Pongratz, Stephen Sitch, Corinne Le Quéré, et al (2020) "Global Carbon Budget 2020. *Earth System Science Data* 12:3269–3340

Gibb R, Redding DW, Chin KQ, Donnelly CA, Blackburn TM (2020) Tim Newbold and Kate E. Jones. "Zoonotic host diversity increases in human-dominated ecosystems." *Nature* 584:398-402

Glenk K and Julia Martin-Ortega (2018) The economics of peatland restoration. J Environ Econ Policy 7(4):345–362

Glenk K, Faccioli M, Martin-Ortega J, Schulze C, and Jacqueline Potts (2021) The opportunity cost of delaying climate action: Peatland restoration and resilience to climate change. Glob Environ Change 70:102323

Griscom BW, Busch J, Cook-Patton SC, Ellis PW, Funk J, Leavitt SM, Guy Lomax, Will Turner, Melissa Chapman, Jens Engelmann, et al (2020) "National mitigation potential from natural climate solutions in the tropics." *Philosophical Transactions of the Royal Society B:Biological Sciences* 375(1794):20190126

Groom B and Zachary Turk (2021) Reflections on the Dasgupta Review on the Economics of Biodiversity. Environ Resource Econ 79:1–23

Günther A, Böther S, Couwenberg J, Hüttel S, Gerald, Jurasinski (2018) Profitability of direct greenhouse gas measurements in carbon credit schemes of peatland rewetting. Ecol Econ 146:766–771

Hansson A and Paul Dargusch (2018) An estimate of the financial cost of peatland restoration in Indonesia. Case Stud Environ 2(1):1–37

Haupt F, Streck C, Bakhtary H, Behm K, Alan Kroeger and Ingrid Schulte (2018). *Zero-Deforestation Commodity Supply Chains by 2020: Are We on Track.* Background Paper Prepared for the Prince of Wales' International Sustainability Unit. January, 2018. https://climatefocus.com/publications/zero-deforestation-commodity-supply-chains-2020-are-we-track

Havranek T, Hovrath R, Zeynalov A (2016) Natural Resources and Economic Growth: A Meta-Analysis. World Dev 88:134–151

Hecht SB (2014) Forests lost and found in tropical Latin America: the woodland 'green revolution.'. J Peasant Stud 41:877–909

Holden S (2019) Economics of Farm Input Subsidies in Africa. Annual Reviews of Resource Economics 11:501–522

Holland TG, Oliver T, Coomes, Robinson BE (2016) Evolving frontier land markets and the opportunity cost of sparing forests in western Amazonia. Land Use Policy 58:456–471

Huang J (2018) Facilitating Inclusive Rural Transformation in the Asian Developing Countries. World Food Policy 4(2):31–55

Humpenöder F, Karstens K, Lotze-Campen H, Leifeld J, Menichetti L Alexandra Barthelmes and Alexander Popp. 2020. "Peatland protection and restoration are key for climate change mitigation."Environmental Research Letters15(10):104093

Intergovernmental Science-Policy Platform on Global Biodiversity and Ecosystem Services (IPBES) (2019) *Global Assessment Report on Biodiversity and Ecosystem Services.* E.S. Brondizio, J. Settele, S. Díaz, and H.T. Ngo (editors). IPBES secretariat, Bonn, Germany https://ipbes.net/global-assessment-report-biodiversity-ecosystem-services

Jayne TS, Nicole M, Mason WJ, Burke and Joshua Ariga (2018) Review: Taking stock of Africa's second-generation agricultural subsidy program. Food Policy 75:1–14

Jones KE, Nikkita G, Patel MA, Levy A, Storeygard D, Balk JL, Gittleman, Peter Daszak (2008) Global trends in emerging infectious diseases. Nature 451(7181):990–993

Jones KR, Venter O, Fuller RA, Allan JR, Maxwell SL, Watson EM (2018) "One-third of global protected land is under intense human pressure." *Science* 360(6390):788-791

