# Harnessing the potential of nature-based solutions for mitigating and adapting to climate change

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## Abstract

While many governments, financial institutions and corporations are embracing nature-based solutions as part of their sustainability and net-zero carbon strategies, some nations, Indigenous People and Local Community groups and grassroots organisations have rejected the approach. This pushback is fuelled by: 1) critical uncertainties about when, where, how and for whom nature-based solutions are effective; and 2) controversies surrounding their misuse in greenwashing, violations of human rights and threats to biodiversity. To clarify how the science community can help address these issues, I provide an overview of recent research on the benefits and limits of nature-based solutions, including how they compare with technological approaches, and highlight critical areas for future research.

## Main text

Nature-based solutions are actions that involve people working with nature, as part of nature, to address societal challenges, providing benefits for both human well-being and biodiversity (*1, 2*). Climate change is one such key societal challenge. Examples of nature-based solutions that can help people adapt to climate change impacts include: community-led protection, restoration and management of natural and semi-natural ecosystems within river catchments or along coastlines to protect against flooding and erosion; sustainable management of working lands to sustain or enhance yields during unpredictable growing conditions; and creation of green and blue infrastructure in urban areas for cooling and to reduce flood risk. In addition to supporting human adaptation, such actions can increase carbon storage to help mitigate climate change and protect biodiversity (*3*, Figure 1).

The rapid rise in the prominence of nature-based solutions in policy, research, and business agendas (Figure 2, *2*) is based on their perceived or documented effectiveness, readiness, scalability and affordability compared to technological solutions (*3*). It also reflects broader recognition of the interdependency of societal wellbeing and ecosystem health (*4*). Yet, in the final hours of the negotiations at the 26$^{th}$ Conference of the Parties (CoP26) to the United Nations Framework

Convention on Climate Change, the term “nature-based solution” was removed from the decision text (i.e., the Glasgow Climate Pact). What remained was a commitment by the Pact’s 197 signatories to recognize “the critical role of protecting, conserving and restoring nature and ecosystems in delivering benefits for climate adaptation and mitigation, while ensuring social and environmental safeguards” *(5).* Although it could be claimed that nature-based solutions were included in all but name, CoP26 revealed that while many organisations and governments are embracing the approach as an essential tool for tackling climate change, others, particularly grass roots organisations, have dismissed it as a dangerous distraction from systemic change (*6*). Contrasting narratives partly reflect uncertainty in the underlying evidence as well as controversies on how nature-based solutions are conceptualized and implemented. Here, I review recent research on the effectiveness of nature-based solutions to climate change mitigation and adaptation, and provide an overview of how an improved evidence base, supported by interdisciplinary research and traditional knowledge, can and must help address these issues.

**The role of nature-based solutions for addressing climate change**

There is general scientific consensus that to achieve the Paris Agreement ambition of limiting mean temperature increase to 1.5°C, the global economy will require significant, rapid greenhouse gas (GHG) emission reductions, reaching net-zero $CO_2$ by around 2050, and likely needing ongoing net-$CO_2$ removals thereafter *(7)*. Nature-based solutions play a key role by reducing the release of GHGs from the agriculture, forest and landuse sector—which currently account for around 22% of annual GHG emissions —and by protecting and enhancing the carbon sink on land and in the sea *(7)*. Specifically, improving the management of working lands and seas (e.g. cropland, pastures, timberlands and aquatic systems) reduces emissions of $CO_2$, methane, and nitrous oxide, and sequesters carbon; restoring native vegetation across rural landscapes and planting trees in cities enhances $CO_2$ removal from the atmosphere; and effectively protecting intact forests, grasslands and wetlands keeps critical reserves of carbon locked in the biosphere (*7*).

