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Global recognition of the importance of nature-based solutions to the impacts of climate change

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Non-technical summary

Ecosystems across the globe are vulnerable to the effects of climate change, as are the communities that depend on them. However, ecosystems can also protect people from climate change impacts. As the evidence base strengthens, nature-based solutions (NbS) are increasingly prominent in climate change policy, especially in developing nations. Yet intentions rarely translate into measurable, evidence-based targets. As Paris Agreement signatories revise their Nationally Determined Contributions, we argue that NbS are key to meeting global goals for climate and biodiversity, and we urge researchers to work more closely with policy-makers to identify targets that benefit both people and ecosystems.

Technical summary

Recent research demonstrates that nature-based solutions (NbS) can help protect communities and infrastructure from the impacts of climate change while providing a range of other benefits for society. As nations revise or prepare new Nationally Determined Contributions (NDCs) in support of the Paris Agreement, there is a major opportunity to increase global ambition on NbS. To support this process and to provide a baseline against which ambition for NbS can be tracked, here we report on the prominence of NbS in the 168 NDCs that were submitted to the United Nations Framework Convention on Climate Change. In total, 104 nations include NbS in the adaptation component of their NDCs, 77 nations include them in both their adaptation and mitigation components and an additional 27 include them as part of their mitigation plans only. In other words, 131 nations – or 66% of all signatories to the Paris Agreement – have articulated intentions of working with ecosystems, in one form or another. However, national intentions to deliver NbS for adaptation vary by level of economic development, region and habitat type, and rarely translate into measurable evidence-based targets. We discuss possible reasons for these findings and provide recommendations on how national governments, practitioners and researchers can together enhance ambition for NbS to climate change impacts. As climate pledges are revised during successive global 'stock takes' of the Paris Agreement, we urge the research community to work closely with practitioners and policy-makers to identify meaningful targets that benefit both people and the ecosystems on which they depend.

Social media summary

Ecosystems can help us adapt to climatic impacts but robust policy targets that benefit people and nature are needed.

1. Introduction

According to the World Economic Forum (2020) Global Risks Report, failure to mitigate and adapt to climate change presents the greatest risk to the global economy in terms of severity of impact. Meanwhile, extreme weather – which is exacerbated by climate change (National Academies of Sciences, Engineering, and Medicine, 2016) – is listed as the risk most likely to damage the economy. Identifying and implementing robust climate change adaptation approaches that are cost-effective and build resilience across a range of potential future climates is therefore critical. The prevailing approach across the world has involved a mix of direct, engineered (or 'grey') interventions such as sea walls, levees or irrigation infrastructure, and indirect (or 'soft') interventions such as early warning systems (Enríquez-de-Salamanca *et al.*, 2017). However, there is widespread recognition that nature-based (or 'green') solutions (NbS) can complement these approaches in both rural and urban contexts (Global Commission on Adaptation, 2019; Hobbie & Grimm, 2020; Royal Society, 2014).

A specific type of NbS targeting human adaptation to climate change is widely referred to as ecosystem-based adaptation (EbA). This is defined by the Convention on Biological Diversity (CBD) as "the use of biodiversity and ecosystem services … to help people adapt to the adverse effects of climate change" (Secretariat of the Convention on Biological Diversity, 2009). Examples include: protecting natural wetlands and forests in upper catchments to reduce the impacts of flooding downstream; restoring mangroves and salt marshes to protect communities and infrastructure from storm surges and to reduce coastal erosion; and planting trees amongst crops or crops within forest to maintain or even enhance yields in drier, more variable climates. For specific examples of NbS for climate change adaptation, or EbA, see Box 1 (adapted from Seddon *et al.*, 2020). EbA is often described as an alternative to 'grey' engineering. However, in reality, there is a spectrum of interventions, some including components of both (i.e., hybrid or "grey–green" approaches) (Browder *et al.*, 2019; Royal Society, 2014). Reports from projects implemented by non-governmental organizations and United Nations (UN) institutions suggest that EbA can provide low-risk, low-cost protection from a range of climatic impacts, whilst also delivering other vital ecosystem services (e.g., Reid *et al.*, 2019; Rizvi, 2014; Osti *et al.*, unpublished data). However, although project-specific accounts of the benefits of EbA are increasingly backed up by more systematic research, there is a need for robust scientific synthesis (Seddon *et al.*, 2020).

2. Nature-based solutions for adaptation in the Paris Agreement

As the evidence base for the efficacy of NbS strengthens, so ecosystems are receiving attention in international climate change policy fora. Of particular importance, the Paris Agreement of the United Nations Framework Convention on Climate Change (UNFCCC) recognizes the importance of ecosystems for mitigation and adaptation. It calls on all Parties to acknowledge "the importance of the conservation and enhancement, as appropriate, of sinks and reservoirs of the greenhouse gases," and to "note the importance of ensuring the integrity of all ecosystems, including oceans, and the protection of biodiversity." It then includes in its Articles several references to ecosystems, forests and natural resources (Seddon *et al.*, 2019a). For example, Article 5.2 encourages Parties to adopt "…policy approaches and positive incentives for activities relating to reducing emissions from deforestation and forest degradation, and the role of conservation and sustainable management of forests and enhancement of forest carbon stocks in developing nations; and alternative policy

Box 1. Examples of nature-based solutions for climate change adaptation (taken from Seddon *et al.*, 2020 with permission of Royal Society Publishing).

Protection from soil erosion

- **Ethiopia:** Farmer-managed natural regeneration of 2728 ha of degraded native forests with living tree stumps in Humbo reduced soil erosion and flash flooding and increased groundwater recharge, which was associated with higher crop productivity. In 2006–2036, the project will remove an estimated ~870,000 tonnes of CO_2 equivalent, while diversifying livelihoods (Brown *et al.*, 2011).
- **China:** A combination of afforestation, reforestation and conservation of existing natural forests over 25 years in the Poyang Lake basin halved heavy soil erosion while increasing net carbon sequestration five-fold and net income for local farmers six-fold (Huang *et al.*, 2012). Meanwhile, restoration of natural herbaceous and shrubland vegetation on the Loess Plateau reduced soil erosion to a comparable or significantly greater extent than low-diversity tree plantations across a range of soil erosion indices. Compared to afforested slopes, these naturally re-vegetated slopes also had 1.3–2.0 times higher soil water content (Jia *et al.*, 2017).

Protection from inland flooding

- **Europe:** Restoration of all but one of six rivers reduced flood damage and was associated with increased agricultural production, carbon sequestration and recreation, with a net societal economic benefit over unrestored rivers of €1400 ± 600. Interventions included floodplain re-wetting, restoration of riparian vegetation, assisting upstream fish migration and the re-meandering and re-connection of channels (Vermaat *et al.*, 2016).
- **Canada:** Reforestation in the headwaters of a river basin significantly reduced peak stream flows compared to an adjacent deforested basin, offering greater protection against flooding during spring snow melt (Buttle, 2011).
- **USA:** Natural regeneration of mixed-species hardwood watersheds following forest clear-cutting reduced flood risk in lowland areas, reducing stream flows during periods of high precipitation by >104 L/ha/day (Kelly *et al.*, 2016).

Buffering natural resources against drier and more variable climates

- **Panama:** Agroforestry systems yield up to 21% higher economic returns than farm mosaic approaches (i.e., where trees and crops are on separate parcels), including under a climate change scenario of more frequent droughts, in models that account for market and climate uncertainty (Paul *et al.*, 2017).
- **Europe:** Agroforestry has reduced erosion, increased soil fertility, increased precipitation and reduced temperatures, with greatest effects in hotter, drier regions such as the Mediterranean basin (which is suffering from soil damage through increasing aridity under climate change) (Torralba *et al.*, 2016).

Protection from coastal hazards and sea-level rise

- **Global:** Natural coastal habitats significantly reduce wave heights, with coral reefs and salt marshes being most effective,

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Box 1. Continued.

causing a reduction of 70%, followed by seagrass and kelp beds (36%) and mangroves (31%). Across 52 sites harnessing these habitats in coastal defence projects, nature-based solutions were two to five times more cost-effective at lowering wave heights and at increasing water depths compared to engineered structures (Narayan *et al.*, 2016). Globally, mangroves protects 15 million people from flooding every year and provide over US$65 billion in flood protection services (Menendez *et al.*, 2020).