Joosten, Hans and Donal Clarke (2002) Wise use of mires and peatlands. Background and principles including a framework for decision-making. International Mire Conservation Group and International Peat Society, Distributed by NHBS Ltd, Devon, UK

Köhl M, Neupane PR, Philip Mundhenk (2020) REDD+ measurement, reporting and verification–A cost trap? Implications for financing REDD+ MRV costs by result-based payments. Ecol Econ 168:106513

Larson DF, Murakoda R, Otsuka K (2016) Why African rural development strategies must depend on small farms. Global Food Security 10:39–51

Leblois A, Damette O, Wolfersberger J (2017) What has driven deforestation in developing countries since the 2000s? Evidence from new remote-sensing data. World Dev 92:82–102

Leclére D, Obersteiner M, Barrett M, Stuart HM, Butchart A, Chaudhary AD, Palma, Fabrice AJ, DeClerck MD, Marco JC, Doelman, Martina Dñrauer, et al (2020) "Bending the curve of terrestrial biodiversity needs an integrated strategy." *Nature* 585:551-556

Leifeld J and Lorenzo Menichetti (2018) The underappreciated potential of peatlands in global climate change mitigation strategies. Nat Commun 9(1):1–7

Leifeld J Chloé Wüst-Galley and Susan Page. 2019. "Intact and managed peatland soils as a source and sink of GHGs from 1850 to 2100."Nature Climate Change9(12):945–947

Lowder SK, Skoet J and Terri Raney (2016) The Number, Size, and Distribution of Farms, Smallholder Farms, and Family Farms Worldwide. World Dev 87:16–29

Mace GM, Barrett M, Burgess ND, Cornell SE Robin Freeman, Monique Grooten and Andy Purvis. 2018. "Aiming higher to bend the curve of biodiversity loss."Nature Sustainability1:448–451

Martin-Ortega, Julia, Timothy EH, Allott K, Glenk, Marije Schaafsma (2014) Valuing water quality improvements from peatland restoration: Evidence and challenges. Ecosyst Serv 9:34–43

Mehlum, Halvor, Karl Moene, and Ragnar Torvik. 2006. "Institutions and the resource curse." Economic Journal 116(508):1–20

Mehrabi Z, Ellis EC and Navin Rmankutty (2018) The challenge of feeding the world while conserving half the planet. Nat Sustain 1:409–412

Miles L, Ravilious C (2017) Shaenandhoa García-Rangel, Xavier de Lamo, Greta Dargie and Simon Lewis. *Carbon, biodiversity, and land-use in the Central Congo Basin Peatlands*. UNEP-WCMC, Geneva. https://wedocs.unep.org/bitstream/handle/20.500.11822/22918/Congo_Peatland_EN.pdf?sequence=1&isAllowed=y

Newbold T, Hudson LN, Arnell AP, Contu S, Palma AD, Ferrier S, Samantha LL, Hill et al (2016) Has land use pushed terrestrial biodiversity beyond the planetary boundary? A global assessment. Science 353(6296):288–291

Organization for Economic Cooperation and Development (OECD) (2019) *Biodiversity: Finance and the Economic and Business Case for Action*, report prepared for the G7 Environment Ministers' Meeting, 5-6 May 2019. OECD, Paris. https://www.oecd.org/environment/resources/biodiversity/G7-report-Biodiversity-Finance-and-the-Economic-and-Business-Case-for-Action.pdf

Organization for Economic Cooperation and Development (OECD) (2020a) A Comprehensive Overview of Global Biodiversity Finance. OECD, Paris. https://www.oecd.org/environment/resources/biodiversity/report-a-comprehensive-overview-of-global-biodiversity-finance.pdf

Organization for Economic Cooperation and Development (OECD) (2020b) Biodiversity and the economic response to COVID-19: Ensuring a green and resilient recovery. OECD, Paris. https://www.oecd.org/coronavirus/policy-responses/biodiversity-and-the-economic-response-to-covid-19-ensuring-a-green-and-resilient-recovery-d98b5a09/