Estimates of the extent to which nature-based solutions can cool the planet vary considerably. To date, there have been over 30 published estimates for nature-based solutions’ global contribution to climate change mitigation *(8).* These include terrestrial and coastal ecosystems but exclude the ocean, where knowledge of carbon fluxes is limited (*9*). The large range in estimates of land-based mitigation globally (from around 100 to over 1000 Gt of accumulated $CO_2$ by the end of the century) reflects differences in studies’ methods and assumptions (*8*). High estimates assume society is willing to pay a high price for carbon (>100 $ per tonne), consider few biophysical or socioeconomic constraints on implementation, include a wide range of ecosystems, and do not distinguish between afforestation (i.e. planting forests where they did not previously exist) from reforestation approaches (*8*). Conversely, low estimates assume a carbon price <100 $ per tonne, consider stricter biophysical and socioeconomic limits on where nature-based solutions can be implemented, and/or include a smaller subset of ecosystems or types of interventions (*8*). When net climate effects are included in models, global estimates of climate change mitigation potential of nature-based solutions also tend to be lower *(8, 10).* While nature-based solutions generally increase carbon storage, they can also have local biophysical or biochemical effects that increase temperatures (for example by decreasing albedo) depending on latitude and the type of vegetation.

Even the most constrained estimates of the contribution of land-based nature-based solutions to global climate change mitigation are highly uncertain. They do not consider the risk of impermanence, as climate change and other anthropogenic stressors can undermine health of ecosystems *(11).* Nor do they account for the serious problem that scaling up of nature-based solutions in one region can result in the export of ecosystem loss and damage to another (a phenomenon termed "leakage"). Leakage is especially problematic when it results in biodiversity loss through the degradation and destruction of native vegetation elsewhere (e.g. *12*). In view of such issues, a conservative potential for nature-based solutions on land globally to contribute to climate change mitigation is around 100–200 Gt $CO_2$ during the remainder of the twenty-first century (*8*) or at most 11.5 Gt $CO_2$eq per year up to 2050 (*7*). This is equivalent to a reduction in mean global temperature by 0.3°C if temperature rise since pre-industrial times peaks at 2°C by 2075 *(13).* In other words, while important, the contribution of nature-based solutions to global cooling is much smaller than what must also be achieved through drastic cuts in the use of fossil fuels (*14*).

In recognition that significant climate change has already occurred and further warming is inevitable*,* Paris Agreement signatories have committed to "enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change" *(15).* While no single metric can track adaptation progress and it is as much a process as an outcome, there are many examples of successful adaptation at the local level (Figure 3). However, a recent systematic review of 1,682 publications found that humans are failing to implement adaptation strategies, other than by making minor adjustments such as developing drought-resistant crops *(16).* Consequently, there is a large and widening gap between climate change adaptation needs and action. This is especially true in developing countries where there is a lack of international climate finance and adaptation costs are five to ten times greater than current flows of public funding *(17)*.

Nature-based solutions can help to bridge this gap. People have been working with nature to help adapt to environmental changes since time immemorial. Nature-based solutions harness this process and contribute to different aspects of adaptation (*3, 18, 19).* In particular, there is robust evidence showing they can reduce direct exposure to climate change impacts. For example, restoring native ecosystems can promote healthy soil and vegetation that reduce the risks of floods, droughts and landslides by increasing infiltration and storage of water, stabilizing slopes and shores, and attenuating wave energy (*20-22*; Figure 1). Introducing green and blue infrastructure, such as bio-swales, green roofs, and constructed wetlands, into urban areas can help moderate heatwaves and reduce flooding (*22, 23*). There is also evidence that nature-based solutions can reduce sensitivity, or the degree to which people are affected by climate impacts. For example, nature-based agricultural practices such as agroforestry can sustain or enhance yields in drier or more unpredictable climates (*24, 25*). Further, implementing nature-based solutions can build capacity to innovate or adjust in response to changing conditions, thereby supporting adaptation as a process (*19*).