- **Gulf of Mexico:** Construction of 'living shorelines' by aiding the natural recruitment of oyster reefs can reduce vegetation retreat by 40% compared to unprotected sites, stabilizing the shoreline from the effects of waves and erosion and increasing the abundance and diversity of economically important species (Scyphers *et al.*, 2011).

Moderating urban heatwaves and heat island effects

- **Global:** Green spaces are on average 0.94°C cooler in the day than urban spaces, with stronger effects the larger the green space, according to a meta-analysis of 47 studies comparing the cooling effects of green spaces in cities (parks, areas with trees) with those of purely urban areas (Bowler *et al.*, 2010).

Managing storm-water and flooding in urban areas

- **Italy:** The establishment of wetlands and green recreational space has been effective at reducing flood risks, with a 10% higher reduction of downstream flooding and 7.5% higher reduction of peak flow compared to potential grey infrastructure alternatives. Nature-based solutions also outperform grey infrastructure in terms of water purification and provide greater social-ecological benefits such as recreation and habitat for biodiversity (Liquete *et al.*, 2016).

approaches, such as joint mitigation and adaptation approaches for the integral and sustainable management of forests, while reaffirming the importance of incentivizing, as appropriate, non-carbon benefits associated with such approaches" (UNFCCC, 2016).

2.1. Analysis

In order to determine the extent to which this has translated into high-level national intent, we conducted a comparative analysis of the prominence of NbS in the Nationally Determined Contributions (NDCs) that were submitted to the UNFCCC by signatories of the Paris Agreement, with a particular focus on the those 142 NDCs that included adaptation components. Full details of our methodology can be found in the Supplementary Materials, while all of the data are available to explore on an interactive web platform, the Nature-based Solutions Policy Platform (www.nbspolicyplatform.org). We focused on the NDCs, rather than other policy documents (e.g., National Adaptation Plans), because the Paris Agreement has considerable political momentum, meaning that NDC targets are often in the limelight and under scrutiny. Furthermore, unlike any other policy processes, the Agreement has an inbuilt ratchet mechanism for increasing ambition: every 5 years, progress towards targets set out in the NDCs must be reported on, monitored and compared with other nations. We focused on adaptation because this has not been fully addressed in prior research on NbS in the NDCs. Instead, most studies to date have examined the extent to which nations have incorporated forestry, agriculture and/or forest landscape restoration (FLR) for the purpose of increasing sinks and reducing sources of greenhouse gas emissions (Forsell *et al.*, 2016; Grassi *et al.*, 2017).

In our detailed analysis of the text of the adaptation components of the NDCs, we make a distinction between nature-based 'visions', 'actions' and 'targets' for NbS. A vision was defined as a high-level pledge or statement of recognition of the importance of NbS for adaptation. An action was defined as tangible, locally relevant action or intervention in a particular habitat or the development/implementation of a specific and relevant policy or process that is being implemented or planned for. We considered an action to be broadly 'nature-based' if it referred to the protection, restoration or management of ecosystems, including assisted natural regeneration, reforestation and afforestation. We defined a target as either a time-bound or quantitative target linked to an adaptation action that could, in theory, be tracked over time. We make a distinction between nature-based interventions aimed at delivering direct positive adaptation outcomes and other socioeconomic benefits through ecosystem services (i.e., ecosystem-based adaptation (EbA)) and those aimed at delivering positive outcomes for species or habitats (which, for simplicity, we refer to as conservation). For full details, see Supplementary Materials.

2.2. Results

2.2.1. Global recognition that ecosystems are both vulnerable to climate change and can support human adaptation

We found that two-thirds of all NDCs (112/168) acknowledge that ecosystems[i] are vulnerable to climate change (Figure 1(a)). Some nations highlight negative impacts on ecosystems in general (China's NDC states that "climate change has significant impacts on global natural ecosystems"), while others focus on specific contexts (Morocco's NDC states that "climate change will have an impact on how vibrant and dynamic forest ecosystems are, on their ability to regenerate and to adapt to regular climate fluctuations, their biodiversity, their consistency, and their spatial distribution").

The protection of ecosystems is a declared motivation for adaptation planning in 63% of NDCs (106/168) and was the fifth most frequently mentioned intended outcome of adaptation planning (ranked below increased resilience, protection against extreme events, food security and water security, but above protection of the economy or human health; Figure 1(b)). Indeed, ecosystems feature in climate change adaptation 'vision statements' in 58% (97) of the NDCs (Table S1; for all adaptation vision statements in the NDCs that referred to ecosystems, see www.nbspolicyplatform.org). For some nations, the aim is to address impacts on ecosystems directly (e.g., the Republic of Congo's NDC emphasizes the "protection of natural heritage, biodiversity, forests and fishery resources, through an adaptation approach rooted in the protection of ecosystems"). Others are instead explicit that protecting ecosystems is for the benefit of human communities (e.g., Cambodia's NDC commits to "promoting and improving the adaptive capacity of communities, especially through community based adaptation actions, and restoring the natural ecology system to respond to climate change").

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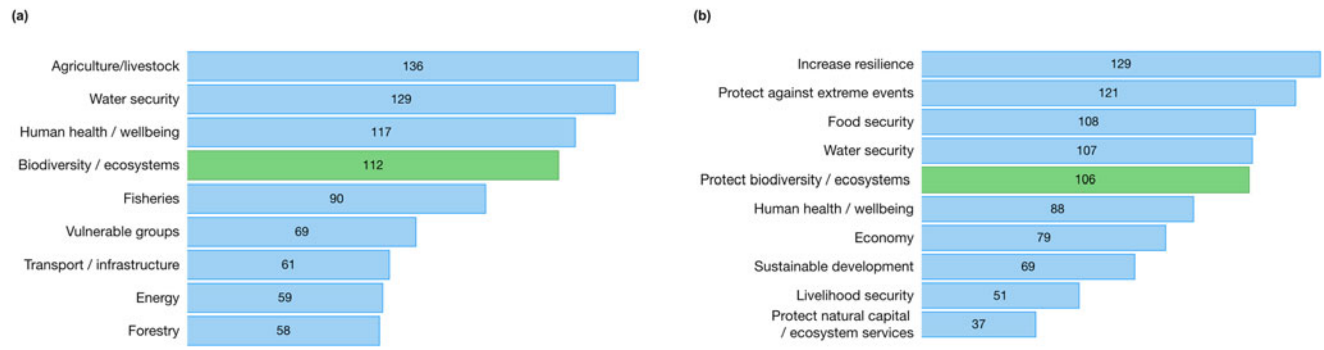

Fig. 1. Overview of how biodiversity and/or ecosystems are included in the adaptation components of the Nationally Determined Contributions (NDCs) submitted to the United Nations Framework Convention on Climate Change (UNFCCC) by signatories of the Paris Agreement. (a) Those sectors most commonly described as being vulnerable to climate change impacts; biodiversity and/or ecosystems are ranked fourth (green bar). (b) Common reasons given for developing a climate change adaptation plan; protecting biodiversity and/or ecosystems is ranked fifth (green bar). For data and more information on the inclusion of nature-based solutions in the NDCs, see www.nbspolicyplatform.org.

Of those nations that articulated a broadly 'nature-based' vision for adaptation in their NDCs, most (79; i.e., 81%) go on to propose a range of actions to achieve their vision. However, a small number (18) have nature-based visions but no associated tangible actions (Table S1). Those with NbS actions describe the restoration and/or protection that fall within five broad types of ecosystems and/or the implementation of nature-based agricultural practices such as agroforestry (Figure 2). Specifically, we found that the adaptation component of the NDCs of 70 nations (42% of NDCs) include actions that appear to have the characteristics of EbA as defined by the CBD (Secretariat of the Convention on Biological Diversity, 2009) (see Supplementary Materials). For example, El Salvador states it will establish and manage 1 million ha through an integrated approach "where forest areas will be rehabilitated and conserved, biological corridors will be established through the adoption of resilient agroforestry systems and transformation of agricultural areas with low carbon sustainable practices." An additional 34 nations (20% of NDCs) outline conservation activities such as the establishment of protected areas or habitat restoration without any explicit links to promoting social or ecological resilience to climate change or the involvement of local communities. For example, Bahrain refers to "a mangrove transplantation project for the cultivation of plants and planting mangrove seedlings in order to rehabilitate degraded coastal areas," and Tunisia commits to "conservation of the ecological functions of low-lying coastal areas." Twenty-seven additional nations, though lacking reference to EbA or conservation in the adaptation components of their NDCs, refer to such actions or broad commitments in the mitigation component. For example, Vietnam seeks to "manage and develop sustainable forests, enhance carbon sequestration and environmental services."

