Biodiversity's contributions to sustainable development

Malgorzata Blicharska[1*], Richard J. Smithers[2*], Grzegorz Mikusiński[3], Patrik Rönnbäck[1], Paula A. Harrison[4], Måns Nilsson[5], William J. Sutherland[6]

Affiliations

[1]Natural Resources and Sustainable Development, Department of Earth Sciences, Uppsala University, Uppsala, Sweden

[2]Ricardo Energy & Environment, Harwell, Didcot, UK

[3]Grimsö Wildlife Research Station, Department of Ecology, Swedish University of Agricultural Sciences (SLU), Riddarhyttan, Sweden

[4]Centre for Ecology & Hydrology, Lancaster Environment Centre, Bailrigg, Lancaster, UK

[5]Stockholm Environment Institute, Stockholm, Sweden

[6]Department of Zoology, University of Cambridge, Cambridge, UK

Correspondence to: malgorzata.blicharska@geo.uu.se

*These authors contributed equally to this work

Preface

International concern to develop sustainably challenges us to act upon the inherent links between our economy, society and environment, and is leading to increasing acknowledgement of biodiversity's importance. This Review discusses the breadth of ways in which biodiversity can support sustainable development. It uses the Sustainable Development Goals (SDGs) as a basis for exploring scientific evidence of the benefits delivered by biodiversity. It focuses on papers that provide examples of how biodiversity components (i.e. ecosystems, species and genes) directly deliver benefits that may contribute to the achievement of individual SDGs. It also considers how biodiversity's direct contributions to fulfilling some SDGs may indirectly support the achievement of other SDGs to which biodiversity does not contribute directly. How the attributes (e.g. diversity, abundance or composition) of biodiversity components influence the benefits delivered is also presented, where described by the papers reviewed. While acknowledging potential negative impacts and trade-offs between different benefits, the study concludes that biodiversity may contribute to fulfilment of all SDGs.

Introduction

The concept of sustainable development (Box 1) is based on the notion of three pillars supporting sustainability: economy, society and environment[1]. However, there is growing evidence of their interrelations and recognition that the environment, particularly its biodiversity (Box 2), provides benefits that help to support our society and economy[2]. In 2008, the Millennium Development Goals (MDGs) incorporated the Convention on Biological Diversity (CBD) target "to achieve by 2010 a significant reduction of the current rate of biodiversity loss (…) as a contribution to poverty alleviation and to the benefit of life on earth". The subsequent 2030 Agenda for Sustainable

Development ("the 2030 Agenda") comprises the 17 Sustainable Development Goals (SDGs)[3], including SDG 14 (Life below water) and SDG 15 (Life on land). The SDGs are presented as an interconnected whole, however, by only explicitly considering biodiversity at the goal level in the wording of SDGs 14 and 15, the breadth of ways in which it can contribute to human well-being, the key rationale of the CBD Strategic Plan 2011-2020 (a worldwide framework for biodiversity conservation), may not be fully acknowledged. The academic and policy communities are striving to increase societal appreciation of the value of ecosystem services for human well-being[4]. However, they often focus on ecosystem services without identifying the biodiversity components (i.e. ecosystems, species and genes) responsible for delivering benefits to people[5]. Thus, our study aims to review and exemplify the ways in which biodiversity can deliver benefits that support sustainable development.

The CBD Secretariat and others analysed how the CBD Strategic Plan's Aichi Targets are reflected in SDGs and associated targets[6]. They showed that the 2030 Agenda may help to address drivers of biodiversity loss and improve associated governance. They also highlighted that biodiversity may contribute to the achievement of a number of SDGs and to some of their targets. In December 2016, the thirteenth Conference of the Parties (CoP) to the CBD called for integration of the 2030 Agenda strategies and plans with national biodiversity strategies and actions plans. This was motivated by increasing recognition that the 2030 Agenda provides a major opportunity to mainstream biodiversity considerations and enhance achievement of the Aichi Targets[7]. In pursuing our aim, we use the SDGs as a basis for exploring how biodiversity helps to support sustainable development. Although some studies have descriptively summarised how benefits delivered by biodiversity may contribute to the fulfilment of all SDGs[8,9], our study goes further in exploring the scientific evidence and providing specific examples in relation to each SDG.

Our study is pertinent to assessments by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). IPBES was established in 2012 to strengthen the scientific evidence base for developing policy on biodiversity conservation and sustainable development. The four Regional Assessments published in 2018[10-13] reviewed past and current trends and synthesized projections of future trends in nature (including biodiversity), nature's contributions to people (including ecosystem services) and human well-being. Although the Regional Assessments highlight biodiversity's role in "maintaining and promoting multiple contributions of nature to people", they do not explain how biodiversity may contribute to each SDG. Instead, they broadly interpret what the trends in biodiversity, ecosystem services and human well-being may mean for achieving the Aichi Targets and SDGs. Building upon the Regional Assessments, in May 2019, IPBES published the Global Assessment[14], which will contribute to the fifth Global Biodiversity Outlook of the CBD that will report in 2020 on implementation of the CBD Strategic Plan. The Global Assessment specifically acknowledges how benefits delivered by biodiversity may contribute to fulfilment of SDGs 1 (poverty), 2 (hunger), 3 (health), 6 (water), 11 (cities), 13 (climate) and 14 and 15. It points to positive synergies between biodiversity and SDGs 4 (education), 5 (gender equality), 10 (reducing inequalities) and 16 (peace and justice). It also notes that some pathways to achieving the remaining SDGs could have positive or negative impacts on biodiversity and, thus, on achieving the other SDGs. By explicitly exemplifying how biodiversity may contribute directly or indirectly to fulfilling all SDGs, we hope that our study may be a useful supplement to the IPBES assessments and help to support negotiations on follow-up to the CBD Strategic Plan.

Establishing links between biodiversity and sustainable development is a complex task[15]. Global connectivity of socioeconomic and environmental interactions across space and time[16] encompasses various forms of "coupling"[17], which present challenges and opportunities for sustainable development and its impacts and dependencies on biodiversity. From a spatial perspective, biodiversity may contribute to sustainable development through benefits generated locally, imported from elsewhere, or generated at larger scales[18]. From a temporal perspective, while biodiversity may deliver some immediate benefits for sustainable development, other benefits may take decades or even centuries to be realised[19]. Furthermore, sustainable development demands delivery of biodiversity benefits that meet present needs should be maintained for future generations. This is increasingly challenging at a local scale, given species movement in response to climate change, irrespective of efforts to halt and reverse habitat loss[20]. These spatial and temporal considerations mean that our local and wider impacts on biodiversity may have lasting and cumulative consequences for human well-being beyond their immediate outcomes[21].

The "Environmentalist's Paradox"[22] is that most biodiversity exists in developing countries, while developed countries, which in many cases historically had less biodiversity[23] that was further degraded during their development, actually thrive economically[24]. For example, Figure 1a identifies that many countries ranked by the United Nations Development Programme (UNDP) in the highest tier of human development (in relation to life expectancy, education, and per capita income)[25] have low biodiversity intactness (i.e. the average number of originally-present species across a broad range of species, relative to their number in an undisturbed habitat[26]). Several hypotheses have been suggested to explain this paradox", including that: 1) there may be a time-lag after ecosystem degradation before human well-being is negatively affected and 2) a higher level of development may be sustained with less biodiversity where such countries can import benefits associated with degradation of less-developed countries' biodiversity (Figure 1b, large white arrow). Indeed, international trade chains contribute to biodiversity loss far from the place of consumption[27], and biodiversity footprints have been calculated for specific goods produced in developing countries and exported to developed ones[28]. As such, unless spatial and temporal dimensions are considered, links between biodiversity and development may not be fully acknowledged.

Exploring the evidence

We searched the Web of Science for scientific evidence of how biodiversity components (i.e. ecosystems, species and genes) may contribute directly to each SDG across space and time (see Supplementary Information 2 for search terms). Although we focused on how these components may contribute, if the studies considered the influence of their attributes (e.g. diversity, abundance or composition) on the benefits delivered, these are also presented. We defined "direct contribution" as the way that benefits delivered by biodiversity may directly support fulfilment of an SDG, e.g. pollination of crops by insects may contribute to the achievement of SDG 2 (food security). Where we were unable to find examples of how biodiversity may contribute directly to an SDG, we sought examples of how it may do so indirectly. An "indirect contribution" was defined as the way in which biodiversity's direct contribution to an SDG may lead to subsequent fulfilment of other SDGs, e.g. biodiversity's direct contribution to SDG 2 may improve children's nutrition and thereby indirectly contribute to them having better educational opportunities (SDG 4), which may, in turn, support achievement of yet other SDGs. We excluded SDGs 14 and 15 from our search, as they specifically address use of biodiversity for sustainable development.

To identify relevant examples from publications found by the literature search, we addressed the following questions for each SDG: 1) How may biodiversity contribute directly to the SDG? 2) Can biodiversity contribute directly to the SDG over a smaller (local to sub-national) and/or larger (national to global) spatial scale? 3) Can biodiversity contribute directly to the SDG over a shorter (months to years) and/or longer (decades to centuries) timescale? 4) How may biodiversity's direct contribution to some SDGs then contribute indirectly to the other SDGs to which biodiversity may not contribute directly (i.e. where examples were not found in relation to Question 1)? Where the search provided no examples for an SDG, we used 'snowballing', i.e. following up papers cited by references identified by the search terms, to fill gaps.