Nature-based solutions can complement engineered approaches to address climate mitigation and adaptation, with some key advantages. Technological approaches for greenhouse gas removal, such as direct air capture and enhanced weathering, are effective but expensive and energy-intensive (*26)*. Similarly, structures designed to reduce climate change impacts, such as sea walls and dikes, can be constructed quickly and are efficient in mitigating specific hazards. However, construction brings social and environmental damages locally and the financial costs of maintaining or upgrading engineered structures can be very high (e.g., US$12–71 billion per year to protect against sea level rise with dikes globally (*27*). In contrast, nature-based solutions can take time to establish, and their efficacy can vary with intensity and frequency of threats and the resilience of ecosystems to climate impacts. Yet as living, evolving systems, nature-based solutions have the potential for self-repair and adaptation and may keep pace with a changing climate; for example, some studies suggest that oyster reefs and mangroves can track sea level rise (*3, 28*). Thus, while initial implementation costs of nature-based solutions can be high (*29*), maintenance costs over the long term may be lower than engineered alternatives.

Few studies directly contrast the efficacy of nature-based and other approaches, but some have showed that nature-based and/or hybrid solutions can have benefit cost ratios many times larger than engineered alternatives when their long term and broader benefits are taken into account (*3, 30)*. Further, there are indications that nature-based solutions are more cost-effective than engineered alternatives in lower-intensity hazard scenarios, while hybrid approaches are more cost-effective for high-intensity hazards, especially for flood mitigation along coasts (*31*) and storm water management in cities (*32*). In other words, a combination of approaches is needed to address the drivers and impacts of climate change. Yet the default remains engineered solutions. This is a missed opportunity to build resilience, especially in lower income nations where dependency on natural resources is high and finance for technology limited.

## Varying effectiveness and misuse of nature-based solutions

The effectiveness of nature-based solutions varies depending on the type and condition of the ecosystems, the interventions involved, how they are implemented, and the target beneficiaries (*2,3*). Globally, the most cost-effective land-based mitigation potentials involve forests (especially in the tropics), followed by inland wetlands (peatland soils), coastal wetlands, and grasslands (*33*). According to the "Natural Climate Solutions hierarchy", protecting intact ecosystems has the highest potential for mitigation, followed by management of working lands, and lastly restoration (*34*). Preventing the loss of stored carbon by protecting ecosystems is estimated to be about twice as effective globally as restoring lost or damaged ecosystems (around 4 GT $CO_2$ per year compared to 2 GT $CO_2$ per year for restoration, *13*). Moreover, the gradual accumulation of carbon from restoration cannot compensate, in a timely way, for the rapid emission of large amounts of carbon from deforestation and degradation (*34*). Protecting intact ecosystems, especially old growth forests, also brings the greatest benefits for biodiversity and local communities (including supporting climate change adaptation) and has the lowest risk of impermanence (*35*).

The potential benefits of nature-based solutions are ultimately limited by the availability of suitable land and sea areas, and so it is the larger countries with the highest forest cover that could benefit the most from their implementation (*36*). Ecosystem protection and restoration face intense competition with other uses such as coastal and urban development, the production of food and fibre, and carbon-reduction technologies such as wind and solar farms. However, most (85%) of the land needed for 10 Gt $CO_2$ of cost-effective (<100 US$ per tonne) mitigation per year comes from improving the management of existing working lands, i.e. around 2.5 billion ha of agricultural and grazing lands and production forest (*13*). Rather than displacing food and fibre production, nature-based solutions on these lands (for example by implementing agroforestry) could enhance yields (e.g., *24, 25*).