In total, 104 nations include EbA and/or conservation actions in the adaptation components of their NDCs, 77 nations include them in both their adaptation and mitigation components and an additional 27 nations include them as part of their mitigation plans only (Figure 3(a)). In other words, 131 nations – or 66% of all signatories to the Paris Agreement (78% of NDCs[ii]) – have articulated intentions of working with ecosystems, in one form or another, to address the causes and consequences of climate change. However, we found that there is much variation among nations, regions and ecosystems in the extent to which NbS are included in the adaptation component of the NDCs (Figure 2 & 3).

2.2.2. Regional variation in inclusion of NbS in climate change adaptation plans

A high proportion of the world's poorest nations include NbS as an adaptation tool in their NDCs. Specifically, we found that NbS are referred to in the adaptation plans of 28 of the 30 nations classified as 'low income' by the World Bank (with 22 including EbA specifically) and all but 4 of the 47 nations classified as 'least developed'. In contrast, NbS actions are included in only 9 (26%) of 34 high-income nations (12% include EbA) (Figure 3(b)).

The ecosystems most commonly referred to in the adaptation components of the NDCs are terrestrial forests or woodlands (i.e., their protection, restoration (reforestation) or afforestation (planting trees in naturally treeless environments)); these are highlighted in the adaptation components of 69 NDCs (i.e., 41%) (Figure 2). There was variation among geographical regions in the types of ecosystems most commonly referred to (Figure 2). The protection and/or restoration of coastal or marine habitats appear in 48 NDCs (29% of the total, but 37% of NDCs from nations with coasts), followed by similar actions in river catchments, including wetlands (28% of NDCs). Much less common are references to working with grasslands and rangelands (10% of NDCs) or montane habitats as an adaptation approach (4% of NDCs). Almost all examples of grassland or rangeland NbS adaptation actions come from Africa (Figure 2), despite the extensive presence of these habitats in other regions. Nature-based agricultural practices, such as agroforestry, were included in the adaptation components of 40 NDCs (i.e., 24%), most of which are from African nations (i.e., 27 NDCs) (Figure 2).

2.2.3. Targets for NbS

While many nations outline a theoretical commitment to NbS as an adaptation tool, this rarely translates into clear targets in their NDCs. Of the 104 NDCs that include nature-based adaptation actions, only 30 provide measurable (i.e., time-bound, quantitative) targets; the remainder provide broad goals, which are difficult to measure (for all NbS adaptation targets in the NDCs, see www.nbspolicyplatform.org). For example, Morocco aims to protect "natural heritage, biodiversity, forestry and fishery resources, through an ecosystem-based adaptation approach," and South Sudan will strive to "develop forest reserves and management plans to protect watersheds and improve future water availability." Although such goals are important, without more context-specific, measurable targets and suitable indicators, it

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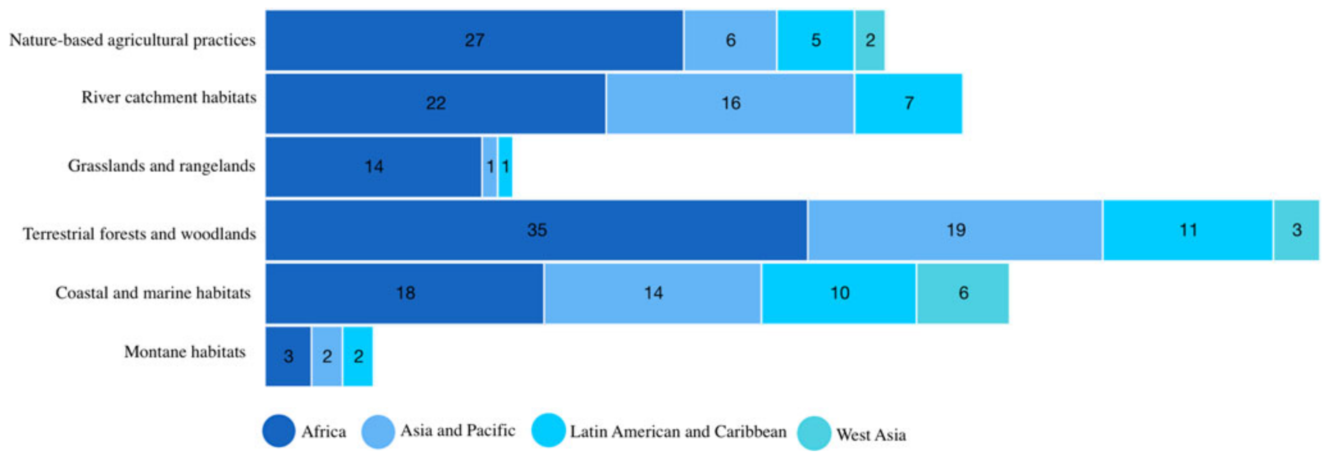

Fig. 2. Regional variation in the types of ecosystems included in the adaptation component of the Nationally Determined Contributions (NDCs). Shown are numbers of NDCs within in each of four geographical regions that include nature-based actions in one or more of the following five broad and non-mutually exclusive ecosystem types: (1) river catchment habitats (includes references to watersheds, wetlands, lakes, rivers, etc.); (2) grasslands and rangelands (includes lowland grasslands, shrub land, savanna, tundra); (3) terrestrial forests and woodlands (excludes mangroves); (4) coastal and marine habitats (includes mangroves, seagrass meadows, coral or shellfish reefs, dune systems, coastal wetlands and salt marshes); and (5) montane habitats (includes a range of habitats at elevation). Also shown are the numbers of NDCs in each region that refer to nature-based agricultural practices (includes agroforestry, conservation agriculture and permaculture).

will be difficult to determine the extent to which they are being achieved.

Even where measurable NbS adaptation targets exist in the NDCs, they tend to focus on the extent of lands to be afforested, reforested or restored, rather than the quality of those lands or the adaptation outcomes of the actions. Afforestation accounts for 22% of the 64 adaptation targets included in 30 NDCs, and the protection and/or restoration of specific areas of habitat (usually forest) within given time frames account for 48% of targets (Table S2). For example, Bolivia states that it will "increase forest areas with integrated and sustainable community management approaches with 16.9 million hectares in 2030, in reference to 3.1 million hectares by 2010," Burundi states it will increase "forest cover by 20% by 2025," and Mongolia includes an intention to increase forest area "to 9% by 2030 through reforestation activities" (NBSPP, 2020). Meanwhile, only 31 nations include intentions in their NDCs to improve ecosystem resilience (e.g., Kenya's adaptation vision is to "enhance the resilience of ecosystems to climate variability and change"). None go on to outline how this might be achieved in practice, and only two NDCs explicitly link ecosystem resilience with biodiversity. Jordan states that "adaptation strategies and measures in biodiversity should be prepared and implemented *in order to achieve* sustainable, healthy and resilient ecosystems in the future under threats of climate change and other stressors" (emphasis added), and Rwanda "intends to use mixed-species approaches which contribute greatly to the achievement of both mitigation objectives and adaptation benefits of ecosystem resilience and biodiversity."

3. Discussion

NbS are prominent in the first iteration of the NDCs submitted to the UNFCCC by the signatories of the Paris Agreement. We found that 131 nations – or 66% of all signatories to the Paris Agreement – outline intentions of working with ecosystems, in one form or another, to address climate change. However, our detailed assessment of the adaptation components of the NDCs revealed that national intentions to deliver NbS for climate change adaptation vary by level of economic development, region and habitat type, and rarely translate into measurable evidence-based actions and targets. Here, we discuss possible reasons for these findings and the problems associated with them.