Categorisation of papers to address Questions 2 and 3 was determined primarily from our expert judgement, as few papers were explicit about the scales at which biodiversity benefits are delivered. In relation to Question 4, we had to deduce some of biodiversity's indirect contributions to such SDGs from papers that did not refer to biodiversity. Instead, they focused only on benefits for SDGs that we determined may be delivered directly by biodiversity and how they may contribute to the delivery of other SDGs. For example, in response to Question 1, we found examples of how biodiversity may contribute to reducing hunger (SDG 2) and, in relation to Question 4, found evidence that a chronic lack of nutrition may reduce children's cognitive abilities. Hence, we could reasonably deduce that biodiversity may indirectly contribute to better school performance (SDG 4).

As our aim was to exemplify the breadth of ways in which biodiversity may support sustainable development, our search for evidence focused on positive impacts of biodiversity for fulfilling SDGs. Nevertheless, we acknowledge that biodiversity can impact negatively on sustainable development (e.g. pathogens causing diseases) and that interconnections between SDGs lead to numerous potential trade-offs. Relationships between the focus of some goals, e.g. poverty (SDG 1) or health (SDG 3), and biodiversity may be particularly complex. However, as we sought to exemplify biodiversity's contributions to each SDG, we needed neither to elucidate such complexities through describing all ways in which it contributes nor to undertake a systematic review nor to use all possible synonyms (e.g. for "poverty") as search terms for SDGs where examples were readily found (e.g. SDG 1). We also did not determine the relative magnitude of biodiversity's contributions or their total in relation to the scale of each goal. We focused on the goals rather than their targets because: 1) the goals are not time bound, enabling us to consider how biodiversity benefits contribute to their fulfilment in the short and long term; and 2) many targets only address processes (e.g. creating policy frameworks, establishing systems and measures, or reforming practices). Nevertheless, we referred to targets, where relevant, to help inspire identification of search terms for each SDG.

Direct contributions of biodiversity

In addition to biodiversity's relevance to SDGs 14 and 15, the literature provided numerous examples of direct contributions of ecosystems or species to the fulfilment of ten other SDGs and of genes to five of them (Table 1). In this section, we use examples derived from references listed in Table 1 to illustrate direct contributions of these biodiversity components to SDGs, further highlighting the influence of their attributes where assessed by these studies. Some examples directly relate to more than one SDG and different examples address issues directly interconnecting several goals. Hence, we provide a narrative on that basis rather than describe examples in relation to each goal sequentially.

Ecosystems

Ecosystems can contribute to poverty alleviation (SDG 1) and ending hunger (SDG 2). For example, a comparative analysis of households in 24 developing countries reveals that ecosystems provide 28 per cent of total household income, 77 per cent of which comes from natural forests[29]. Similarly, mangrove forests provide 74 per cent of income for low-income households in the Sundarbans, Bangladesh[30].

Ecosystems can contribute to people's physical and mental well-being (SDG 3). For example, preserving intact ecosystems reduces the incidence of infectious diseases[31], while experience of 'wilderness' increases happiness and recovery from mental fatigue[32]. Many other examples come from urban areas (SDG 11), . Simply viewing vegetation decreases stress and reduces recovery times after surgery[33]. Vegetation in urban areas also reduces the heat-island effect and improves people's mental state; both mediating cardiovascular disease-related mortality[34]. More parks within cities is also associated with people having a lower body mass index[35]. Furthermore, atopy, the genetic tendency to develop allergies, is more common in less biodiverse environments[36], while asthma associated with heavy traffic is less frequent in children living in areas with over 40 per cent green cover[37]. In addition, garden-based therapies provide numerous benefits for physical and mental well-being[38].

Ecosystems can provide regulating functions relevant to climate action (SDG 13) and water management (SDG 6). For example, forests, wetlands, grasslands and agricultural lands remove carbon dioxide from the atmosphere (SDG 13)[39,40]. Functional diversity can be a key attribute determining ecosystem's role in climate mitigation, for example, many large tropical trees that contribute to carbon storage rely on large vertebrates for seed dispersal[41]. Higher tree species richness of forests may also increase soil carbon storage[42], and mixed-species plantations may sequester more carbon than monocultures[43]. Ecosystems also deliver many other benefits that increase people's resilience to climate change[44] and disaster risk (SDG 13). For example, non-timber forest products may provide a safety net for communities in developing countries that face increasing climate variability[45]. In addition, ecosystems provide resilient infrastructure (SDG 9). For example, wetlands[46] and forests can contribute to water management (SDG 6) by reducing run-off rates[47], enhancing water quality and delaying flood flows. Furthermore, riparian forests with a more complex structure may provide greater flood control[48]. Establishing shrub communities with at least 30 per cent canopy cover can protect soils from erosion[49]. Coral and oyster reefs, intertidal wetlands, and mangrove forests each reduce wave height and erosion, and lessen the impact of storms on people[50-52].

Many regulatory functions provided by ecosystems benefit cities (SDG 11), as well as infrastructure (SDG 9) and energy (SDG 7). Green infrastructure can contribute to cities' resilience and adaptability. Increasing urban forest cover can make an important contribution to reducing the heat-island effect[34]. 'Blue-green' measures can mitigate the effects of heavy rains[53], for example, green roofs increase water retention and reduce flooding[54]. Furthermore, roof gardens cool buildings[55], while vegetative cover decreases energy consumption in nearby buildings[56]. Ecosystems can also bolster the sustainability and resilience of grey infrastructure, for example, green roofs increase the longevity of roofing membranes[57].

In a wider sense, ecosystems may contribute to economic growth (SDG 8). For example, countries with global biodiversity-hotspots have higher annual growth of tourism investments[58] than other places and visitor numbers to protected areas are increasing globally[59]. Ecosystems can help to achieve higher economic productivity by providing cost-efficient solutions, for example, for increasing resilience to climate change[60] or reducing nutrient loads in watercourses[61]. Management of ecosystems can also provide a wide range of jobs, for example, China's Natural Forest Protection Programme may increase national employment by 0.93 million[62].

Species

Species can contribute to reducing poverty (SDG 1) and hunger (SDG 2) by supporting production. For example, soil organisms improve soil productivity[63] and biomass production increases with species richness[64]. Similarly, species diversity across trophic levels may contribute to the productivity and stability of marine ecosystems[65]. A diversity of pollinators[66], rather than their abundance[67], ensures crop pollination and 35 per cent of global food production is dependent on them[67]. Some predators also increase agricultural output through their impact on pests[68]. In that context, plant diversity provides temporal continuity of resources for arthropod foodwebs[69] with consequent benefits for controlling pest[70]. The potential of biological control has led to approximately 2,000 non-native species being introduced to control arthropod pests in 196 countries[71]. In addition, edible wild plants provide future opportunities to develop new crops[72] matched to environmental change[73]. Each additional species consumed is also positively associated with the nutrient adequacy of people's diets[74].

Species can contribute to human health and well-being (SDG 3) by helping to mitigate or cure diseases. The composition and diversity of people's microbiota[75] helps to establish balanced immune responses and may be undermined by overuse of antibiotics, dietary changes, and elimination of parasitic infections[76]. Similarly, atopic individuals tend to have skin with less diverse gammaproteobacteria[36]. Gut microbiota also influence many aspects of health[75]. Transmission of infectious diseases can be affected by the abundance, behaviour or condition of the host, vector or parasite[31]. For example, incidence of diseases can be reduced by species providing a dilution effect and, in that way, species diversity among tick-hosts of Lyme disease or the hosts of West Nile virus can reduce their prevalence in people[31]. Predators of species that host or spread fatal human diseases also lower associated risks[68]. In addition, species have long been sources of medicines[77], for example, at least 584 animal species are used in traditional medicine in Latin America[78]. Species also provide sources of vitamins and minerals, for example, wildlife consumption has been found to reduce anaemia in children in rural Madagascar[79]. Furthermore, people's health in cities and human settlements (SDG 11) may benefit from species. For example, urban trees remove dust thereby improving people's health[80], while species richness increases the psychological benefits of greenspaces[81] and bird song contributes to people's sense of well-being[82].

Many of the benefits that species contribute often go largely unnoticed; for example, ivy *Hedera helix* covering buildings reduces energy consumption[83] (SDG 7), and many species inspire biomimicry-based innovations[84] (SDG 9). Likewise, many benefits provided by microorganisms are overlooked. For example, microorganisms contribute to waste management, and thereby sustainable consumption and production (SDG 12), through their involvement in biogeochemical cycling and organic contaminant degradation[85,86]. Soil microorganism diversity improves carbon sequestration[87] (SDG 13) and increases denitrification[88,89] that may help sustainable water management (SDG 6). Fungi, algae and higher plants also contribute to water quality by reducing heavy metals in the environment through bioremediation[90]. In contrast with the low profile of those benefits, some species contributions are renowned, such as the role of Marram grass *Ammophila* spp. in stabilising sand dunes[91] (SDG 13). Other species deliver benefits that have a global profile, such as the charismatic large mammals that attract tourists[92] (SDG 8).