Even where suitable space for nature-based solutions is available, major anthropogenic stressors threaten the health and resilience of ecosystems and their ability to provide benefits to society (Figure 1). Ecosystems are usually well-adapted to natural disturbances, and some require a degree of disturbance to thrive. However, under anthropogenic climate change, the frequency and intensity of fire, floods, droughts and invasion by new pests and pathogens may be too high to allow for recovery and/or adaptation (*7*). Such climate-driven risks are already causing forest die back across the world (*11)* and are predicted to reduce carbon sequestration by tropical forests (*37),* and many ecosystems have transitioned or are in the process of transitioning to alternative states under climate change that either cannot support human adaptation or are net-sources of GHGs (*3, 37, 38*). Thus, unless GHG emissions are curbed, the impacts of climate change will cause the carbon stored in ecosystems to be released back into the atmosphere, accelerating warming and compromising human adaptation *(2, 11).* Such climate-driven threats to ecosystem integrity are compounded by pollution, logging and fragmentation (*38*) which reduce resilience via loss of biodiversity and curtail species' abilities to track shifting climate niches (*39*). Conversely, careful adaptive management of nature-based solutions over time can reduce these threats and increase resilience (*19*).

In addition, a wide range of institutional, socioeconomic and cultural factors hinder implementation and maintenance of nature-based solutions (Figure 1), especially in the areas of governance and finance (*8, 40, 41*). Implementing nature-based solutions requires overcoming siloed governance, as it is often a multisectoral trans-jurisdictional policy issue requiring cooperation within and between governments and among stakeholders with differing or conflicting priorities. Nature-based solutions are rarely implemented unless they are mainstreamed or integrated with existing planning tools (*41).* Successful implementation also requires secure and sustainable flows of finance to the communities and projects that need it most, in the form most suitable for the local socio-cultural and political context. Land ownership and access are also critical considerations; there is evidence that nature-based solutions projects in Europe are more successful when implemented in designated conservation areas where land rights and access are already established (*41*). Such constraints on the feasibility of implementing nature-based solutions can reduce their potential (*36*), (for example, the mitigation potential of restoring of degraded lands in Southeast Asia was reduced by 80% when implementation barriers were considered, *42*).

Despite growing evidence for the multiple benefits of well-designed nature-based solutions, the term has become controversial for three broad reasons. First, nature-based solutions are being used in "greenwashing", delaying and distracting from the urgent need to decarbonize the economy. As a result, some have dismissed nature-based solutions as a "dangerous distraction" from the urgent need to keep fossil fuels in the ground that has been co-opted by those wanting to perpetuate the "unsustainable, unjust status quo" of an energy-intensive global economy *(6)*. Specifically, many of the biggest emitters (such as fossil fuel companies and the wealthy nations that subsidise them) invest in activities badged as nature-based solutions as part of their net-zero carbon plans without also investing in robust plans to rapidly decarbonize their operations (*43*). Including nature-based solutions as carbon 'offsets' while continuing business as usual not only allows for continued emissions, dismissing the need for systemic change, but also distracts attention from harmful, and often catastrophic, local impacts of fossil fuel extraction on people and the environment.

A second major concern is that actions badged as nature-based solutions are sometimes implemented through top-down governance structures that do not respect local rights; fail to account for local voices, values and knowledges in decision-making; and perpetuate power asymmetries (*6*). For example, there is evidence that poor quality 'carbon offsets', such as plantations of single, non-native tree species, are leading to land grabs. Sometimes plantations or protected areas are established in the name of climate change mitigation within Indigenous Peoples' territories without their knowledge or consent, ignoring their rights and cultural links with ecosystems (Figure 3E-H). Similar problems can arise in externally imposed adaptation strategies, which can cause maladaptation or benefit only some people at the expense of others (*2*, *19*). Local social outcomes of nature-based solutions, such as empowerment and community cohesion, are key to ensuring nature-based solutions can be maintained over time (*2, 19*). Not only are human rights dependent on a healthy and safe environment, but the "recognition of human rights can itself be essential for restoring and protecting healthy ecosystems" (*44*). Indeed, Indigenous People and local communities often have considerable knowledge on how to form reciprocal relationships with nature and adapt to change, and are playing a key role in tackling the biodiversity and climate crises (*2, 45*). Projects that ignore their knowledge and rights are therefore both unethical and unlikely to be maintained over the long term (*2, 45*). A related concern is that nature-based solutions are instrumentalizing cultural practices and commodifying nature, thus violating many people's values and worldviews; this issue underpins pushback against the term "nature-based solutions" by some Indigenous People and local community groups *(6)*.

