Comment

MAHENDRA PARIKH/*HINDUSTAN TIMES* VIA GETTY

Women in northern Mumbai, India, have planted mangrove saplings to protect the area against rising sea levels.

Nature-based solutions can help cool the planet — if we act now

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Analysis suggests that to limit global temperature rise, we must slash emissions and invest now to protect, manage and restore ecosystems and land for the future.

Projects that manage, protect and restore ecosystems are widely viewed as win–win strategies for addressing two of this century's biggest global challenges: climate change and biodiversity loss. Yet the potential contribution of such nature-based solutions to mitigating climate change remains controversial.

Decision-makers urgently need to know: what role do nature-based solutions have in the race to net-zero emissions and stop further global temperature increases?

Analyses of nature-based solutions often focus on how much carbon they can remove from the atmosphere. Here, we provide a new perspective by modelling how these solutions will affect global temperatures — a crucial metric as humanity attempts to limit global warming.

Our analysis shows that nature-based solutions can have a powerful role in reducing temperatures in the long term. Land-use changes will continue to act long past the point at which net-zero emissions are achieved and global temperatures peak (known as peak warming), and will have an important role in planetary cooling in the second half of this century. Before then, nature-based solutions can provide real but limited mitigation benefits. Crucially, the more ambitious the climate target, the shorter the time frame for such solutions to have an effect on peak warming.

In other words, nature-based solutions must be designed for longevity. This means paying closer attention to their long-term carbon-sink potential, as well as their impacts on biodiversity, equity and sustainable development goals. It also means continuing to limit global warming through other methods, from decarbonization to geological storage of carbon dioxide.

Our model reinforces the conclusion that an ambitious scaling-up of nature-based solutions needs to be implemented fast and thoughtfully – and not at the expense of other measures.

Win–wins

The world is currently likely to hit 3 °C of warming above pre-industrial levels by 2100 (although recent policy announcements from the United States and China could reduce this). The 2015 Paris climate agreement aims to limit the global temperature rise this century to well below 2 °C, and, ideally, to 1.5 °C. There is no date for either goal, beyond the "end of this century". The metric that matters most is the peak temperature, with more-aggressive efforts required to stay below 1.5 °C of warming than for the 2 °C target.

It is impossible to achieve the needed reduction in peak warming solely through cuts to greenhouse gases, because emissions from certain sectors, such as agriculture and some heavy industry, cannot be driven to zero any time soon. For this reason, we also need to remove greenhouse gases from the atmosphere on an unprecedented scale[1].

There are various options for doing this. For example, when biomass vegetation is burnt for energy, the emitted CO_2 can be retained and stored underground. This process, known as bioenergy with carbon capture and storage (BECCS), requires vast areas of land – compromising food security and biodiversity – as well as time to develop on a large scale. Other options involve industrial machines that capture CO_2 from the air; these are currently nascent, expensive technologies.

"Nature-based solutions can deliver many local ecological and socio-economic benefits."

A subset of nature-based solutions can be used specifically to limit warming. These 'natural climate solutions' aim to reduce atmospheric greenhouse-gas concentrations in three ways. One is to avoid emissions by protecting ecosystems and thus reducing carbon release; this includes efforts to limit deforestation. Another is to restore ecosystems, such as wetlands, so that they sequester carbon. The third is to improve land management – for timber, crops and grazing – to reduce emissions of carbon, methane and nitrous oxide, as well as to sequester carbon (see 'Three steps to natural cooling').

Decades of work provide strong evidence that nature-based solutions can deliver many local ecological and socio-economic benefits[2]. Restoring a forest next to a stream, for example, might reduce flooding, improve carbon storage and support fisheries. Growing recognition of such benefits means that interest in nature-based solutions is soaring: they can help people adapt to climate change, achieve sustainable development goals, protect biodiversity and mitigate climate change[3].

Quantifying nature's role

There is still debate around how much nature-based solutions can contribute to achieving net-zero targets by mid-century. This is because results have been estimated across a range of objectives, time frames and model assumptions[4,5] (see Supplementary information; SI). Some researchers say that tree restoration is the most effective climate-change solution we have available[6] (this in itself has been robustly contested); others argue that nature-based solutions won't be nearly as fast or as effective as is often stated[7].