Genes

As with species diversity, genetic diversity across trophic levels may help to sustain the productivity and stability of marine ecosystems[65] and thereby contribute to reducing poverty and hunger (SDGs 1 and 2). Such genetic diversity may also enhance ecosystem resilience in an increasingly uncertain world[93]; contributing to combatting climate change and its impacts (SDG 13). Analogously, natural genetic diversity of grains and legumes and their wild relatives, such as quinoa[94], may enhance our ability to adapt and sustain food production[73] (SDG 2) by providing resources for crop breeding and improvement[95,96]. Genetic resources (e.g. from marine species[97]) also provide opportunities for bioprospecting[98], biotechnology and business[99], which may support economic growth (SDG 8).

Spatial and temporal scales

Biodiversity may directly contribute to all ten SDGs in Table 1 at a local to sub-national (i.e. 'small') scale. A total of 39 out of the 51 ways in which biodiversity benefits may contribute to SDGs identified in Table 1 can only be related to this scale. For example, biodiversity provides resources and income to local communities (SDG 1); pollination of local crops (SDG 2); and urban cooling thereby enhancing people's well-being (SDG 3), reducing energy use (SDG 7) and making cities more sustainable (SDG 11). One example in Table 1 is relevant only at a national to international (i.e. 'large') scale: carbon storage and sequestration by ecosystems, which contributes to climate change mitigation globally (SDG 13). The remaining 11 ways in which biodiversity may contribute to fulfilling four goals can occur at both a small and a large scale. For example, food (SDG 2), medicines (SDG 3) and other goods (SDG 8) provided by biodiversity can be used locally or exported, natural resources management and tourism can provide employment locally and internationally (SDG 8), and biodiversity can provide and inspire environmentally-sound technologies close to and distant from where it is located (SDG 9).

Our study highlights that biodiversity delivers benefits that may directly help to fulfil each of the ten goals in Table 1 over both short and long timescales. This is relevant, given sustainable development "meets the needs of the present without compromising the ability of future generations to meet their own needs" (Box 1). For example, biodiversity not only contributes to provision of food needed to reduce hunger (SDG 2) in the short-term but also to ensuring long-term food supply.

Indirect contributions of biodiversity

We found examples of how biodiversity's direct contribution to fulfilling some SDGs may also then indirectly support the achievement of all other SDGs to which biodiversity benefits do not contribute directly: Quality education (SDG 4); Gender equality (SDG 5); Reduced inequalities (SDG 10); Peace, justice and strong institutions (SDG 16); and Partnerships for the goals (SDG 17) (Figure 2).

Biodiversity's direct contributions to reducing poverty (SDG 1) and to food (SDG 2), health (SDG 3), water supply (SDG 6) and resilient cities (SDG 11), may indirectly support fulfilment of SDG 4 on education and SDG 5 on gender equality. Biodiversity benefits may indirectly lead to better school performance (SDG4), as they may directly address issues that reduce children's cognitive abilities. For example, they may reduce poverty[100] and a chronic lack of nutrition[101] by supporting increased production (SDGs 1 and 2) and improve health (SDG 3)[101], or children's cumulative exposure to heat[102] through green infrastructure reducing the urban heat-island effect in cities (SDG 11). The latter can also provide green spaces that present educational opportunities to learn about human-nature interactions (SDG 4)[103]. Furthermore, biodiversity may indirectly increase rural school attendance in developing countries (SDG 4), as its role in reducing run-off or providing bioremediation may increase likelihood of safe freshwater locally (SDG 6) and mean mothers no longer fulfil responsibilities for water supply[104] by using children to fetch water from distant sources. Also in developing countries, where women are the holders of relevant knowledge and skills, diverse food systems that include a wide range of crops and wild sources (SDG 2) can strengthen women's societal role and, thus, contribute to gender equity (SDG 5)[105]. Ultimately, biodiversity's indirect contributions to education (SDG 4) and gender equality (SDG 5) may, in turn, help to reduce inequalities more generally (SDG 10)[106].

Biodiversity's direct contribution to reducing poverty (SDG 1) and hunger (SDG 2), promoting healthy lives and well-being (SDG 3), ensuring availability and sustainable management of water (SDG 6), sustaining economic growth (SDG 8) and safe, resilient and sustainable cities (SDG 11), and combatting climate change (SDG 13) may, in turn, help to maintain peaceful societies (SDG 16). For example, in making cities safer and more sustainable (SDG 11), green spaces may indirectly contribute to reducing incidences of violent crime[107] (SDG 16). Also, in providing benefits that directly contribute to climate change mitigation (SDG 13), biodiversity may indirectly contribute to reducing potential for armed conflicts (SDG 16) that might otherwise be precipitated by drought[108], or inadequate food production[109]. In addition, by indirectly improving education (SDG 4), biodiversity may help to enhance scope for participatory, representative decision making and the protection of freedoms (SDG 16)[110].

By contributing benefits to fulfilling some SDGs, biodiversity may indirectly strengthen how other SDGs can be implemented (SDG 17). For example, biodiversity's contributions to reducing illness (SDG 3) and, therefore, absence from work may, in turn, strengthen potential for tax payments[111] (SDG 17). The various ways in which biodiversity may directly lower risks, e.g. associated with poverty (SDG 1), ill health of the workforce (SDG 3), cities (SDG 11) or climate change (SDG 13), may induce greater financing by the private sector[112] (SDG 17). Finally, how biodiversity directly contributes to delivery of a range of products, e.g. in relation to food (SDG 2) or energy (SDG 7), may subsequently enable developing countries to export goods[113] (SDG 17).

Implications for future policy and research directions

While the 2030 Agenda only explicitly addresses the use of biodiversity for sustainable development in SDGs 14 and 15 at the goal level, our study demonstrates that biodiversity may also directly support fulfilment of ten of the other SDGs, which may then indirectly contribute to achieving the remaining five. In doing so, biodiversity can thereby help to support sustainable development. We acknowledge that our study does not determine all biodiversity's potential contributions, their relative magnitude or their total in relation to the scale of each goal. Differences between the ways that biodiversity may directly contribute to some goals, and how those may indirectly further achievement of other goals, may not always be easy to discern. As such, there may be numerous other indirect links between SDGs in addition to those depicted in Figure 2 and their relationships may be far more nuanced.

Although biodiversity benefits may support delivery of many targets associated with some SDGs, factors beyond biodiversity, including technical solutions, are crucial to fulfilling other SDGs for which biodiversity may only contribute benefits to one or two targets. For example, social, cultural, political and governance factors that affect the distribution of benefits may be important, particularly for reducing inequality within and among countries (SDG 10). Nevertheless, our study not only implies that benefits delivered by biodiversity may help to meet our immediate and short-term needs, but also that further biodiversity loss, as a result of population growth[114], production and trade, may constrain future sustainable development[14].

Policy implications

Examples presented in this paper reveal that biodiversity benefits may contribute to fulfilling SDGs at different scales. This may have implications for governance at all levels. Almost all biodiversity's direct contributions to fulfilling SDGs are delivered at the local and subnational scale (Table 1). At the same time, effective interventions to maintain or restore individual countries' biodiversity at this scale may also require national, transboundary and international actions.

Irrespective of policy interventions, a country's starting point may limit its future biodiversity potential and possibilities for achieving sustainable development. For example, while Canada and the UK are both highly developed, they face different challenges. Canada has a relatively low population density and high biodiversity intactness, with extensive tracts of natural ecosystems, including forests that are being logged for domestic use and export[115]. The UK is densely populated, has low biodiversity intactness, had already converted its natural ecosystems to farmland by Roman times[116] and benefits substantially from biodiversity in less-developed countries, for example, as the second largest net importer of forest products in 2015[117]. While Canada might sustain high biodiversity intactness for a considerable time, irrespective of whether it develops sustainably, by comparison the UK may always have lower biodiversity intactness than Canada, although its biodiversity could be substantially enhanced. Similarly, the challenges faced by least developed countries differ greatly. For example, Mali's ability to retain biodiversity intactness, and its potential to achieve sustainable development, is constrained by spread of the Sahara and by being land-locked. In contrast, while the Democratic Republic of Congo has a wealth of natural resources, weak governance and accelerating global commodity demand may promote unsustainable development at the expense of biodiversity.

Given the different starting points, a first step for every country's sustainable development could be to build upon our examples and systematically identify specific interactions between its biodiversity and SDGs to identify mutually beneficial actions. This could then enable national biodiversity plans and national development plans to be integrated, rather than developed and implemented separately. Our examples suggest that biodiversity contributes to sustainable development in many sectors, including agricultural production, health, water management, economic development, and urban planning. Hence, biodiversity could be mainstreamed in national and sub-national policy processes. Moreover, these processes could identify transboundary arrangements that maintain biodiversity benefits emanating from neighbouring countries, for example, related to water quantity and quality associated with river basins and forest cover.