Finally, there is evidence that the misuse of nature-based solutions can harm biodiversity, which secures the flow of ecosystem functions and services and is the cornerstone of resilient, adaptive ecosystems (*2, 46*). A key concern is that current policy and funding emphasise afforestation rather than ecosystem restoration *(47*) and that investments incorrectly badged as nature-based solutions can involve low-diversity commercial plantations of non-native species (Figure 3). This drives biodiversity loss when plantations replace native forests, grasslands, moorland and peatland (*2, 48*). Fast-growing plantations can also compromise human adaptation by reducing water supplies (*20*). Recent work highlights the high risks of carbon loss from tree plantations, either because the wood is harvested for short-lived products or because the plantations are more susceptible to the impacts of fires, pests and diseases (*2, 47, 48*). A paired global analysis found that plantations produce more commercially useable biomass than comparable native forests, but store less carbon, have lower water availability, prevent erosion less effectively, and harbor fewer species

(*49*). Plantations can also cause net harm when they distract from the imperative of effectively protecting remaining intact ecosystems. Several governments have committed to investing in large scale tree-planting schemes whilst also opening up previously protected forests for logging (e.g. *50*).

**Avoiding the bad, harnessing the good**

To address these issues, a growing number of organisations are developing evidence-based guidance on what constitute successful, sustainable nature-based solutions *(2).* Some are framed as policy guardrails for the uptake of the concept in international climate policy (e.g., www.nbsguidelines.info); others present evaluative standards for the investment, planning and practice of nature-based solutions (e.g. the IUCN's global standard for nature-based solutions, *51*). All guidance converges on a set of key recommendations. In particular, there is strong agreement that nature-based solutions must be designed, implemented and monitored by or in close partnership with Indigenous Peoples and local communities, reinforcing local rights and delivering benefits for local people. However, more clarity is needed on how the concept of nature-based solutions can align with indigenous and local values and worldviews and in particular, that they should not represent a commodification of nature (*6*). Nature-based solutions need to be understood as ways of working with and as part of nature and framed in a way that ensures multiple values of nature are respected. For this, the nature-based solutions community could learn from the Intergovernmental Platform on Biodiversity and Ecosystem Services in their efforts to develop an inclusive framework for understanding how contributions from nature affect people both positively and negatively (*52*).

There is also consensus on the critical importance of ensuring that nature-based solutions support biodiversity, by protecting, restoring and connecting a wide range of native habitats across landscapes and seascapes, and by monitoring ecological outcomes (which are rarely quantified at present). Guidelines could better support biodiversity by recommending the use of the natural climate solutions hierarchy that prioritises protection of intact ecosystems (*34*), and approaches that allow ecosystems to reach their full potential with minimal intervention (i.e. through "pro-forestation", *53*). Practitioners would also benefit from understanding impermanence risks and adopting adaptive approaches to restoration. Given that local climate and disturbance regimes are changing, in some locations it may be necessary to restore and manage ecosystems using different species able to thrive under new conditions, including through assisted migration (*54*).

Guidelines are also clear that nature-based solutions are not an alternative to keeping fossil fuels in the ground. The challenge is how to direct rapidly growing public and private sector finance (especially via booming voluntary carbon markets) towards well-planned high-integrity nature-based solutions projects that do not delay decarbonisation. Part of the solution is regulation that restricts investment in nature-based solutions-related offsets to those organisations with ambitious yet robust and verifiable actions plans to rapidly phase-out the use of fossil fuels. This includes meeting stringent criteria for companies to reduce emissions throughout their operations and supply chains to be in line with 1.5°C before or in addition to investing in robust nature-based solutions, for example by adhering to Science Based Targets (https:// sciencebasedtargets.org/). To ensure compliance, nature-based solutions should be rigorously assessed and validated, including long-term monitoring of ecological and socioeconomic impacts. Government policy that supports robust accountability and regulatory frameworks for nature-based solutions would be transformative (*2*).