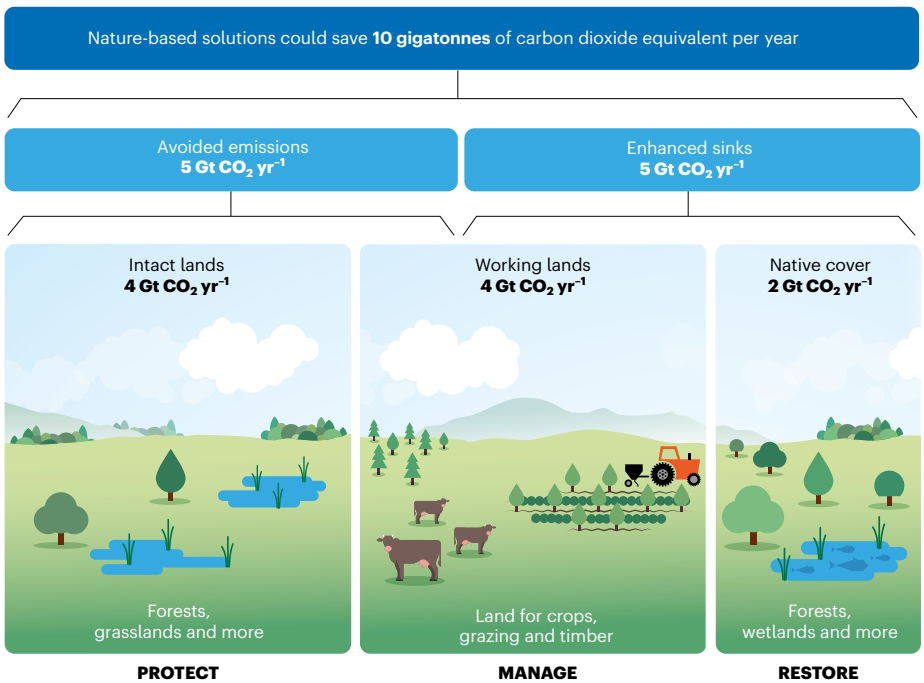
Part of the reason for the impasse is this: many well-known papers discuss the annual carbon uptake possibilities of nature-based solutions; they do not discuss their cooling impact year on year. Because the Paris agreement is framed in terms of temperature, we argue that this gap is critical: researchers need to know how nature-based solutions will affect global temperature.

To model this, we consider an ambitious but realistic scenario – an update to previous estimates by one of our co-authors (B.W.G)[4,8,9]. This scenario considers only those projects for nature-based solutions that are constrained by many factors: they are cost-effective (costing less than US$100 per tonne of CO_2 equivalent); ensure adequate global production of food and wood-based products; and involve sufficient biodiversity conservation. They also respect land tenure rights and don't change the amount of sunlight reflected from Earth, or albedo (see SI). In our scenario, nature-based solutions that avoid emissions ramp up quickly – by 2025 – and absorb carbon while avoiding emissions at a rate of 10 gigatonnes of CO_2 per year (Gt CO_2 yr^{-1}). This rises to 20 Gt CO_2 yr^{-1} in the most ambitious scenario (peak warming of 1.5 °C by 2055), in which we assume a higher price of carbon. The 10-Gt value is cost-contained. But we also account for 30 years of higher-priced nature-based solutions in the 1.5 °C scenario (up to $200 per tonne of CO_2 equivalent; see SI). For comparison, 10 Gt CO_2 yr^{-1} is more than the emissions from the entire global transportation sector.

Achieving 10 Gt CO_2 yr^{-1} of mitigation in this way would involve stopping the destruction of ecosystems worldwide (including 270 million hectares of deforestation); restoring 678 million hectares of ecosystems (more than twice the size of India); and improving the management of around 2.5 billion hectares of land by mid-century[4]. This is ambitious, but it is important to note that the bulk of land required

THREE STEPS TO NATURAL COOLING

Protect intact ecosystems, manage working lands and restore native cover to avoid emissions and enhance carbon sinks.



Underlying data are in Supplementary information, Table S1.

SOURCE: S. JENKINS *ET AL. GEOPHYS. RES. LETT.* **45**, 2795–2804 (2018).