Secondly, coupling of socioeconomic and environmental interactions[16,17] means international actions are required to ensure that countries' dependencies on other countries for benefits delivered by biodiversity (i.e. in relation to SDGs 2, 3, 8, 9 and 13; Table 1) contribute to maintaining or restoring biodiversity, particularly to reduce inequalities within and among countries (SDG 10). For example, reducing emissions from deforestation and degradation (REDD+), a mechanism developed by Parties to the United Nations Framework Convention on Climate Change, seeks to address the implications of trade in forest products, not only for greenhouse-gas emissions but also for sustainable development, due to its incremental impact on biodiversity. Further mechanisms, such as international regulations, voluntary certification schemes or financial incentives, can be promoted to address other internationally-driven impacts on biodiversity that adversely affect sustainable development, for example, resulting from agriculture, palm oil production, fishing or tourism.

Finally, globally, biodiversity is only directly addressed through the CBD Strategic Plan and at the goal level in the 2030 Agenda by SDGs 14 and 15. Parties to the CBD are currently considering a new global framework for biodiversity conservation, as a follow-up to the CBD Strategic Plan, including synergies between the Aichi Targets and SDGs. This may represent an opportunity to link SDGs 14 and 15 more explicitly to all other SDGs and thereby clarify how biodiversity can contribute to sustainable development more broadly.

Implications for research

Development of action-based targets with measurable metrics for the new global biodiversity framework[118] will require identification of necessary evidence, existing knowledge and research gaps. Our literature search identified how biodiversity may contribute directly to fulfilling SDGs. However, the temporal and spatial distribution of these contributions, their relative strength, significance and cumulative effects, and particularly the influence of biodiversity attributes, require further research. In addition, we focused on exemplifying how biodiversity's direct contribution of benefits to fulfilling some SDGs may also then indirectly support the achievement of all other SDGs to which biodiversity does not contribute directly. However, fulfilment of many SDGs that may be directly supported by biodiversity benefits may, simultaneously, be indirectly assisted by biodiversity's contributions to other SDGs. For example, biodiversity benefits may directly contribute to healthy lives (SDG 3) and, at the same time, biodiversity's direct contributions to provision of food (SDG 2) and water quality (SDG 6) may also indirectly support people's health (SDG 3), as malnutrition and unsafe water are important drivers of disease. Thus, a more comprehensive review of biodiversity's contributions to some SDGs and the interactions between different SDGs could be undertaken. In addition, research on interactions between the SDGs needs to address similar issues to those listed above in relation to biodiversity's direct contributions, i.e. their temporal and spatial distribution, relative strength, significance and cumulative effects.

This study has focused on how biodiversity may contribute to fulfilling SDGs. However, we recognize that biodiversity's impacts on SDGs can also be negative. There is a need to consider both positive and negative impacts of biodiversity on sustainable development in developing strategies to achieve SDGs. Furthermore, biodiversity's interactions with SDGs are not only one-way but two-way and other studies have paid greater attention to how fulfilling individual SDGs may impact on biodiversity[119]. In that regard, trade-offs among temporal and spatial scales should be considered between achieving individual SDGs and those relating to biodiversity (i.e. SDGs 14 and 15). For example, a large increase in forest cover is currently proposed in various countries to contribute to reductions in greenhouse-gas emissions (SDG 13)[120]. This may directly impact, positively or negatively, in the short- and/or long-term, on biodiversity (SDG 15) depending on the nature of the land affected, how it is afforested, and the tree species involved. It may also have negative impacts on biodiversity by displacing other land uses, including food production, locally or internationally, with potential knock-on effects for a range of SDGs. Hence, more research is needed to explore two-way relationships between biodiversity and the SDGs.

To facilitate each country's exploration of potential pathways to sustainable development (see policy implications section), research needs to establish minimum biodiversity thresholds required at a local to sub-national scale to support fulfilment of SDGs, as biodiversity contributes to almost all SDGs at this scale (Table 1). However, there is a risk that such thresholds may be treated as "safe limits" to which biodiversity can be eroded. Consequently, it has been suggested[121] that they may be better communicated prudently as the minimum necessary to maintain or restore biodiversity's contribution to sustainable development[122]. In that context, research is needed on how global trade in biodiversity benefits may cumulatively impact on countries' biodiversity. Such impacts may not only affect individual countries' abilities to fulfil SDGs but also global achievement of sustainable development.

Conclusions

Our review exemplifies the breadth of ways in which biodiversity may support sustainable development, but the recent IPBES assessments have reaffirmed that biodiversity continues to decline worldwide[10-13]. The ramifications for sustainable development may be profound: humankind is meeting current needs in ways that will compromise the ability of future generations to meet their own needs[14]. Recognition by policymakers that benefits provided by biodiversity may help to fulfil all SDGs, and mainstreaming biodiversity considerations across a broad range of development sectors, may help to halt and reverse this trend. As E.O. Wilson has suggested "The one process now going on that will take millions of years to correct is the loss of genetic and species diversity by the destruction of natural habitats. This is the folly our descendants are least likely to forgive us."[123]

References

1 WCED. Our common future. (World Commission on Environment and Development, Oxford, UK, 1987).

2 Cardinale, B. J. *et al.* Biodiversity loss and its impact on humanity. *Nature* **486**, 59-67, doi:10.1038/nature11148 (2012).

A review of two decades of research on how biodiversity loss influences ecosystem functions and the provision of goods and services

3 Norström, A. V. *et al.* Three necessary conditions for establishing effective Sustainable Development Goals in the Anthropocene. *Ecology and Society* **19**, 8 (2014).

4 Costanza, R. *et al.* Twenty years of ecosystem services: How far have we come and how far do we still need to go? *Ecosystem Services* **28**, 1-16, doi:10.1016/j.ecoser.2017.09.008 (2017).

5 Blicharska, M. *et al.* Shades of grey challenge practical application of the Cultural Ecosystem Services concept. *Ecosystem Services* **23**, 55-70 (2017).

6 UNEP. Biodiversity and sustainable development: Technical note. (Cancun, Mexico, 2016).

7 SBSTTA. Note of Subsidiary Body on Scientific, Technical and Technological Advice Twenty-first meeting: Biodiversity and the 2030 Agenda for Sustainable Development. (Montreal, Canada, 11-14 December 2017, 2017).

8 Wood, S. L. R. *et al.* Distilling the role of ecosystem services in the Sustainable Development Goals. *Ecosystem Services* **29**, 70-82, doi:10.1016/j.ecoser.2017.10.010 (2018).

9 Schultz, M., Tyrrell, T. D. & Ebenhard, T. The 2030 Agenda and Ecosystems - A discussion paper on the links between the Aichi Biodiversity Targets and the Sustainable Development Goals. (SwedBio at Stockholm Resilience Centre, Stockholm, Sweden, 2016).

10 IPBES. Summary for policymakers of the regional assessment report on biodiversity and ecosystem services for Europe and Central Asia of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. (Bonn, Germany, 2018).

11 IPBES. Summary for policymakers of the regional assessment report on biodiversity and ecosystem services for Africa of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. (Bonn, Germany, 2018).

12 IPBES. Summary for policymakers of the regional assessment report on biodiversity and ecosystem services for the Americas of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. (Bonn, Germany, 2018).

13 IPBES. Summary for policymakers of the regional assessment report on biodiversity and ecosystem services for Asia and the Pacific of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. (Bonn, Germany, 2018).

14 IPBES. 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, 2019).

15 Sachs, J. D. *et al.* Biodiversity conservation and the Millennium Development Goals. *Science* **325**, 1502-1503, doi:10.1126/science.1175035 (2009).

16 Carrasco, L. R., Chan, J., McGrath, F. L. & Nghiem, L. T. P. Biodiversity conservation in a telecoupled world. *Ecology and Society* **22**, doi:10.5751/es-09448-220324 (2017).

17 Liu, J. An integrated framework for achieving Sustainable Development Goals around the world. *Ecology, Economy and Society - the INSEE Journal* **1**, 11-17 (2018).

A study introducing an integrated coupling framework for achieving Sustainable Development Goals

18 Syrbe, R. U. & Walz, U. Spatial indicators for the assessment of ecosystem services: Providing, benefiting and connecting areas and landscape metrics. *Ecological Indicators* **21**, 80-88, doi:10.1016/j.ecolind.2012.02.013 (2012).

19 Ziter, C., Graves, R. A. & Turner, M. G. How do land-use legacies affect ecosystem services in United States cultural landscapes? *Landscape Ecology* **32**, 2205-2218, doi:10.1007/s10980-017-0545-4 (2017).

20 O'Neill, B. C. *et al.* IPCC reasons for concern regarding climate change risks. *Nature Climate Change* **7**, 28-37, doi:10.1038/nclimate3179 (2017).

21 Essl, F. *et al.* Historical legacies accumulate to shape future biodiversity in an era of rapid global change. *Divers. Distrib.* **21**, 534-547 (2015).

22 Raudsepp-Hearne, C. *et al.* Untangling the Environmentalist's Paradox: Why is human well-being increasing as ecosystem services degrade? *Bioscience* **60**, 576-589, doi:10.1525/bio.2010.60.8.4 (2010).

23 Gaston, K. J. Global patterns in biodiversity. *Nature* **405**, 220–227 (2000).

24 Mayer, A. L., Kauppi, P. E., Angelstam, P. K., Zhang, Y. & Tikka, P. M. Importing timber, exporting ecological impact. *Science* **308**, 359-360, doi:10.1126/science.1109476 (2005).