3.1. Prominence of NbS in the climate adaptation plans of developing nations

The world's poorest nations currently experience the most severe socioeconomic impacts from climate change and are in urgent need of robust cost-effective adaptation action (IPCC, 2018). These nations also more commonly include NbS as an adaptation tool in their NDCs compared to Annex 1 nations. This may reflect greater dependency of the rural poor on natural resources (Uy *et al.*, 2012) and the generally lower economic costs of implementing NbS compared to engineered alternatives (Narayan *et al.*, 2016; Royal Society, 2014). It may also reflect the role of local and international conservation and development organizations in the programming and mainstreaming of EbA in lower- and middle-income nations over the past 10 years (e.g., Reid *et al.*, 2019; Rizvi, 2014; Osti *et al.*, unpublished data). We note that no Annex 1 nations (i.e., industrialized Organisation for Economic Co-operation and Development (OECD) members and economies in transition) include NbS in the adaptation component of their NDCs, even though a number are implementing NbS on the ground. For example, many European nations are restoring rivers with the aim of reducing flood risk (e.g., Giełczewski, 2016); the UK and Germany are both implementing managed coastal realignment to deal with flooding and erosion (e.g., Rupp-Armstrong & Nicholls, 2007); and in the USA, a wide range of NbS activities are being undertaken, including to protect coasts from erosion, such as saltmarsh restoration and oyster reef rehabilitation (e.g., Narayan *et al.*, 2017; Scyphers *et al.*, 2011).

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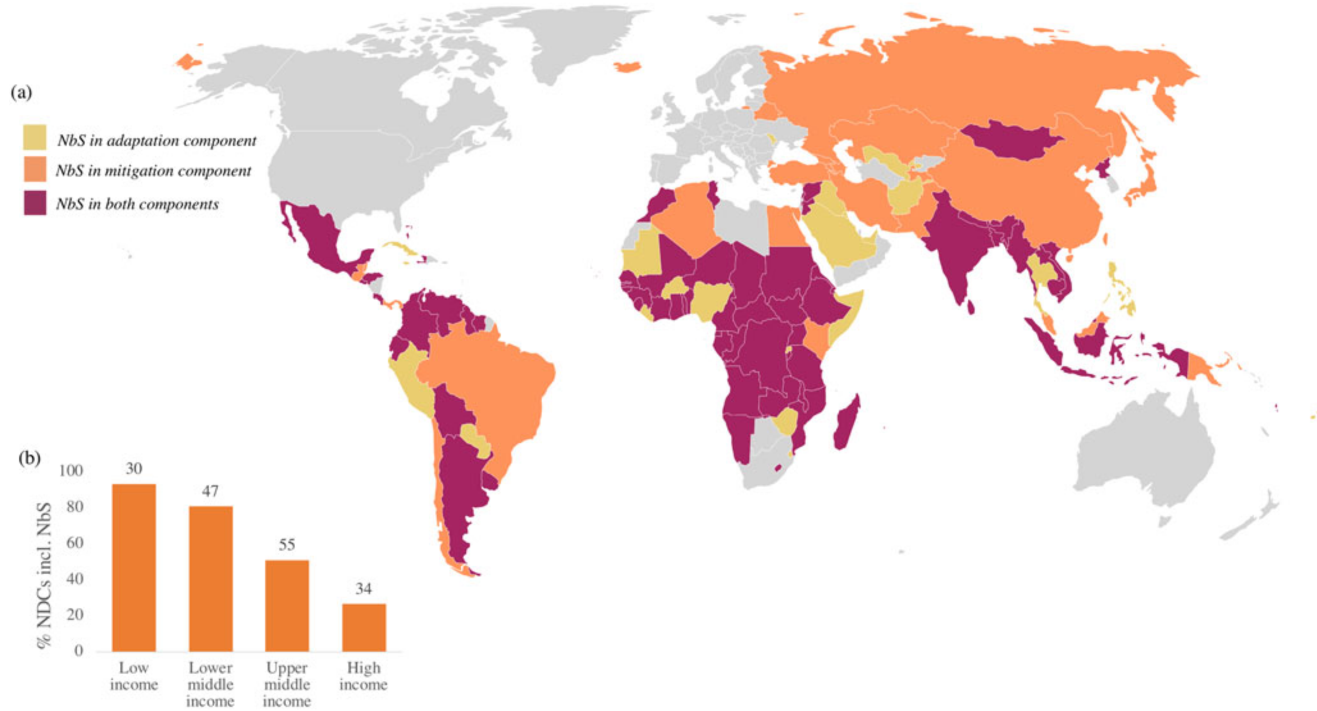

Fig. 3. (a) Global distribution of nations that include nature-based solutions (ecosystem-based adaptation and/or conservation) in the adaptation and/or mitigation component of the first iteration of their Nationally Determined Contribution (NDC). (b) The percentages of NDCs from nations from each of the four World Bank income groups that include nature-based solutions in their adaptation components (numbers above bars show how many nations fall within that income group).

These nations may not have featured such information in their NDCs because the requirement to include an adaptation component came after they had compiled their NDCs. Equally, they may not have viewed the NDC as a relevant vehicle to communicate adaptation intentions: the Kyoto Protocol emphasized stringent mitigation commitments by Annex 1 nations in particular, and in the decade leading up to the Paris Agreement, adaptation was largely ignored. Consequently, the recognition of the role of NbS in adaptation is more global than is indicated across the current iteration of NDCs. As these are revised, and as the climate impacts on Annex 1 nations intensify, so we may see a greater balance between mitigation and adaptation planning by all nations, with NbS recognized as an important means by which to achieve synergy between them.

3.2. Emphasis on forestry and agroforestry

The widespread inclusion of nature-based agricultural practices such as agroforestry in the NDCs of African nations likely reflects their low cost and multiple benefits compared to industrial agriculture (Scherr & Sthapit, 2009; Waldron *et al.*, 2017), especially for smallholder farmers who have a long history of working with nature (Mbow *et al.*, 2014). Meanwhile, the emphasis on forest and forestry in general across the NDCs may simply reflect the fact that forests are high on the agenda in international negotiations and in national policy-making contexts (e.g., Reduced Emissions from Deforestation and Degradation (REDD), New York Declaration on Forests and the Bonn Challenge) (Seddon *et al.*, 2019b). The policy focus on forests to date has largely been framed in terms of their value for mitigation (i.e., as carbon sinks). Nevertheless, it may have created awareness among policy-makers of, for example, sustainable forest management, arguably paving the way for the inclusion of such actions in adaptation plans. Forests are also regarded as a valuable economic resource (i.e., for timber and non-timber forest products), whereas the direct economic value of other habitats is perhaps less clear to policy-makers. An emphasis on forests in the NDCs may also reflect a more extensive evidence base for the effectiveness of these habitats in providing key regulating services, in particular erosion control along coasts (Temmerman *et al.*, 2013) and in river catchments (Dadson *et al.*, 2017; Huang *et al.*, 2012). Conversely, fewer studies have rigorously determined the extent to which grasslands or montane habitats protect communities from climate change impacts (www.naturebasedsolutionsevidence.info).

The focus on forests and (agro)forestry is problematic for at least two major reasons. First, it can encourage the establishment of low-diversity plantations of fast-growing non-native species (Brancalion & Chazdon, 2017; Lewis *et al.*, 2019). For example, according to Lewis *et al.* (2019), 45% of the 350 Mha currently pledged for reforestation to meet the Bonn Challenge is set to be achieved through commercial plantations (but see Dave *et al.*, 2019)." While fast-growing single-species plantations may sequester carbon and reduce vulnerability to specific climate change impacts in the short term, their capacity to support human adaptation or store carbon over the long term may be impaired by changing conditions and disturbances that are becoming more severe under climate change (Frank *et al.*, 2015).

Second, forestry plantations sometimes comes at the expense of vital naturally occurring ecosystems, such as natural grasslands and peatlands (Veldman, *et al.*, 2015), which may be more resilient to climate change impacts and/or support human adaptation in other ways (Brancalion & Chazdon, 2017). Evidence of forest dieback across the globe as a result of climate stress (in particular drought and the increased frequency of pests and wildfires) (Allen *et al.*, 2010) suggests that afforestation might not be a viable long-term adaptation solution in some regions. Instead, scientific research increasingly suggests that areas allowed to regenerate naturally can deliver a wider range of climate change adaptation services with fewer trade-offs (Brancalion & Chazdon, 2017; Morecroft *et al.*, 2019) and be more cost-effective than afforestation (Crouzeilles *et al.*, 2020). For example, although large-scale afforestation projects have reduced soil erosion in China (e.g., Liu *et al.*, 2008; Ouyang *et al.*, 2016; but see Cao, 2008), the plantations have higher rates of evapotranspiration compared to natural vegetation (Cao *et al.*, 2016). This has resulted in water shortages (e.g., Zhang *et al.*, 2017) and may have threatened the survival of the plantations themselves (Cao *et al.*, 2009). Such plantations have also had negative effects on biodiversity (Hua *et al.*, 2016; Xu *et al.*, 2011). Conversely, areas allowed to regenerate naturally (e.g., into herbaceous cover and shrubland) provide comparable levels of erosion control without compromising soil moisture or biodiversity (Jiao *et al.*, 2012) (also see Box 1).