(85%) comes from improving management of existing lands for agriculture, grazing and production forest without displacing yields of food, wood-based products or fuel (see 'Three steps to natural cooling').

These estimates come with caveats (see SI). The role of nature-based solutions could be larger if one considers, for example, their impacts on other greenhouse gases besides CO_2. This could represent an additional amount of roughly 1–3 Gt CO_2 equivalent yr^{-1} of climate mitigation. Alternatively, the contribution of such solutions might be smaller in the long term, if the carbon drawdown from land-based interventions decreased over time. This could happen if these natural sinks became saturated or were affected by climate impacts such as forest fires. These caveats are not included in our estimates.

We then modelled how this level of nature-based solutions would affect global temperature up to 2100 (see 'The long game' and SI). We looked at illustrative pathways from the Intergovernmental Panel on Climate Change, in which peak warming is constrained to 1.5 °C or 2 °C, and ran these scenarios with the added contribution of nature-based solutions as described. These pathways include BECCS, but no nature-based solutions beyond some avoided deforestation.

CHRISTIAN ENDER/GETTY

Instituto Terra, an initiative in Aimorés, Brazil, is restoring a devastated ecosystem.

Taking the temperature

Our analysis shows that implementing this level of nature-based solutions could reduce the peak warming by an additional 0.1 °C under a scenario consistent with a 1.5 °C rise by 2055; 0.3 °C under a scenario consistent with a 2 °C rise by 2085; and 0.3 °C under a 3 °C-by-2100 scenario (see 'The long game').

The most significant contribution nature-based solutions can make to mitigating the peak temperature is in the 2 °C scenario. In a more ambitious 1.5 °C scenario, there isn't enough time for nature-based solutions to have as great an impact on peak warming. In the 3 °C scenario, several issues constrain the impact of nature-based solutions, including the limited ability of ecosystems to absorb carbon in a warmer world.

Overall, the mitigation potential of nature-based solutions remains small compared to what can be achieved by decarbonizing the economy. Yet, assuming that decarbonization takes place, nature-based solutions can still suppress a chunk of the warming (see SI).

Crucially, nature-based solutions cool the planet long after the peak temperature is reached. In the 1.5 °C scenario, they take a total of 0.4 °C off warming by 2100 — four times their suppression to the 2055 peak temperature (see SI, Table S2).

Achieving these significant long-term benefits requires several things. Nature-based solutions of good quality must be scaled up rapidly — and not at the expense of other robust strategies. Long-term geological storage of CO_2, for example, will need to be ramped up significantly in the next decade as technologies mature and prices fall. The long-term benefits of nature-based solutions also depend on warming being held in check. The increased frequency and intensity of impacts such as wildfires can undermine ecosystems and their capacity to store carbon or provide other benefits to society.

Ecosystems that are protected and carefully managed — such as intact peatlands and old-growth tropical rainforests — are very likely to continue to store carbon for thousands of years. These are also more resilient to climate extremes and pathogens.

The right metrics

Restoration of forest cover is widely considered the most viable near-term opportunity for carbon removal. Unfortunately, some of this enthusiasm has been used to promote plantation forestry — growing trees of a limited variety of ages and species (for example, in monoculture plantations) does not have the same carbon benefits as maintaining an intact forest ecosystem[10].

One serious problem is that some nature-based solutions, as currently implemented, can have unintended and unwanted consequences. For example, an area of 34,007 hectares of intact forest ecosystem in Cambodia became a logging concession, with much of it replaced with an acacia monoculture. This was the first large-scale reforestation project to be funded in Cambodia in the context of climate-change mitigation. The project resulted in unethical ecological devastation, affecting 1,900 families in the area[11].

Similarly, Chilean government subsidies for new plantations of pine and eucalyptus have resulted in plantations expanding by 1.3 million hectares since 1986, with an associated sequestration of about 5.6 million tonnes of carbon. However, regulations stating that expansion cannot happen at the expense of native biodiverse forests were not enforced, resulting in large-scale reductions in native forest cover. Clearing of the original forest has resulted in a net decrease of approximately 0.05 million tonnes of stored carbon since 1986 (ref. 12).