25 UNDP. Human Development Report 2016. Human development for everyone. (United Nations Development Programme, New York, 2016).

26 Scholes, R. J. & Biggs, R. A biodiversity intactness index. *Nature* **434**, 45-49 (2005).

27 Lenzen, M. *et al.* International trade drives biodiversity threats in developing nations. *Nature* **486**, 109-112, doi:10.1038/nature11145 (2012).

A global analysis of the threats posed to biodiversity by international trade

28 Moran, D., Petersone, M. & Verones, F. On the suitability of input output analysis for calculating product-specific biodiversity footprints. *Ecological Indicators* **60**, 192-201, doi:10.1016/j.ecolind.2015.06.015 (2016).

29 Angelsen, A. *et al.* Environmental income and rural livelihoods: a global-comparative analysis. *World Development* **64**, S12-S28, doi:10.1016/j.worlddev.2014.03.006 (2014).

30 Abdullah, A. N. M., Stacey, N., Garnett, S. T. & Myers, B. Economic dependence on mangrove forest resources for livelihoods in the Sundarbans, Bangladesh. *Forest Policy Econ.* **64**, 15-24, doi:10.1016/j.forpol.2015.12.009 (2016).

31 Keesing, F. *et al.* Impacts of biodiversity on the emergence and transmission of infectious diseases. *Nature* **468**, 647-652, doi:10.1038/nature09575 (2010).

A comprehensive review of the evidence that biodiversity loss affects the transmission of infectious diseases

32 Hartig, T., Mang, M. & Evans, G. W. Restorative effects of natural-environment experiences. *Environment and Behavior* **23**, 3-26, doi:10.1177/0013916591231001 (1991).

33 Ulrich, R. S. View through a window may influence recovery from surgery. *Science* **224**, 420-421, doi:10.1126/science.6143402 (1984).

34 van den Bosch, M. & Sang, A. O. Urban natural environments as nature-based solutions for improved public health - A systematic review of reviews. *Environ. Res.* **158**, 373-384, doi:10.1016/j.envres.2017.05.040 (2017).

A systematic review of the health effects of nature-based solutions

35 Veitch, J. *et al.* Park availability and physical activity, TV time, and overweight and obesity among women: Findings from Australia and the United States. *Health & Place* **38**, 96-102, doi:10.1016/j.healthplace.2015.12.004 (2016).

36 Hanski, I. *et al.* Environmental biodiversity, human microbiota, and allergy are interrelated. *Proceedings of the National Academy of Sciences of the United States of America* **109**, 8334-8339, doi:10.1073/pnas.1205624109 (2012).

37 Feng, X. Q. & Astell-Burt, T. Is neighborhood green space protective against associations between child asthma, neighborhood traffic volume and perceived lack of area safety? multilevel analysis of 4447 Australian children. *International Journal of Environmental Research and Public Health* **14**, 11, doi:10.3390/ijerph14050543 (2017).

38 Cipriani, J. *et al.* A systematic review of the effects of horticultural therapy on persons with mental health conditions. *Occup. ther. Ment. Health* **33**, 47-69, doi:10.1080/0164212x.2016.1231602 (2017).

39 Bonan, G. B. Forests and climate change: Forcings, feedbacks, and the climate benefits of forests. *Science* **320**, 1444-1449, doi:10.1126/science.1155121 (2008).

40 Griscom, B. W. *et al.* Natural climate solutions. *Proceedings of the National Academy of Sciences of the United States of America* **114**, 11645-11650, doi:10.1073/pnas.1710465114 (2017).

A study identifying and quantifying nature-based solutions to climate change

41 Johnson, C. N. *et al.* Biodiversity losses and conservation responses in the Anthropocene. *Science* **356**, 270-274, doi:10.1126/science.aam9317 (2017).

42 Gamfeldt, L. *et al.* Higher levels of multiple ecosystem services are found in forests with more tree species. *Nature Communications* **4** (2013).

43 Liu, C. L. C., Kuchma, O. & Krutovsky, K. V. Mixed-species versus monocultures in plantation forestry: Development, benefits, ecosystem services and perspectives for the future. *Global Ecology and Conservation* **15**, doi:10.1016/j.gecco.2018.e00419 (2018).

44 Jones, H. P., Hole, D. G. & Zavaleta, E. S. Harnessing nature to help people adapt to climate change. *Nature Climate Change* **2**, 504-509, doi:10.1038/nclimate1463 (2012).

45 Pramova, E., Locatelli, B., Djoudi, H. & Somorin, O. A. Forests and trees for social adaptation to climate variability and change. *Wiley Interdiscip. Rev.-Clim. Chang.* **3**, 581-596, doi:10.1002/wcc.195 (2012).

46 Bullock, A. & Acreman, M. The role of wetlands in the hydrological cycle. *Hydrology and Earth System Sciences* **7**, 358-389 (2003).

47 Farley, K. A., Jobbágy, E. G. & Jackson, R. B. Effects of afforestation on water yield: a global synthesis with implications for policy. *Glob. Change Biol.* **11**, 1565-1576 (2005).

48 Thomas, H. & Nisbet, T. An assessment of the impact of floodplain woodland on flood flows. *Water and Environment Journal* **21**, 114 – 126 (2007).

49 Quinton, J. N., Edwards, G. M. & Morgan, R. P. C. The influence of vegetation species and plant properties on runoff and soil erosion: results from a rainfall simulation study in south east Spain. *Soil Use and Management* **13**, 143-148 (1997).

50 Gedan, K. B., Kirwan, M. L., Wolanski, E., Barbier, E. B. & Silliman, B. R. The present and future role of coastal wetland vegetation in protecting shorelines: answering recent challenges to the paradigm. *Clim. Change* **106**, 7-29, doi:10.1007/s10584-010-0003-7 (2011).

51 Brandon, C. M., Woodruff, J. D., Orton, P. M. & Donnelly, J. P. Evidence for elevated coastal vulnerability following large-scale historical oyster bed harvesting. *Earth Surf. Process. Landf.* **41**, 1136-1143, doi:10.1002/esp.3931 (2016).

52 Ouyang, X. G., Lee, S. Y., Connolly, R. M. & Kainz, M. J. Spatially-explicit valuation of coastal wetlands for cyclone mitigation in Australia and China. *Scientific Reports* **8**, doi:10.1038/s41598-018-21217-z (2018).

53 Nawaz, R., McDonald, A. & Postoyko, S. Hydrological performance of a full-scale extensive green roof located in a temperate climate. *Ecol. Eng.* **82**, 66-80, doi:10.1016/j.ecoleng.2014.11.061 (2015).

54 Brandao, C., Cameira, M. D., Valente, F., de Carvalho, R. C. & Paco, T. A. Wet season hydrological performance of green roofs using native species under Mediterranean climate. *Ecol. Eng.* **102**, 596-611, doi:10.1016/j.ecoleng.2017.02.025 (2017).

55 Vijayaraghavan, K. Green roofs: A critical review on the role of components, benefits, limitations and trends. *Renewable & Sustainable Energy Reviews* **57**, 740-752, doi:10.1016/j.rser.2015.12.119 (2016).

56 Wong, N. H. *et al.* The effects of rooftop garden on energy consumption of a commercial building in Singapore. *Energy and Buildings 35: 353–364* **35**, 353–364 (2003).

57 Getter, K. L. & Rowe, D. B. The role of extensive green roofs in sustainable development. *Hortscience* **41**, 1276-1285 (2006).

58 Guo, Z. W., Zhang, L. & Li, Y. M. Increased dependence of humans on ecosystem services and biodiversity. *Plos One* **5**, doi:10.1371/journal.pone.0013113 (2010).

59 Balmford, A. *et al.* A global perspective on trends in nature-based tourism. *Plos Biology* **7**, e1000144 (2009).

60 Brink, E. *et al.* Cascades of green: A review of ecosystem-based adaptation in urban areas. *Glob. Environ. Change-Human Policy Dimens.* **36**, 111-123, doi:10.1016/j.gloenvcha.2015.11.003 (2016).

61 Trepel, M. Assessing the cost-effectiveness of the water purification function of wetlands for environmental planning. *Ecol. Complex.* **7**, 320-326, doi:10.1016/j.ecocom.2010.02.006 (2010).

62 Shen, Y. Q., Liao, X. C. & Yin, R. S. Measuring the socioeconomic impacts of China's Natural Forest Protection Program. *Environment and Development Economics* **11**, 769-788, doi:10.1017/s1355770x06003263 (2006).

63 Thrupp, L. A. Linking agricultural biodiversity and food security: the valuable role of agrobiodiversity for sustainable agriculture. *Int. Aff.* **76**, 265-+ (2000).

64 Duffy, J. E., Godwin, C. M. & Cardinale, B. J. Biodiversity effects in the wild are common and as strong as key drivers of productivity. *Nature* **549**, 261-265 (2017).

65 Worm, B. *et al.* Impacts of biodiversity loss on ocean ecosystem services. *Science* **314**, 787-790, doi:10.1126/science.1132294 (2006).