Papyrakis E (2017) The Resource Curse - What Have We Learned from Two Decades of Intensive Research: Introduction to the Special Issue. J Dev Stud 53(2):175–185

Pingali PL (2012) "Green Revolution: Impacts, limits, and the path ahead." *Proceedings of the National Academy of Sciences* 109:12302-12308

Richards PD (2015) "What Drives Indirect Land Use Change? How Brazil's Agriculture Sector Influences Frontier Deforestation. Ann Assoc Am Geogr 105:1026–1040

Richards PD, Robert T, Walker, Eugenio Y, Arima (2014) Spatially complex land change: The indirect effect of Brazil's agricultural sector on land use in Amazonia. Glob Environ Change 29:1–9

Sommer JM, Restivo M, Shandra JM (2020) The United States, Bilateral Debt-for-Nature Swaps, and Forest Loss: A Cross-National Analysis. J Dev Stud 56(4):748–764

Springmann M, Clark M, Weibe DMason-D'CrozK, Bodirsky BL, Lassaletta L, de Vries W, Vermeulen SK, Herrero KM, Carson et al (2018) "Options for keeping the food system within environmental limits." *Nature* 562:519-524

Sterner T, Barbier EB, Bateman I, van den Bijgaart A-S, Crépin O, Edenhofer C, Fischer et al (2019) "Policy design for the Anthropocene." *Nature Sustainability* 2(1):14-21

ten Kate A, Kuepper B, Piotrowski M (2020) NDPE Policies Cover 83% of Palm Oil Refineries; Implementation at 78%. Chain Reaction Research. https://chainreactionresearch.com/wp-content/uploads/2020/04/NDPE-Policies-Cover-83-of-Palm-Oil-Refining-Market.pdf Washington, D.C.

Tilman D, Balzer C, Hill J, Befort BL (2011) "Global food demand and the sustainable intensification of agriculture." *Proceedings of the National Academy of Sciences* 108(50):20260-20264

United Nations Environment Programme (UNEP) (2021) State of Finance for Nature. UNEP, Nairobi

van der Ploeg F (2011) Natural Resources: Curse or Blessing? J Econ Lit 49:366–420

Waldron A, Miller DC, Redding D, Mooers A, Kuhn TS, Nibbeline N, Roberts JT, Tobia JA, Gittleman JL (2017) Reductions in global biodiversity loss predicted from conservation spending. Nature 551:364–367

*Green Bonds: Impact Report 2020 Program Summary.* World Bank, World Bank, Washington DC (2020) https://thedocs.worldbank.org/en/doc/154ba77509388e75fdb5461e75614536-0340022021/original/WB-SDB-Impact-Report-2020-Green-Program-Summary.pdf

World Economic Forum (WEF) (2020) *New Nature Economy Report II: The Future of Nature and Business.* World Economic Forum in collaboration with AlphaBeta. WEF, Geneva. http://www3.weforum.org/docs/WEF_The_Future_Of_Nature_And_Business_2020.pdf

WWF. *Living Planet Report 2020 - Bending the curve of biodiversity loss*. Almond, R.E.A., Grooten M. and Petersen, T. (Eds). WWF, Gland, Switzerland. https://www.zsl.org/sites/default/files/LPR%202020%20Full%20report.pdf

WWF UK (2021) *WWF UK Response to the Dasgupta Review.* WWF UK, February 2021. https://www.wwf.org.uk/sites/default/files/2021-02/WWF_UK_response_Dasgupta%20Review_1_2_21.pdf

Xu J, Morris PJ, Holden J (2018a) Hotspots of peatland-derived potable water use identified by global analysis. Nat Sustain 1(5):246–253

Xu J, Morris PJ, Junguo Liu, and Joseph Holden (2018b) PEATMAP: Refining estimates of global peatland distribution based on a meta-analysis. CATENA 160:134–140