These examples show how a singular focus on rapid carbon sequestration as the metric of success for land-based climate mitigation can result in perverse outcomes. Activities should be evaluated and monitored with the right metrics, to account for the multitude of benefits they provide in the long term.

To ensure long-term resilience, projects involving nature-based solutions should adhere to four high-level principles (see nbsguidelines.info). First, nature-based solutions are not an alternative to decarbonization; second, they need to involve a wide range of ecosystems; third, they should be designed in partnership with local communities while respecting Indigenous and other rights; and, finally, they must support biodiversity, from the level of the gene to the ecosystem. In addition, the Oxford principles[13] for high-quality offsets call for safe and durable CO_2 removal and storage for every tonne of CO_2 emitted. Metrics of success

should include those for carbon dynamics, biodiversity across multiple trophic levels, and socio-economic factors such as women's empowerment and youth employment.

There are many examples of good-practice projects (see also case studies by the University of Oxford's Nature-based Solutions Initiative, where N.S. and C.A.J.G. work). For example, mangrove forests in eastern India that have been protected from deforestation since 1985 have been shown to protect coastal regions from the negative impacts of cyclones much better than artificial defences do, while also soaking up carbon[14]. In Sierra Leone's tropical rainforest, cocoa agroforestry — where cocoa is planted with trees for shade, alongside pineapples, chillies and maize (corn) as an additional source of food and income — has been shown to produce cocoa sustainably while diminishing forest clearance. One agroforestry project in the Gola Rainforest National Park, initiated 30 years ago, has increased biodiversity and the profitability of crops while saving an estimated 500,000 tonnes of carbon each year through sequestration and avoiding deforestation.

Invest wisely

This much is clear: we urgently need to increase investment in high-quality nature-based solutions. They currently receive a small proportion of existing climate-mitigation financing[4,15], which does not reflect their potential.

Carbon markets are increasingly relied on to finance nature-based solutions. But carbon offsets on the voluntary market are of variable quality. It can be unclear whether projects really represent a carbon sink, whether they are permanent or if they safeguard social and ecological factors. Offsets that adhere to standards can allow organizations to deliver lower-cost and hence larger climate-mitigation outcomes through nature-based solutions; however, budgets to emit fossil fuels should be ratcheted down rapidly to avoid delaying decarbonization from continued greenhouse-gas emissions.

Nature-based solutions need both public and private finance; in particular, governments need to reward ecosystem stewardship while taxing polluters and ramping up regulation to ensure that companies meet strict social and environmental safeguards.

The United Nations Framework Convention on Climate Change (UNFCCC) needs to provide clear guidelines on national-level accounting for nature-based solutions. This will guide the targets set in the Paris agreement's Nationally Determined Contributions, and the monitoring, reporting and verification methodologies required to comply with these targets.

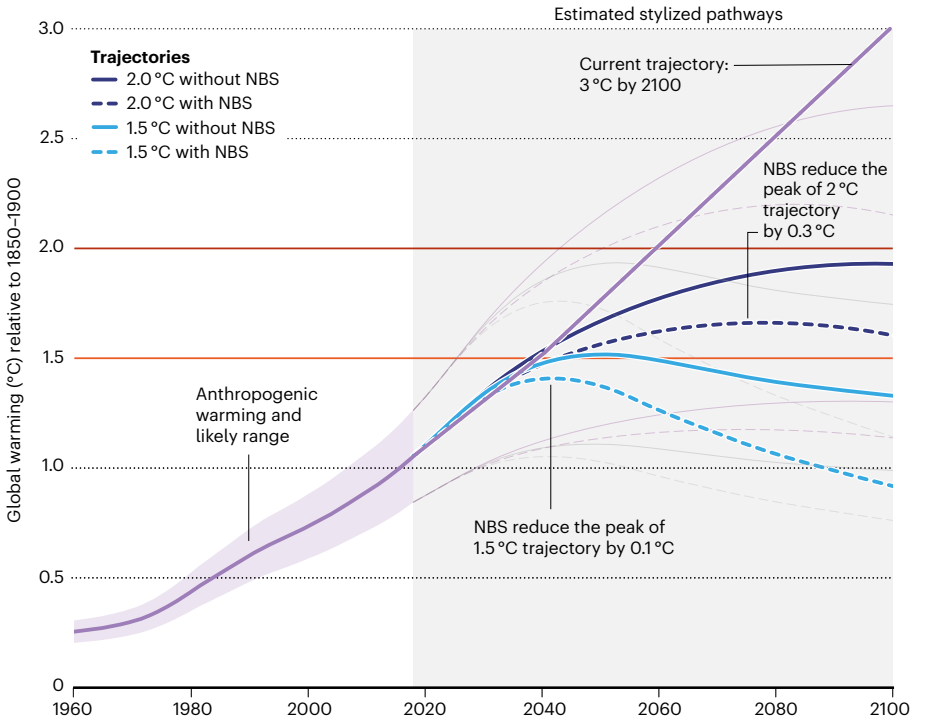
The next UNFCCC meeting, COP26, is due to be held in Glasgow, UK, this November and provides an opportunity for national reporting systems to tighten national carbon accounting related to nature-based solutions. This would ensure that such solutions make a real, long-term contribution to carbon mitigation and could set metrics to ensure high biodiversity levels and maximize human well-being. One pressing issue for COP26 is Article 6 of the Paris agreement, which established a "mechanism to contribute to the mitigation of greenhouse gas emissions and support sustainable development". A tightly regulated compliance market defined in Article 6 will provide the grounding for a tightly regulated voluntary offsetting market.