Climate change policy, whether articulated in the NDCs or other national plans, should not prioritize forestry plantations at the expense of other ecosystems such as grasslands or wetlands that, in context, provide effective adaptation and contribute to mitigation. Those advocating for increased ambition for nature in climate change policy need to be more inclusive in how they describe the value of NbS. Taking into account the potential value of all ecosystems is likely to lead to more balanced and effective nature-based components of adaptation and mitigation strategies (Seddon *et al.*, 2019b).

3.3. Improving targets for NbS

For ecosystems to provide services to people, they must themselves be able to resist, recover and/or adapt to change. Such resilience is, in turn, strongly determined by habitat connectivity, heterogeneity and diversity (Oliver *et al.*, 2015). Connectivity allows for migration and range shifts to track moving ecological niches as an adaptive response to climate change (McGuire *et al.*, 2016). Diversity, meanwhile, allows for sustained productivity through extreme floods and droughts (Hutchinson *et al.*, 2018), pests and diseases (Jactel *et al.*, 2017) via the buffering effects of multiple species, which differ independently in their responses to similar environmental conditions (Loreau & de Mazancourt, 2008). Genetic diversity also safeguards the evolutionary potential for adaptation to a changing environment (Mijangos *et al.*, 2015).

If NbS targets are to deliver positive outcomes for adaptation and/or mitigation over the long term, they should therefore encourage actions that sustain or enhance these ecological attributes. Meanwhile, to deliver long-term benefits for people dealing with climate change impacts, targets should also encourage working with nature in such a way as to: (1) reduce exposure (e.g., limit coastal or inland flooding); (2) build adaptive capacity (e.g., empower local communities to manage their natural environment); and (3) reduce sensitivity to the impacts of climate change (e.g., secure diverse portfolios of livelihoods to increase resilience to climatic shocks) (Lavorel *et al.*, 2019; Ostrom, 2009). In other words, targets must derive from an understanding of the effectiveness of NbS not only for dealing with direct climate change impacts, but also for their capacity to provide positive outcomes for ecosystems and people in a rapidly changing world (Morecroft *et al.*, 2019; Seddon *et al.*, 2020).

The dynamic and complex nature of social-ecological systems (Ostrom, 2009) makes it challenging to identify such targets, especially those that work across scales. However, on the basis of the best available evidence from science and practice, broadly speaking, NbS targets for both mitigation and adaptation should involve protecting and/or restoring a wide range of naturally occurring, intact ecosystems, supporting the diversity within them and ensuring connectivity between them (Seddon *et al.*, 2020). Compared to degraded or artificially created ecosystems (e.g., low-diversity tree plantations), intact ecosystems are more resilient (Hutchinson *et al.*, 2018; Jactel *et al.*, 2017), store more carbon (Maxwell *et al.*, 2019; Osuri *et al.*, 2020) and offer greater protection to people from climate change impacts (Martin & Watson, 2016; Watson *et al.*, 2018). However, the means by which protection and/or restoration are achieved are critically important, and most evidence to date shows that full engagement and consent of local communities and Indigenous Peoples in the design and implementation of NbS are needed if they are to deliver their intended benefits over the long term (Woroniecki, 2019; Woroniecki *et al.*, 2019). Therefore, nations would benefit from emphasizing in their NDCs NbS targets that support locally led ecosystem stewardship with robust social safeguards.

The metrics or indicators by which we measure progress towards meeting the national targets included in the NDCs and other national policies need to be locally relevant. They need to be context specific and drawn from an understanding of the effects of different nature-based interventions on social-ecological systems and their resilience under different climate change scenarios. Devising such metrics is an urgent priority for the research community and will require a huge interdisciplinary effort that brings together knowledge systems from science and practice (see below).

4. Enhancing ambition for NbS in adaptation policy

On the basis of the foregoing findings and discussion, we provide a set of recommendations as to how national governments, practitioners and researchers can together enhance ambition for NbS for climate change adaptation in the NDCs and in general (see Box 2). Here, we expand on the specific role of the research community in this process and highlight the importance of building communities of science, policy and practice.

4.1. Increasing engagement from the research community

Researchers from the natural and social sciences and economists need to work together to build a strong evidence base for the socioeconomic and ecological effectiveness of NbS compared to other adaptation options and to facilitate the development of targets and costed plans for the NDCs. To promote consistency and comparability of adaptation planning across the globe, researchers also need to align methods for evaluating the effectiveness of NbS and work with agencies revising the NDCs to ensure information is available in a useful format. In addition to consolidating existing evidence, the research community also needs to address major knowledge gaps in the evidence underlying NbS (Seddon *et al.*, 2020). In particular, studies are needed into how the performance of NbS relative to alternatives varies across different temporal and spatial scales, levels of urgency, socioeconomic contexts and ecological settings, and the extent to which they are 'climate proofed' (Calliari, 2019; Lavorel, 2019). There is also uncertainty about how different climate change adaptation services trade off against one another and over what scales, and around how climate

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Box 2. Recommendations for enhancing ambition for nature-based solutions (NbS) to climate change impacts in the Nationally Determined Contributions (NDCs).

A. Recommendations for national governments

Building on growing global recognition of the importance of ecosystems and biodiversity for addressing climate change mitigation and adaptation, national governments are encouraged to:

1) *Rank NbS alongside other key elements of sustainable development* and incorporate NbS in development planning processes.
2) *Fully integrate NbS in future NDCs* without lowering the level of ambition in other sectors.
3) *Increase investment in NbS actions that address both climate change adaptation and mitigation while supporting biodiversity*. This would enable integrated climate, development and biodiversity agendas and action plans. To this end, nations could *prioritize the protection of intact ecosystems*.
4) *Increase investment in NbS actions in a wide range of naturally occurring intact ecosystems*, not only terrestrial forests. Currently, high-level multilateral pledges for nature focus on forests, but other ecosystems, such as peatlands, mangroves, estuaries, seagrass, natural grasslands and soils, are often as rich or richer in carbon and support high levels of biodiversity.
5) *Avoid investment in large-scale afforestation with monoculture or low-diversity commercial tree plantations, especially non-native species.* These generally have lower or less stable rates of carbon sequestration, little or no biodiversity value compared to restoring natural ecosystems, release much of their stored carbon when harvested and are often more susceptible to damage and loss from pests, diseases, drought, fire and climate change than primary intact natural forests
6) *Align NDCs with other national plans and international processes*, such as National Adaptation Plans and National Adaptation Programmes of Action, as well as with other relevant international policy processes outside of the UNFCCC and the Paris Agreement, with common frameworks and indicators for reporting and tracking NbS-related actions under these.

B. Agencies revising NDCs

To help track the level of ambition for NbS for climate change adaptation more systematically, revised or new NDCs would benefit from including information on:

1) *Ecosystem dependencies*, i.e., ways in which human communities benefit from healthy, functioning ecosystems, including the biodiversity they support and are supported by.
2) *Adaptation synergies and linked benefits of mitigation actions*, i.e., be explicit about the degree to which mitigation actions using NbS will deliver adaptation benefits, and quantify the mitigation benefits of NbS for adaptation so that the full values of NbS are clear and can be monitored
3) *How NbS actions address specific vulnerabilities to climate change*, i.e., whether they reduce exposure and sensitivity to the impacts of climate change such as flooding, erosion or droughts, and/or whether they increase resilience and adaptive capacity.

Those revising NDCs are also encouraged to include *measurable nature-based adaptation targets and indicators* that:

4) Are drawn from the *best available knowledge of the socioeconomic and ecological effectiveness* of NbS from science and/or local expertise and consultation.
5) Encompass *a wide range of naturally occurring ecosystems*, not only forests, but also grasslands, wetlands, peatlands, drylands and coastal and marine ecosystems.
6) Are implemented with the engagement and consent of Indigenous Peoples and local communities.
7) *Sustain or enhance biodiversity* and reflect the *quality of ecosystems protected or restored* (not just the extent).