A global analysis revealing the importance of biodiversity for the productivity and stability of marine ecosystems

66 Winfree, R. *et al.* Species turnover promotes the importance of bee diversity for crop pollination at regional scales. *Science* **359**, 791-793 (2018).

67 Klein, A. M. *et al.* Importance of pollinators in changing landscapes for world crops. *Proceedings of the Royal Society B-Biological Sciences* **274**, 303-313, doi:10.1098/rspb.2006.3721 (2007).

68 O’Bryan, C. J. *et al.* The contribution of predators and scavengers to human well-being. *Nature Ecology & Evolution* **2**, 229-236 (2018).

A comprehensive review of the role of predators in providing a range of benefits for people

69 Haddad, N. M., Crutsinger, G. M., Gross, K., Haarstad, J. & Tilman, D. Plant diversity and the stability of foodwebs. *Ecology Letters* **14**, 42-46, doi:10.1111/j.1461-0248.2010.01548.x (2011).

70 Chaplin-Kramer, R. & Kremen, C. Pest control experiments show benefits of complexity at landscape and local scales. *Ecol. Appl.* **22**, 1936-1948, doi:10.1890/11-1844.1 (2012).

71 Bale, J. S., van Lenteren, J. C. & Bigler, F. Biological control and sustainable food production. *Philos. Trans. R. Soc. B-Biol. Sci.* **363**, 761-776, doi:10.1098/rstb.2007.2182 (2008).

72 Motlhanka, D. M. & Makhabu, S. W. Medicinal and edible wild fruit plants of Botswana as emerging new crop opportunities. *J. Med. Plants Res.* **5**, 1836-1842 (2011).

73 Jackson, L. *et al.* Biodiversity and agricultural sustainagility: from assessment to adaptive management. *Curr. Opin. Environ. Sustain.* **2**, 80-87, doi:10.1016/j.cosust.2010.02.007 (2010).

74 Lachat, C. *et al.* Dietary species richness as a measure of food biodiversity and nutritional quality of diets. *Proceedings of the National Academy of Sciences of the United States of America* **115**, 127-132, doi:10.1073/pnas.1709194115 (2018).

75 Flint, H. J., Scott, K. P., Louis, P. & Duncan, S. H. The role of the gut microbiota in nutrition and health. *Nature Reviews Gastroenterology and Hepatology* **9**, 577-589 (2012).

76 Belkaid, Y. & Hand, T. W. Role of the Microbiota in Immunity and Inflammation. *Cell* **157**, 121-141, doi:10.1016/j.cell.2014.03.011 (2014).

77 Atanasov, A. G. *et al.* Discovery and resupply of pharmacologically active plant-derived natural products: A review. *Biotechnology Advances* **33**, 1582-1614, doi:10.1016/j.biotechadv.2015.08.001 (2015).
78 Alves, R. R. N. & Alves, H. N. The faunal drugstore: Animal-based remedies used in traditional medicines in Latin America. *Journal of Ethnobiology and Ethnomedicine* **7**, doi:10.1186/1746-4269-7-9 (2011).
79 Golden, C. D., Fernald, L. C. H., Brashares, J. S., Rasolofoniaina, B. J. R. & Kremen, C. Benefits of wildlife consumption to child nutrition in a biodiversity hotspot. *Proceedings of the National Academy of Sciences of the United States of America* **108**, 19653-19656, doi:10.1073/pnas.1112586108 (2011).
80 Liu, L., Guan, D. S. & Peart, M. R. The morphological structure of leaves and the dust-retaining capability of afforested plants in urban Guangzhou, South China. *Environmental Science and Pollution Research* **19**, 3440-3449, doi:10.1007/s11356-012-0876-2 (2012).
81 Fuller, R. A., Irvine, K. N., Devine-Wright, P., Warren, P. H. & Gaston, K. J. Psychological benefits of greenspace increase with biodiversity. *Biology Letters* **3**, 390-394, doi:10.1098/rsbl.2007.0149 (2007).
82 Hedblom, M., Heyman, E., Antonsson, H. & Gunnarsson, B. Bird song diversity influences young people's appreciation of urban landscapes. *Urban Forestry & Urban Greening* **13**, 469-474, doi:10.1016/j.ufug.2014.04.002 (2014).
83 Cameron, R. W. F., Taylor, J. & Emmett, M. A Hedera green facade - Energy performance and saving under different maritime-temperate, winter weather conditions. *Build. Environ.* **92**, 111-121, doi:10.1016/j.buildenv.2015.04.011 (2015).
84 Lurie-Luke, E. Product and technology innovation: What can biomimicry inspire? *Biotechnology Advances* **32**, 1494-1505, doi:10.1016/j.biotechadv.2014.10.002 (2014).
85 Caracciolo, A. B., Topp, E. & Grenni, P. Pharmaceuticals in the environment: Biodegradation and effects on natural microbial communities. A review. *J. Pharm. Biomed. Anal.* **106**, 25-36, doi:10.1016/j.jpba.2014.11.040 (2015).
86 Megharaj, M., Ramakrishnan, B., Venkateswarlu, K., Sethunathan, N. & Naidu, R. Bioremediation approaches for organic pollutants: A critical perspective. *Environment International* **37**, 1362-1375, doi:10.1016/j.envint.2011.06.003 (2011).
87 Six, J., Frey, S. D., Thiet, R. K. & Batten, K. M. Bacterial and fungal contributions to carbon sequestration in agroecosystems. *Soil Sci. Soc. Am. J.* **70**, 555-569, doi:10.2136/sssaj2004.0347 (2006).
88 Martin, T. L., Trevors, J. T. & Kaushik, N. K. Soil microbial diversity, community structure and denitrification in a temperate riparian zone *Biodiversity and Conservation* **8**, 1057-1078 (1999).
89 Cardinale, B. J. Biodiversity improves water quality through niche partitioning. *Nature* **472**, 86-U113, doi:10.1038/nature09904 (2011).
90 Kulshreshtha, A., Agrawal, R., Barar, M. & Saxena, S. A review on bioremediation of heavy metals in contaminated water. *IOSR Journal of Environmental Science, Toxicology and Food Technology* **8**, 44-50 (2014).
91 Hewett, D. G. The colonization of sand dunes after stabilization with Marram Grass (Ammophila Arenaria). *Journal of Ecology* **58**, 653-668 (1970).
92 Di Minin, E., Fraser, I., Slotow, R. & MacMillan, D. C. Understanding heterogeneous preference of tourists for big game species: implications for conservation and management. *Animal Conservation* **16**, 249-258, doi:10.1111/j.1469-1795.2012.00595.x (2013).
93 Hoffmann, A. A. & Sgro, C. M. Climate change and evolutionary adaptation. *Nature* **470**, 479-485, doi:10.1038/nature09670 (2011).
94 Ruiz, K. B. *et al.* Quinoa biodiversity and sustainability for food security under climate change. A review. *Agronomy for Sustainable Development* **34**, 349-359, doi:10.1007/s13593-013-0195-0 (2014).

95 Munoz, N., Liu, A., Kan, L., Li, M. W. & Lam, H. M. Potential uses of wild germplasms of grain legumes for crop improvement. *International Journal of Molecular Sciences* **18**, doi:10.3390/ijms18020328 (2017).
96 Burke, M. B., Lobell, D. B. & Guarino, L. Shifts in African crop climates by 2050, and the implications for crop improvement and genetic resources conservation. *Glob. Environ. Change-Human Policy Dimens.* **19**, 317-325, doi:10.1016/j.gloenvcha.2009.04.003 (2009).
97 Arrieta, J. M., Arnaud-Haond, S. & Duarte, C. M. What lies underneath: Conserving the oceans' genetic resources. *Proceedings of the National Academy of Sciences of the United States of America* **107**, 18318-18324, doi:10.1073/pnas.0911897107 (2010).
98 Swanson, T. The reliance of northern economies on southern biodiversity: Biodiversity as information. *Ecol. Econ.* **17**, 1-8, doi:10.1016/0921-8009(95)00101-8 (1996).
99 David, B., Wolfender, J. L. & Dias, D. A. The pharmaceutical industry and natural products: historical status and new trends. *Phytochem. Rev.* **14**, 299-315, doi:10.1007/s11101-014-9367-z (2015).
100 Duncan, G. J., Brooksgunn, J. & Klebanov, P. K. Economic deprivation and early-childhood developments. *Child Development* **65**, 296-318, doi:10.2307/1131385 (1994).
101 Victora, C. G. *et al.* Maternal and child undernutrition 2 - Maternal and child undernutrition: consequences for adult health and human capital. *Lancet* **371**, 340-357, doi:10.1016/s0140-6736(07)61692-4 (2008).
102 Goodman, J., Hurwitz, M., Park, J. & Smith, J. Heat and learning. (National Bureau of Economic Research, Cambridge, 2018).
103 Cole, L. B., McPhearson, T., Herzog, C. P. & Russ, A. in *Urban Environmental Education Review* (eds A. Russ & M.E. Krasny) (Cornell University Press, 2017).
104 Kevany, K. & Huisingh, D. A review of progress in empowerment of women in rural water management decision-making processes. *Journal of Cleaner Production* **60**, 53-64, doi:10.1016/j.jclepro.2013.03.041 (2013).
105 Patria, H. D. Uncultivated Biodiversity in Women's Hand: How to Create Food Sovereignty. *Asian Journal of Womens Studies* **19**, 148-161 (2013).
106 Adekola, O., Mitchell, G. & Grainger, A. Inequality and ecosystem services: The value and social distribution of Niger Delta wetland services. *Ecosystem Services* **12**, 42-54, doi:10.1016/j.ecoser.2015.01.005 (2015).
107 Bogar, S. & Beyer, K. M. Green space, violence, and crime: a systematic review. *Trauma Violence & Abuse* **17**, 160-171, doi:10.1177/1524838015576412 (2016).
108 Schleussner, C. F., Donges, J. F., Donner, R. V. & Schellnhuber, H. J. Armed-conflict risks enhanced by climate-related disasters in ethnically fractionalized countries. *Proceedings of the National Academy of Sciences of the United States of America* **113**, 9216-9221, doi:10.1073/pnas.1601611113 (2016).
109 Wischnath, G. & Buhaug, H. Rice or riots: On food production and conflict severity across India. *Political Geography* **43**, 6-15, doi:10.1016/j.polgeo.2014.07.004 (2014).
110 Aspergis, N. Education and democracy: New evidence from 161 countries. *Economic Modelling*, doi:doi:https://doi.org/10.1016/j.econmod.2017.12.001 (2018).
111 McCoy, D., Chigudu, S. & Tillmann, T. Framing the tax and health nexus: a neglected aspect of public health concern. *Health Economics Policy and Law* **12**, 179-194, doi:10.1017/s174413311600044x (2017).
112 Truong, C., Trück, S. & Mathew, S. Managing risks from climate impacted hazards – The value of investment flexibility under uncertainty. *European Journal of Operational Research*, doi:https://doi.org/10.1016/j.ejor.2017.07.012 (2018).
113 Lectard, P. & Rougier, E. Can developing countries gain from defying comparative advantage? distance to comparative advantage, export diversification and sophistication, and the dynamics of specialization. *World Development* **102**, 90-110, doi:10.1016/j.worlddev.2017.09.012 (2018).