Ensuring the long-term social and environmental integrity of nature-based solutions requires an improved evidence base, informed by science, practitioner and local and indigenous knowledges. There is urgent need for better understanding of where, when, how and for whom nature-based solutions can support both mitigation and adaptation, especially in marine and non-forest ecosystems, low-income nations in general and their cities in particular (*20, 21*). This research needs to take a holistic approach, for example by considering how nature-based solutions influence the multiple dimensions of adaptation, not just exposure to immediate climate change impacts, and by comparing the benefits and costs of nature-based solutions with hybrid and technological alternatives (Table 1).

More regional and national scenario and sectoral models of nature-based solutions climate change mitigation potentials are urgently required. These must be firmly grounded in the local policy and socioeconomic and cultural context with robust consideration of permanence and leakage risks, interactions between ecosystems, feasibility and outcomes for biodiversity, local people and the economy (*14*). Such models must also distinguish afforestation from reforestation (*47-49*). Integrating landscape scale experiments with recent advances in multispectral remote sensing, large-scale ecological observation networks, disturbance ecology, and mechanistic vegetation modelling will improve quantification of risks to the stability of ecosystems (*11*). Such research would also support the development of high-quality metrics that capture the multi-dimensional nature of biodiversity as well as the social outcomes of interventions. This information will allow baselines to be established and effects of nature-based solutions to be mapped and monitored over time, which is critical to improving adaptive management. Meanwhile, new research indicates that participation in nature-based solutions can lead to more sustainable lifestyle choices (*55*); the role of nature-based solutions in enabling system change is a rich area for future study.

Addressing these knowledge gaps involves genuine collaboration between social and natural scientists, as well as between the science community and those Indigenous Peoples and local communities who have been working with nature, as part of nature, for millennia. Only through such inter- and transdisciplinary efforts will we be able to implement nature-based solutions in a way that accounts for their multiple values. These are urgently needed to channel growing private and public climate finance to the projects and people that need it most, and in a form that will build rather than compromise the resilience of the social-ecological systems involved.

## Conclusion

Nature-based solutions can make an important contribution to reaching net-zero carbon emissions this century, but only if combined with other climate solutions, including dramatic cuts in GHG emissions across all sectors of the economy. This is not an argument against scaling-up nature-based solutions. Instead, it underscores the need to consider the many other well-evidenced benefits of nature-based solutions, especially their critical roles supporting human adaptation to climate change and protecting biodiversity. Achieving net-zero carbon emissions and transitioning to a nature-positive economy will also require systemic change in the way we behave as societies and run our economies, shifting to a dominant world view that is based on valuing quality of life and human wellbeing rather than material wealth, and connection with nature rather than its conquest. There are signals that this shift is taking place, such as the rise of climate and nature grassroots activism. Carefully implemented to ensure that multiple values of the natural world are respected, nature-based solutions offer an opportunity to accelerate this transition, whilst also slowing warming, building resilience and protecting biodiversity.

### FIGURE LEGENDS

**Figure 1 | Nature-based solutions and the key factors that limit them**

Nature-based solutions are “place-based partnerships between people and nature” that are underpinned by biodiversity and implemented by and for local communities (*2*). They involve the protection and restoration natural and semi-natural ecosystems; the sustainable management of aquatic systems and working lands; and the creation of novel ecosystems in urban areas. Well designed and implemented nature-based solutions can help us mitigate and adapt to climate change, but they are not an alternative to keeping fossil fuels in the ground.  Not only do a wide range of socioeconomic and cultural factors hinder the implementation and maintenance of nature-based solutions, but climate change driven risks (e.g., increased frequency of extreme events) undermine the health of ecosystems and their ability to provide any benefits to society. Such threats are compounded by pollution, logging and fragmentation, but these impacts can be reduced through careful adaptive management.