C. Recommendations for practitioners

Practitioners implementing NbS projects across the globe have considerable understanding of how nature can support human adaptation to climate change. They are encouraged to:

1) *Scale-up monitoring and evaluation of NbS projects and share knowledge on what makes NbS effective for people and nature*, as well as *share learning on failure*. Of particular importance to share is knowledge on the types of interventions, scales and/or social-ecological contexts in which NbS do *and do not* help people adapt whilst also supporting biodiversity, and on the enabling conditions for scaling-up.
2) *Consult with local communities and Indigenous Peoples* and enable traditional knowledge to inform the design, implementation and monitoring of NbS.
3) *Help policy-makers identify robust targets for NbS* during the redrafting of the NDCs in 2020 and beyond.
4) Work closely with other practitioners from different sectors and with researchers *to align standards or principles about successful, sustainable NbS to climate change adaptation* and communicate these clearly to decision-makers in business and government.

D. Recommendations for the research community

Researchers from the natural and social sciences and economists are encouraged to work together to ensure that the current momentum for NbS is informed by the best available evidence. In particular, researchers need to:

Box 2. Continued.

1) *Align definitions around NbS and establish consensus terminology* for different types of nature-based interventions as well as for monitoring and evaluation.
2) *Build a strong evidence base* for the effectiveness and long-term socioeconomic and ecological outcomes of NbS, compared to other adaptation options, to facilitate the development of targets, costed plans and mainstreaming of NbS into national policy, where appropriate.
3) *Develop locally relevant, context-specific metrics* or indicators with which to measure measure progress towards meeting national targets. These need to be based on a deep understanding of the effects of different nature-based interventions on social-ecological systems and their resilience under different climate change scenarios.
4) *Engage in two-way knowledge exchange with end-users of their research.* In particular, they would benefit from joining communities of practitioners and policy-makers to ensure stakeholder knowledge needs are understood, addressed and communicated in the most suitable format.

impacts interact with other stressors (e.g., land-use change) to influence the flow of services and determine tipping points beyond which ecosystem functions fail and cannot recover. At the same time, there is an urgent need to develop more robust mechanisms for evaluating and contrasting the performance of different approaches and for defining, measuring and tracking the effectiveness of NbS, taking future climate change into account (Calliari, 2019; Lavorel, 2019). New research is also needed to identify novel forms of financing and incentivizing the implementation of NbS, and of the economic and governance implications of these instruments (Seddon *et al.*, 2020).

To address such knowledge gaps demands a transdisciplinary approach, one that integrates knowledge from across the natural, physical and social sciences, from finance, governance and political ecology, as well as from local and traditional knowledge (e.g., Nalau *et al.*, 2018). Even if future research reduces uncertainty about the contexts and scales at which nature can support human adaptation, without appropriate governance structures in place and suitable flows of finance, NbS will not be implemented on the ground.

4.2. Building communities of science, policy and practice for NbS

For the adaptation needs of communities and ecosystems to be met by NbS, policy targets should aim to be clearly informed by scientific and local indigenous knowledge about ecosystems, their sustainable management and their local dependencies. To enable this, NbS communities made up of researchers, practitioners and policy-makers will need to be developed locally and globally. Such communities enable researchers to better identify not only the knowledge needs of different NbS stakeholders, but also the form of knowledge most relevant and understandable to them. Although such NbS 'communities of practice' exist, they currently either focus on adaptation and disaster risk reduction in Europe (e.g., OPERANDUM (www.operandum-project.eu), ThinkNature (www.think-nature.eu) and NATURVATION (www.naturvation.eu)) or, if more global, place greatest emphasis on learning from practice (e.g., weADAPT (www.weadapt.org)). Moving forward, we need to create NbS communities that can establish and improve an evidence base that draws together scientific, traditional and experiential knowledge about the scales and contexts in which NbS are effective (Kabisch *et al.*, 2016). Such communities are particularly needed at the national level, where unique combinations of socioeconomic, political and ecological conditions require finely tuned approaches and targets, with suitable metrics or indicators by which we measure progress towards meeting those targets.

Greater integration of researchers, local communities and, where relevant, Indigenous Peoples also helps to foster local participation in implementation and makes NbS more equitable and inclusive NbS (Brink & Wamsler, 2018). These factors, in turn, are key determinants of successful sustainable NbS, as they reduce the likelihood of unintended and inequitable outcomes on the ground such as increased burden of labour, reinforced marginalization or increased vulnerability (Woroniecki, 2019; Woroniecki *et al.*, 2019).

5. Conclusions

The potential of NbS to address the climate crisis currently has much political traction. NbS were highlighted in the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) Global Assessment (IPBES, 2019), the Climate Change and Land Report of the Intergovernmental Panel on Climate Change (IPCC, 2019) and the Global Commission on Adaptation Report (Global Commission on Adaptation, 2019). They were included as one of nine key action tracks at the 2019 UN Climate Action Summit (www.un.org/en/climatechange/un-climate-summit-2019.shtml) at which there were several high-profile endorsements of NbS in the corporate sector, as well as by the UN and other national governments. For example, the NbS Coalition grew to encompass 32 nations, the EU Commission, 21 civil society organizations and 8 private-sector groups, all of whom signed the Nature-based Solutions for Climate Manifesto (2019). Meanwhile, a group of six nations (Costa Rica, the Seychelles, Mozambique, Gabon, the United Arab Emirates and Monaco) formed a new High Ambition Coalition for Nature and People and committed to protect 30% of the planet's natural ecosystems by 2030. Several major new funding streams for NbS were announced at the summit (Nature4Climate, n.d.), while in early January 2020, the Trillion Trees Platform (www.1t.org) was launched by the World Economic Forum in Davos.

A growing body of science demonstrates the interdependency of the climate and biodiversity crises and increasingly supports the key role of NbS in addressing both (IPBES, 2019). Therefore, this broad recognition of NbS by governments and businesses is to be welcomed. However, much of the recent focus has been on the role of NbS for mitigation rather than adaptation, with the emphasis often being placed on afforestation (Lewis *et al.*, 2019) and numbers of trees to be planted. However, as discussed above, the protection and restoration of intact ecosystems play more important roles than afforestation in climate change mitigation, especially in tropical nations

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(Griscom *et al.*, 2020). Moreover, it is vital that the current emphasis on tree-planting as a 'climate solution' does not distract from or delay ambitious action to decarbonize our economies (Seddon *et al.*, 2020)

As nations revise their NDCs in 2020 and beyond, policy-makers need support if they are to enhance ambition for both climate change mitigation and adaptation. Such support should include much greater engagement by the research community, including two-way knowledge exchange, making use of the opportunities and incentives provided by international initiatives such as the Nairobi Work Programme of the UNFCCC. To align high-level ambition with local action, the science, practitioner and policy communities must: work together to clarify and properly disseminate information on what makes NbS effective for people and nature; build practitioners' capacity to develop robust adaptation plans that are retuned to local social-ecological contexts; and access suitable levels of adaptation finance and/or technical support.

With incentives such as the Bonn Challenge, the New York Declaration on Forests, the Aichi Biodiversity Targets and the CBD post-2020 Biodiversity Framework, growing numbers of nations are pledging to work with, protect and restore their ecosystems. Provided these pledges are met by actions that are informed by the best available knowledge from science and practice, they will help nations deliver on international commitments with limited finance, and ultimately achieve sustainable and equitable development in a warming world.

Supplementary material. To view supplementary material for this article, please visit https://doi.org/10.1017/sus.2020.8

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Notes

[i] We use 'ecosystems' in a broad way to encompass the wide range of terms used in the NDCs, including biodiversity, wildlife, natural or semi-natural habitats, the natural environment, etc.

[ii] Not all signatories submitted an NDC (see Supplementary Materials).

References

Allen, C. D., Macalady, A. K., Chenchouni, H., Bachelet, D., McDowell, N., Vennetier, M., … Gonzalez, P. (2010). A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. *Forest Ecology and Management, 259*(4), 660–684.

Bowler, D. E., Buyung-Ali, L., Knight, T. M. & Pullin, A. S. (2010). Urban greening to cool towns and cities: a systematic review of the empirical evidence. *Landscape and Urban Planning, 97*(3), 147–155.

Brancalion, P. H. & Chazdon, R. L. (2017). Beyond hectares: four principles to guide reforestation in the context of tropical forest and landscape restoration. *Restoration Ecology, 25*(4), 491–496.