114 Ehrlich, P. R. & Ehrlich, A. H. The population bomb revisited. *The Electronic Journal of Sustainable Development* **1** (2009).
115 NRC. The State of Canada's Forests. Annual Report 2017. (Natural Resources Canada, Canadian Forest Service, Ottawa, 2017).
116 Rackham, O. *Ancient Woodland: Its History, Vegetation and Uses in England*. (Castlepoint Press, 1983).
117 FC. Forestry Statistics 2017. (Forestry Commission, 2017).
118 Mace, G. M. *et al.* Aiming higher to bend the curve of biodiversity loss. *Nature Sustainability* **1**, 448–451 (2018).
119 Scharlemann, J. P. W. *et al.* Global Goals mapping: The environment-human landscape. A contribution towards the NERC, The Rockefeller Foundation and ESRC initiative, towards a sustainable Earth: environment-human sand the UN Global Goals. (Cambridge, UK, 2016).
120 Wolosin, M. Large-scale forestation for climate mitigation: lessons from South Korea, China, and India. (Climate and Land Use Alliance, 2017).
121 Smithers, R. J., Blicharska, M. & Laurance, W. F. Biodiversity boundaries. Letter. *Science* **353**, 1108 (2016).
122 Newbold, T. *et al.* Has land use pushed terrestrial biodiversity beyond the planetary boundary? A global assessment. *Science* **353**, 288-291, doi:10.1126/science.aaf2201 (2016).
123 Wilson, E. O. *Biophilia*. (Harvard University Press, 1986).
124 Roe, D. *et al.* Which components or attributes of biodiversity influence which dimensions of poverty? *Environmental Evidence* **3** (2014).
125 Tanaka, N., Sasaki, Y., Mowjood, M. I. M., Jinadasa, K. B. S. N. & Homchuen, S. Coastal vegetation structures and their functions in tsunami protection: experience of the recent Indian Ocean tsunami. *Landscape and Ecological Engineering* **33**, 33-45 (2007).
126 Mishra, A. *et al.* Building ex ante resilience of disaster-exposed mountain communities: Drawing insights from the Nepal earthquake recovery. *Int. J. Disaster Risk Reduct.* **22**, 167-178, doi:10.1016/j.ijdrr.2017.03.008 (2017).
127 von Wettberg, E. J. B. *et al.* Ecology and genomics of an important crop wild relative as a prelude to agricultural innovation. *Nature Communications* **9**, doi:10.1038/s41467-018-02867-z (2018).
128 Ricketts, T. H., Daily, G. C., Ehrlich, P. R. & Michener, C. D. Economic value of tropical forest to coffee production. *Proceedings of the National Academy of Sciences of the United States of America* **101**, 12579-12582, doi:10.1073/pnas.0405147101 (2004).
129 Wall, D. H., Nielsen, U. N. & Six, J. Soil biodiversity and human health. *Nature* **528**, 69-76, doi:10.1038/nature15744 (2015).
130 Beckett, K. P., Freer-Smith, P. H. & Taylor, G. Particulate pollution capture by urban trees: effect of species and windspeed. *Glob. Change Biol.* **6**, 995-1003, doi:10.1046/j.1365-2486.2000.00376.x (2000).
131 Rahman, M. A., Armson, D. & Ennos, A. R. A comparison of the growth and cooling effectiveness of five commonly planted urban tree species. *Urban Ecosystems* **18**, 371-389 (2015).
132 Santos, A. *et al.* The role of forest in mitigating the impact of atmospheric dust pollution in a mixed landscape. *Environmental Science and Pollution Research* **24**, 12038-12048 (2017).
133 Detweiler, M. B. *et al.* Horticultural Therapy: A Pilot Study on Modulating Cortisol Levels and Indices of Substance Craving, Posttraumatic Stress Disorder, Depression, and Quality of Life in Veterans. *Altern. Ther. Health Med.* **21**, 36-41 (2015).
134 Taylor, M. S., Wheeler, B. W., White, M. P., Economou, T. & Osborne, N. J. Research note: Urban street tree density and antidepressant prescription rates A cross-sectional study in London, UK. *Landscape and Urban Planning* **136**, 174-179, doi:10.1016/j.landurbplan.2014.12.005 (2015).

135 Johnson, C., Schweinhart, S. & Buffam, I. Plant species richness enhances nitrogen retention in green roof plots. *Ecol. Appl.* **26**, 2130-2144, doi:10.1890/15-1850.1 (2016).

136 Meerburg, B. G. *et al.* Surface water sanitation and biomass production in a large constructed wetland in the Netherlands. *Wetlands Ecology and Management* **18**, 463-470, doi:10.1007/s11273-010-9179-x (2010).

137 Osborne, L. L. & Kovacic, D. A. Riparian vegetated buffer strips in water-quality restoration and stream management. *Freshwater Biology* **29**, 243–258 (1993).

138 Verhoeven, J. T. A., Arheimer, B., Yin, C. & Hefting, M. M. Regional and global concerns over wetlands and water quality. *Trends in Ecology & Evolution* **21**, 96-103 (2006).

139 Brauman, K. A., Freyberg, D. L. & Daily, G. C. Forest structure influences on rainfall partitioning and cloud interception: A comparison of native forest sites in Kona, Hawaii. *Agricultural and Forest Meteorology* **150**, 265-275 (2010).

140 Bailis, R., Drigo, R., Ghilardi, A. & Masera, O. The carbon footprint of traditional woodfuels. *Nature Climate Change* **5**, 266-272, doi:10.1038/nclimate2491 (2015).

141 Elliott, L. G. *et al.* Establishment of a bioenergy-focused microalgal culture collection. *Algal Res.* **1**, 102-113, doi:10.1016/j.algal.2012.05.002 (2012).

142 Heinsoo, K., Melts, I., Sammul, M. & Holm, B. The potential of Estonian semi-natural grasslands for bioenergy production. *Agriculture Ecosystems & Environment* **137**, 86-92, doi:10.1016/j.agee.2010.01.003 (2010).

143 Dornburg, V. *et al.* Bioenergy revisited: Key factors in global potentials of bioenergy. *Energy & Environmental Science* **3**, 258-267, doi:10.1039/b922422j (2010).

144 Wang, Z. H., Zhao, X. X., Yang, J. C. & Song, J. Y. Cooling and energy saving potentials of shade trees and urban lawns in a desert city. *Appl. Energy* **161**, 437-444, doi:10.1016/j.apenergy.2015.10.047 (2016).

145 Palmer, C. & Di Falco, S. Biodiversity, poverty, and development. *Oxford Review of Economic Policy* **28**, 48-68, doi:10.1093/oxrep/grs008 (2012).

146 Tumusiime, D. M. & Vedeld, P. Can biodiversity conservation benefit local people? Costs and benefits at a strict protected area in Uganda. *J. Sustain. For.* **34**, 761-786, doi:10.1080/10549811.2015.1038395 (2015).

147 Tzoulas, K. *et al.* Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review. *Landscape and Urban Planning* **81**, 167-178, doi:10.1016/j.landurbplan.2007.02.001 (2007).