COP26 also presents the chance to harmonize the goals of the UNFCCC and those of the Convention on Biological Diversity. For example, nature-based solutions projects are likely to be required to adhere to the principle of free prior informed consent of local people: local communities need to be involved at all stages of project planning and management. Similarly, nature-based solutions should be required to protect and enhance biodiversity. This work can build on existing social and biodiversity standards[3].

Our economy must be decarbonized at unprecedented rates to achieve net-zero targets by mid-century. Carbon must also be removed from the atmosphere to counter emissions that are hard to eliminate, using nature-based solutions and other means. To transform social and economic systems to deliver resilience in the face of ongoing climate impacts, the world must invest now in nature-based solutions that are ecologically sound, socially equitable and designed to pay dividends over a century or more. Properly managed, these could benefit many generations to come.

THE LONG GAME

Nature-based solutions (NBS) could reduce the global peak temperature and suppress warming beyond 2100 — if they are ambitious and designed for longevity.



ADAPTED FROM FIG. SPM.1 OF REF. 1

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1. Intergovernmental Panel on Climate Change. Summary for Policymakers. In *Global Warming of 1.5°C* (eds Masson-Delmotte, V. *et al.*) (World Meteorological Organization, 2018).
2. Chausson, A. *et al. Glob. Change Biol.* **26**, 6134–6155 (2020).
3. Seddon, N. *et al. Glob. Change Biol.* **27**, 1518–1546 (2021).
4. Griscom, B. W. *et al. Proc. Natl Acad. Sci. USA* **114**, 11645–11650 (2017).
5. Roe, S. *et al. Nature Clim. Change* **9**, 817–828 (2019).
6. Bastin, J.-F. *et al. Science* **365**, 76–79 (2019).
7. Baldocchi, D. & Penuelas, J. *Glob. Change Biol.* **25**, 1191–1197 (2019).
8. Griscom, B. W. *et al. Phil. Trans. R. Soc. B* **375**, 20190126 (2020).
9. Busch, J. *et al. Nature Clim. Change* **9**, 463–466 (2019).
10. Lewis, S. L., Wheeler, C. E., Mitchard, E. T. A. & Koch, A. *Nature* **568**, 25–28 (2019).
11. Scheidel, A. & Work, C. *Land Use Policy* **77**, 9–18 (2018).
12. Heilmayr, R., Echeverría, C. & Lambin, E. F. *Nature Sustain.* **3**, 701–709 (2020).
13. Allen, M. *et al. The Oxford Principles for Net Zero Aligned Carbon Offsetting* (Univ. Oxford, 2020).
14. Badola, R. & Hussain, S. A. *Environ. Conserv.* **32**, 85–92 (2005).
15. Buchner, B. *et al. Global Landscape of Climate Finance 2019* (Climate Policy Initiative, 2019).