Brink, E. & Wamsler, C. (2018). Collaborative governance for climate change adaptation: mapping citizen–municipality interactions. *Environmental Policy and Governance, 28*, 82–97.

Browder, G., Ozment, S., Rehberger Bescos, I., Gartner, T. & Lange, G.-M. (2019). Integrating green and gray: creating next generation infrastructure. World Bank and World Resources Institute. Retrieved from https://openknowledge.worldbank.org/handle/10986/31430

Brown, D. R., Dettmann, P., Rinaudo, T., Tefera, H. & Tofu, A. (2011). Poverty alleviation and environmental restoration using the clean development mechanism: a case study from Humbo, Ethiopia. *Environmental Management, 48*(2), 322–333.

Buttle, J. M. (2011) Streamflow response to headwater reforestation in the Ganaraska River basin, southern Ontario, Canada. *Hydrological Processes, 25*, 3030–3041.

Calliari, E., Staccione, A. & Mysiak, J. (2019). An assessment framework for climate-proof nature-based solutions. *Science of the Total Environment, 656*, 691–700.

Cao, S. (2008). Why large-scale afforestation efforts in China have failed to solve the desertification problem. *Environmental Science and Technology, 42*(6), 1826–1831.

Cao, S., Chen, L. & Yu, X. (2009). Impact of China's Grain for Green Project on the landscape of vulnerable arid and semi-arid agricultural regions: a case study in northern Shaanxi Province. *Journal of Applied Ecology, 46*(3), 536–543.

Cao, S., Zhang, J., Chen, L. & Zhao, T. (2016). Ecosystem water imbalances created during ecological restoration by afforestation in China, and lessons for other developing countries. *Journal of Environmental Management, 183*, 843–849.

Crouzeilles, R., Beyer, H. L., Monteiro, L. M., Feltran-Barbieri, R., Pessôa, A. C., Barros, F. S., … Matsumoto, M. (2020). Achieving cost-effective landscape-scale forest restoration through targeted natural regeneration. *Conservation Letters*, e12709.

Dadson, S. J., Hall, J. W., Murgatroyd, A., Acreman, M., Bates, P., Beven, K., … O'Connell, E. (2017). A restatement of the natural science evidence concerning catchment-based 'natural' flood management in the UK. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences, 473*(2199), 20160706.

Dave, R., Maginnis, S. & Crouzeilles, R. (2019). Forests: many benefits of the Bonn Challenge. *Nature 570*, 164.

Enríquez-de-Salamanca, A., Díaz, R. D., Martín-Aranda, R. M. & Santos, M. J. (2017). Environmental impacts of climate change adaptation. *Environmental Impact Assessment Review, 64*, 87–96.

Forsell, N., Turkovska, O., Gusti, M., Obersteiner, M., den Elzen, M. & Havlek, P. (2016). Assessing the INDCs' land use, land use change, and forest emission projections. *Carbon Balance and Management, 11*, 26.

Frank, D., Reichstein, M., Bahn, M., Thonicke, K., Frank, D., Mahecha, M. D., … Beer, C. (2015). Effects of climate extremes on the terrestrial carbon cycle: concepts, processes and potential future impacts. *Global Change Biology, 21*(8), 2861–2880.

Giełczewski, M. (2016) Assessing the societal benefits of river restoration using the ecosystem services approach. *Hydrobiologia*, *769*, 121–135.

Global Commission on Adaptation (2019). Adapt now: a global call for leadership on climate resilience. Retrieved from https://gca.org/global-commission-on-adaptation/report

Grassi, G., House, J., Dentener, F., Federici, S., den Elzen, M. & Penman, J. (2017).The key role of forests in meeting climate targets requires science for credible mitigation. *Nature Climate Change*, *7*, 220.

Griscom, B. W., Busch, J., Cook-Patton, S. C., Ellis, P. W., Funk, J., Leavitt, S. M., … Gurwick, N. P. (2020). National mitigation potential from natural climate solutions in the tropics. *Philosophical Transactions of the Royal Society B, 375*(1794), 20190126.

Hobbie, S. E. & Grimm, N. B. (2020) Nature-based approaches to managing climate change impacts in cities. *Philosophical Transactions of the Royal Society B*, *375*(1794), 20190124.

Hua, F., Wang, X., Zheng, X., Fisher, B., Wang, L., Zhu, J., … Wilcove, D. S. (2016). Opportunities for biodiversity gains under the world's largest reforestation programme. *Nature Communications, 7*(1), 12717.

Huang, L., Shao, Q. & Liu, J. (2012). Forest restoration to achieve both ecological and economic progress, Poyang Lake basin, China. *Ecological Engineering, 44*, 53–60.

Hutchison, C., Gravel, D., Guichard, F. & Potvin, C. (2018). Effect of diversity on growth, mortality, and loss of resilience to extreme climate events in a tropical planted forest experiment. *Scientific Reports, 8*(1), 15443.

IPBES (2019) *Summary for Policymakers of the Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. IPBES Secretariat.

IPCC (2018). *Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C Above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty*. World Meteorological Organization.

IPCC (2019) Climate and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse gas fluxes in Terrestrial Ecosystems. Retrieved from https://www.ipcc.ch/report/srccl

Jactel, H., Bauhus, J., Boberg, J., Bonal, D., Castagneyrol, B., Gardiner, B., … Brockerhoff, E. G. (2017). Tree diversity drives forest stand resistance to natural disturbances. *Current Forestry Reports, 3*(3), 223–243.

Jia, X., Zhu, Y. & Luo, Y. (2017). Soil moisture decline due to afforestation across the Loess Plateau, China. *Journal of Hydrology, 546*, 113–122.

Jiao, J., Zhang, Z., Bai, W., Jia, Y. & Wang, N. (2012). Assessing the ecological success of restoration by afforestation on the Chinese Loess Plateau. *Restoration Ecology, 20*(2), 240–249.

Kabisch, N., Frantzeskaki, N., Pauleit, S., Naumann, S., Davis, M., Artmann, M., … Zaunberger, K. (2016). Nature-based solutions to climate change mitigation and adaptation in urban areas: perspectives on indicators, knowledge gaps, barriers, and opportunities for action. *Ecology and Society, 21*(2), 39.

Kelly, C. N., McGuire, K. J., Miniat, C. F. & Vose, J. M. (2016). Streamflow response to increasing precipitation extremes altered by forest management. *Geophysical Research Letters, 43*(8), 3727–3736.

Lavorel, S., Colloff, M. J., Locatelli, B., Gorddard, R., Prober, S. M., Gabillet, M., … Peyrache-Gadeau, V. (2019). Mustering the power of ecosystems for adaptation to climate change. *Environmental Science & Policy, 92*, 87–97.

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

Liquete, C., Udias, A., Conte, G., Grizzetti, B. & Masi, F. (2016). Integrated valuation of a nature-based solution for water pollution control. Highlighting hidden benefits. *Ecosystem Services, 22*, 392–401.

Liu, J., Li, S., Ouyang, Z., Tam, C. & Chen, X. (2008). Ecological and socioeconomic effects of China's policies for ecosystem services. *Proceedings of the National Academy of Sciences of the United States of America, 105* (28), 9477–9482.

Loreau, M. & de Mazancourt, C. (2008). Species synchrony and its drivers: neutral and nonneutral community dynamics in fluctuating environments. *American Naturalist, 172*(2), E48–E66.

Martin, T. G. & Watson, J. E. (2016). Intact ecosystems provide best defence against climate change. *Nature Climate Change, 6*(2), 122–124.

Maxwell, S. L., Evans, T., Watson, J. E., Morel, A., Grantham, H., Duncan, A., … Wang, S. (2019). Degradation and forgone removals increase the carbon impact of intact forest loss by 626%. *Science Advances, 5*(10), eaax2546.

Mbow, C., Van Noordwijk, M., Luedeling, E., Neufeldt, H., Minang, P. A. & Kowero, G. (2014). Agroforestry solutions to address food security and climate change challenges in Africa. *Current Opinion in Environmental Sustainability, 6*, 61–67.

McGuire, J. L., Lawler, J. J., McRae, B. H., Nuñez, T. A. & Theobald, D. M. (2016). Achieving climate connectivity in a fragmented landscape. *Proceedings of the National Academy of Sciences of the United States of America, 113*(26), 7195–7200.