**Figure 2 | Global traction of nature-based solutions**

Recent years have seen a rapid rise in the prominence of nature-based solutions on policy (A), research (B), and business agendas (*2*). For example, there has been a steep increase in the number of peer reviewed articles identified by Google Scholar using the term nature-based solutions or the related term, Natural Climate Solution (NCS) (which refers specifically to nature-based solutions for climate change mitigation), in their titles, abstracts or key words. Meanwhile, over 80% of revised Paris Agreement climate pledges (Nationally Determined Contributions, NDC) include nature-based solutions in their mitigation and/or adaptation plans (*A*). For (A), note that some nations such as Peru include nature-based solutions in their National Adaptation Plans (but not their NDC); meanwhile, others such as Bolivia and Madagascar, which included nature-based solutions in their initial NDC, have not yet submitted a revised version (and hence are blank in this figure). For more information, visit: www.nbspolicyplatform.org.

**Figure 3| What "counts" as a nature-based solution? Examples of projects that meet guidelines for successful, sustainable nature-based solutions, alongside those that do not**

To count as a nature-based solution, an intervention must address at least one societal challenge, whilst also bringing local benefits and supporting biodiversity. Therefore, while Bio-Energy with Carbon Capture and Storage (commonly referred to as BECCs) and afforestation (planting trees where they do not naturally occur) are biological approaches to carbon sequestration, they are not nature-based solutions; nor are protected areas established without regard to the rights of local communities (*2*). Shown here are good practice examples (*A-D)* in a range of ecosystems involving a variety of different types of nature-based solutions that as far as can be determined meet guidelines for successful, sustainable nature-based solutions (www.nbsguidelines.info). These contrast with projects established for mitigating climate change (E,F), protecting biodiversity (G) or reducing flood and landslide risk (H) that have poor social and/or environmental outcomes and which do not qualify as nature-based solutions. Symbols denote outcomes for mitigation, adaptation, biodiversity and livelihoods or human rights reported as positive or negative (or likely to be on the basis of current evidence). Question marks denote where outcomes are unknown or difficult to predict. Note that a question mark for adaptation is assigned to H because only one dimension of adaptation is addressed (reduction of exposure to the immediate climate change impact, in this case landslides), while other dimensions were compromised. For more information about *A-D* and other examples of best-practice nature-based solutions projects, see: https://casestudies.naturebasedsolutionsinitiative.org/. Information about projects E-H are can be found in references *(54-59).*

BOX

**Box 1 | Critical research questions for evaluating nature-based solutions for climate change mitigation and adaptation**

- Where do nature-based solutions face the greatest impermanence risks and what mechanisms could be used to reduce those risks?
- What are the mechanistic underpinnings of relationships between ecological and socioeconomic resilience to climate change?
- How are the benefits and costs of nature-based solutions distributed within and amongst local stakeholders?
- How does the effectiveness of nature-based solutions vs alternative approaches vary with geographical and temporal scale of implementation and level of urgency, magnitude of threats from natural hazards and climate change?
- How do interactions between ecosystems influence the effectiveness of nature-based solutions for storing carbon, reducing exposure to climate impacts and protecting biodiversity?
- How and why do the different dimensions of effectiveness trade-off with one-another, mitigation with adaptation, social with ecological, short-term versus long-term benefits, and among different dimensions of adaptation?
- What novel forms of public and private finance can incentivize the implementation of nature-based solutions, and what are the economic and governance implications of these?
- To what extent do current policies and implemented nature-based solutions promote or violate human rights, and how can future nature-based solutions avoid this?

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