Menéndez, P., Losada, I. J., Torres-Ortega, S., Narayan, S. & Beck, M. W. (2020). The global flood protection benefits of mangroves. *Scientific Reports, 10*(1), 4404.

Mijangos, J. L., Pacioni, C., Spencer, P. B. & Craig, M. D. (2015). Contribution of genetics to ecological restoration. *Molecular Ecology, 24*(1), 22–37.

Morecroft, M. D., Duffield, S., Harley, M., Pearce-Higgins, J. W., Stevens, N., Watts, O. & Whitaker, J. (2019). Measuring the success of climate change adaptation and mitigation in terrestrial ecosystems. *Science, 366*(6471), eaaw9256.

Nalau, J., Becken, S., Schliephack, J., Parsons, M., Brown, C. & Mackey, B. (2018). The role of indigenous and traditional knowledge in ecosystem-based adaptation: a review of the literature and case studies from the Pacific Islands. *Weather, Climate, and Society, 10*(4), 851–865.

Narayan, S., Beck, M. W., Reguero, B. G., Losada, I. J., van Wesenbeeck, B., Pontee, N., … Burks-Copes, K. A. (2016) The effectiveness, costs and coastal protection benefits of natural and nature-based defences. *PLoS ONE, 11*(5), e0154735.

Narayan, S., Beck, M. W., Wilson, P., Thomas, C. J., Guerrero, A., Shepard, C. C., … Trespalacios, D. (2017). The value of coastal wetlands for flood damage reduction in the northeastern USA. *Scientific Reports, 7*(1), 9463.

National Academies of Sciences, Engineering, and Medicine (2016). *Attribution of Extreme Weather Events in the Context of Climate Change*. National Academies Press.

Nature4Climate (n.d.). Summary of announcements at the UN Climate Summit. Retrieved from https://nature4climate.org/nature-based-solutions-a-summary-of-announcements-and-developments-during-the-un-climate-action-summit-and-climate-week

NBSPP (2020). Nature-based Solutions Policy Platform. Retrieved from www.nbspolicyplatform.org

Oliver, T. H., Heard, M. S., Isaac, N. J., Roy, D. B., Procter, D., Eigenbrod, F., … Proença, V. (2015). Biodiversity and resilience of ecosystem functions. *Trends in Ecology & Evolution, 30*(11), 673–684.

Ostrom, E. (2009) A general framework for analyzing sustainability of social-ecological systems. *Science*, *325*, 419–422.

Osuri, A. M., Gopal, A., Raman, T. S., DeFries, R., Cook-Patton, S. C. & Naeem, S. (2020). Greater stability of carbon capture in species-rich natural forests compared to species-poor plantations. *Environmental Research Letters, 15*(3), 034011.

Ouyang, Z., Zheng, H., Xiao, Y., Polasky, S., Liu, J., Xu, W., … Jiang, L. (2016). Improvements in ecosystem services from investments in natural capital. *Science, 352*(6292), 1455–1459.

Paul, C., Weber, M. & Knoke, T. (2017). Agroforestry versus farm mosaic systems – comparing land-use efficiency, economic returns and risks under climate change effects. *Science of the Total Environment, 587*, 22–35.

Reid, H., Hou Jones, X., Porras, I., Hicks, C., Wicander, S., Seddon, N., … Roe, D. (2019). *Is Ecosystem-based Adaptation Effective? Perceptions and Lessons Learned from 13 Project Sites*. IIED.

Rizvi, A. R. (2014). *Nature Based Solutions for Human Resilience: A Mapping Analysis of IUCN's Ecosystem Based Adaptation Projects*. IUCN.

Royal Society (2014). Resilience to Extreme Weather, Royal Society, London. Retrieved from https://royalsociety.org/topics-policy/projects/resilience-extreme-weather

Rupp-Armstrong, S. & Nicholls, R. J. (2007). Coastal and estuarine retreat: a comparison of the application of managed realignment in England and Germany. *Journal of Coastal Research, 236*, 1418–1430.

Scherr, S. J. & Sthapit, S. (2009). *Sustainable Land Management in Africa: Opportunities for Climate Change Adaptation*. TerrAfrica.

Scyphers, S. B., Powers, S. P., Heck Jr, K. L. & Byron, D. (2011). Oyster reefs as natural breakwaters mitigate shoreline loss and facilitate fisheries. *PLoS ONE, 6*(8), e22396.

Secretariat of the Convention on Biological Diversity (2009). *Connecting Biodiversity and Climate Change Mitigation and Adaptation: Report of the*

https://doi.org/10.1017/sus.2020.8 Published online by Cambridge University Press

Second Ad Hoc Technical Expert Group on Biodiversity and Climate Change. Secretariat of the Convention on Biological Diversity.

Seddon, N., Chausson, A., Berry, P., Girardin, C. A. J., Smith, A. & Turner, B. (2020). Understanding the value and limits of nature-based solutions to climate change and other global challenges. *Philosophical Transactions of the Royal Society B, 375*(1794), 20190120.

Seddon, N., Sengupta, S., García-Espinosa, M., Hauler, I., Herr, D. & Rizvi, A. R. (2019a). *Nature-based Solutions in Nationally Determined Contributions: Synthesis and Recommendations for Enhancing Climate Ambition and Action by 2020*. IUCN and University of Oxford.

Seddon, N., Turner, B., Berry, P., Chausson, A. & Girardin, C. A. (2019b). Grounding nature-based climate solutions in sound biodiversity science. *Nature Climate Change, 9*(2), 84–87.

Temmerman, S., Meire, P., Bouma, T. J., Herman, P. M., Ysebaert, T. & De Vriend, H. J. (2013). Ecosystem-based coastal defence in the face of global change. *Nature, 504*(7478), 79–83.

Torralba, M., Fagerholm, N., Burgess, P. J., Moreno, G. & Plieninger, T. (2016). Do European agroforestry systems enhance biodiversity and ecosystem services? A meta-analysis. *Agriculture, Ecosystems & Environment, 230*, 150–161.

UNFCCC (2016) The Paris Agreement of the United Nations Framework Convention for Climate Change. Retrieved from https://unfccc.int/sites/default/files/resource/docs/2015/cop21/eng/l09r01.pdf

Uy, N., Shaw, R. and Takeuchi, Y. (2012). Linking livelihoods and ecosystems for enhanced disaster management. In R. Shaw, & P. Tran (eds), *Environment Disaster Linkages* (pp. 131–143). Community, Environment and Disaster Risk Management, Vol. 9. Emerald Publishing Ltd..

Veldman, J. W., Overbeck, G. E., Negreiros, D., Mahy, G., Le Stradic, S., Fernandes, G. W., … Bond, W. J. (2015). Where tree planting and forest expansion are bad for biodiversity and ecosystem services. *BioScience, 65* (10), 1011–1018.

Vermaat, J. E., Wagtendonk, A. J., Brouwer, R., Sheremet, O., Ansink, E., Brockhoff, T., … Giełczewski, M. (2016). Assessing the societal benefits of river restoration using the ecosystem services approach. *Hydrobiologia, 769*(1), 121–135.

Waldron, A., Garrity, D., Malhi, Y., Girardin, C., Miller, D. C. & Seddon, N. (2017). Agroforestry can enhance food security while meeting other sustainable development goals. *Tropical Conservation Science, 10*, 1–6.

Watson, J. E., Evans, T., Venter, O., Williams, B., Tulloch, A., Stewart, C., … McAlpine, C. (2018). The exceptional value of intact forest ecosystems. *Nature Ecology & Evolution, 2*(4), 599–610.

World Economic Forum (2020). *Global Risks Report 2020, 15th Edition*. World Economic Forum.

Woroniecki, S. (2019) Enabling environments? Examining social co-benefits of ecosystem-based adaptation to climate change in Sri Lanka. *Sustainability*, *11*, 772.

Woroniecki, S., Wamsler, C. & Boyd, E. (2019). The promises and pitfalls of ecosystem-based adaptation to climate change as a vehicle for social empowerment. *Ecology and Society, 24*(2), 4.

Xu, J. C. (2011) China's new forests aren't as green as they seem. *Nature*, *477*, 371.

Zhang, J., Ding, Z. & Luo, M. (2017). Risk analysis of water scarcity in artificial woodlands of semi-arid and arid China. *Land Use Policy, 63*, 324–330.