148 Schilling, J. & Logan, J. Greening the Rust Belt: a green infrastructure model for right sizing America's shrinking cities. *Journal of the American Planning Association* **74**, 451-466, doi:10.1080/01944360802354956 (2008).

149 Berardi, U., GhaffarianHoseini, A. & GhaffarianHoseini, A. State-of-the-art analysis of the environmental benefits of green roofs. *Appl. Energy* **115**, 411-428 (2014).

150 Charlesworth, S. M., Perales-Momparler, S., Lashford, C. & Warwick, F. The sustainable management of surface water at the building scale: preliminary results of case studies in the UK and Spain. *J. Water Supply Res Technol.-Aqua* **62**, 534-544, doi:10.2166/aqua.2013.051 (2013).

151 Vineyard, D. *et al.* Comparing green and grey infrastructure using life cycle cost and environmental impact: a rain garden case study in Cincinnati, OH. *Journal of the American Water Resources Association* **51**, 1342-1360, doi:10.1111/1752-1688.12320 (2015).

152 Dong, X., Guo, H. & Zeng, S. Y. Enhancing future resilience in urban drainage system: Green versus grey infrastructure. *Water Research* **124**, 280-289, doi:10.1016/j.watres.2017.07.038 (2017).

153 Renaud, F. G., Sudmeier-Rieux, K., Estrella, M. & Nehren, U. *Ecosystem-based disaster risk reduction and adaptation in practice*. (Springer, 2016).

154 Hausmann, A., Slotow, R., Burns, J. K. & Di Minin, E. The ecosystem service of sense of place: benefits for human well-being and biodiversity conservation. *Environ. Conserv.* **43**, 117-127, doi:10.1017/s0376892915000314 (2016).

155 Blicharska, M. & Mikusinski, G. Incorporating social and cultural significance of large old trees in conservation policy. *Conserv. Biol.* **28**, 1558-1567, doi:10.1111/cobi.12341 (2014).

156 Rotherham, I. D. Bio-cultural heritage and biodiversity: emerging paradigms in conservation and planning. *Biodiversity and Conservation* **24**, 3405-3429, doi:10.1007/s10531-015-1006-5 (2015).

157 Bhagwat, S. A. & Rutte, C. Sacred groves: potential for biodiversity management. *Frontiers in Ecology and the Environment* **4**, 519-524, doi:10.1890/1540-9295(2006)4[519:sgpfbm]2.0.co;2 (2006).

158 Kabisch, N., van den Bosch, M. & Lafortezza, R. The health benefits of nature-based solutions to urbanization challenges for children and the elderly - A systematic review. *Environ. Res.* **159**, 362-373, doi:10.1016/j.envres.2017.08.004 (2017).

159 Gunnarsson, B., Knez, I., Hedblom, M. & Sang, A. O. Effects of biodiversity and environment-related attitude on perception of urban green space. *Urban Ecosystems* **20**, 37-49 (2017).

160 Nielsen, A. B., van den Bosch, M., Maruthaveeran, S. & van den Bosch, C. K. Species richness in urban parks and its drivers: A review of empirical evidence. *Urban Ecosystems* **17**, 305-327, doi:10.1007/s11252-013-0316-1 (2014).

161 Shanahan, D. F., Fuller, R. A., Bush, R., Lin, B. B. & Gaston, K. J. The health benefits of urban nature: how much do we need? *BioScience* **65**, 476-485 (2015).

162 McVittie, A., Cole, L., Wreford, A., Sgobbi, A. & Yordi, B. Ecosystem-based solutions for disaster risk reduction: Lessons from European applications of ecosystem-based adaptation measures. *Int. J. Disaster Risk Reduct.* **32**, 42-54 (2018).

163 Salick, J. *et al.* Tibetan sacred sites conserve old growth trees and cover in the eastern Himalayas. *Biodiversity and Conservation* **16**, 693-706, doi:10.1007/s10531-005-4381-5 (2007).

164 Aydin, S. *et al.* Aerobic and anaerobic fungal metabolism and Omics insights for increasing polycyclic aromatic hydrocarbons biodegradation. *Fungal Biol. Rev.* **31**, 61-72, doi:10.1016/j.fbr.2016.12.001 (2017).

165 Ehlers, A., Worm, B. & Reusch, T. B. H. Importance of genetic diversity in eelgrass Zostera marina for its resilience to global warming. *Mar. Ecol.-Prog. Ser.* **355**, 1-7, doi:10.3354/meps07369 (2008).

166 Wilmers, C. C. & Getz, W. M. Gray wolves as climate change buffers in Yellowstone. *Plos Biology* **3**, 571-576, doi:10.1371/journal.pbio.0030092 (2005).

167 Steffen, W. *et al.* Planetary boundaries: Guiding human development on a changing planet. *Science* **347**, doi:10.1126/science.1259855 (2015).

168 Stahel, W. R. The circular economy. *Nature* **531**, 435-438 (2016).

169 Burch-Brown, J. & Archer, A. In defence of biodiversity. *Biology and Philosophy* **32**, 969–997 (2017).

170 Myers, N., R.A., M., Mittermeier, C. G., da Fonseca, G. A. B. & Kent, J. Biodiversity hotspots for conservation priorities. *Nature* **403**, 853-858 (2000).

171 Shaw, J. D., Terauds, A., Riddle, M. J., Possingham, H. P. & Chown, S. L. Antarctica's Protected Areas are inadequate, unrepresentative, and at risk. *Plos Biology* **12**, 5, doi:10.1371/journal.pbio.1001888 (2014).

172 Roe, D., Elliott, J., Sandbrook, C. & Walpole, M. in *Biodiversity conservation and poverty alleviation: Exploring the evidence for a link* (eds D. Roe, J. Elliott, C. Sandbrook, & M. Walpole) (Wiley-Blackwell, 2013).

173 Redford, K. H. & Richter, B. D. Conservation of biodiversity in a world of use. *Conserv. Biol.* **13**, 1246-1256 (1999).

Table 1. How biodiversity benefits may contribute directly to SDGs. *References cited provide examples in relation to biodiversity components: genes (G), species (S) and ecosystems (E). Review/synthesis papers are cited in bold and underlined. Spatial scale (Space): small = local to sub-national (Sm); large = national to global (La). Credit: United Nations (UN/SDG).*

Goal	How biodiversity benefits may contribute directly to the Goal	Space	G	S	E
Goal 1: End poverty in all its forms everywhere	Provides resources	Sm	**124**	**124**	
	Generates income directly and indirectly	Sm	**124**		29; 30
	Maintains productivity in marine ecosystems	Sm/La	65	65	
	Provides natural infrastructure to buffer hazards	Sm		**50**; **125**	**50**; 51; 49;
		Sm			91; 44; 48
	Provides a safety net, including for post-disaster recovery and 'lean times'			126	**45**;
Goal 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture	Improves dietary quality	Sm/La		**74**	
	Improves soil fertility, structure, quality and health	Sm/La	**63**;	**63**	
	Provides crop pollination	Sm		**67**; 128; 66	
	Provides pest control	Sm		70; 71	70
	Increases agricultural output and future yields	Sm/La	94; **73**; **96**	**73**; 64; **68**	**73**
	Increases resilience of agricultural systems	Sm		69	
	Provides potential for new crops	Sm	95; 127	72	
	Maintains productivity in marine ecosystems	Sm/La	65	65	
Goal 3: Ensure healthy lives and promote well-being for all at all ages	Provides source of medicines, vitamins and minerals	Sm/La		78; 79; **77**	
	Improves immunity and reduces allergic dispositions	Sm		**76**	36; 37
	Improves gut metabolism	Sm		**75**	
	Dilutes disease reservoirs	Sm		**31**	
	Improves air and water quality	Sm		**129**	
	Reduces air, water and soil pollution	Sm		80; 130	132
	Provides urban cooling	Sm		131	**34**
	Promotes healthier life-styles, reducing obesity	Sm			35
	Reduces hospital recovery time	Sm			33
	Decreases stress and substance dependence	Sm			**38**; 133
	Improves and restores mental health and well-being	Sm		81; 82	134; 32
Goal 6: Ensure availability and sustainable management of water and sanitation for all	Reduces heavy metals in the environment	Sm		**90**	
	Reduces water pollution and improves water quality	Sm		88; 89; 135;	137; **138**
	Reduces and delays run off	Sm		136	**47**
	Contributes to freshwater provision	Sm			139
Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all	Provides sources of heat and power	Sm		136; 140; 141; 142;143	142
	Reduces energy use through cooling, shade and shelter	Sm		83	**55**; 56; 144
Goal 8: Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	Produces market and non-market goods and services	Sm/La	**97**; **145**	**97**; **145**	**145**
	Enables sustainable economic growth	Sm/La	**97**; **98**; **99**	**97**; **98**; **99**	58
	Provides cost-efficient solutions	Sm/La			**60**; 61
	Provides employment, e.g. in natural resources management, protected areas, and tourism	Sm/La		92	62; 146; 59
Goal 9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation	Provides green infrastructure	Sm			**147**
	Increases resilience of grey infrastructure	Sm			**57**; 148
	Provides environmentally sound technologies	Sm/La		84	**46**; **149**; 150; 151; 152
Goal 11: Make cities and human settlements inclusive, safe, resilient and sustainable	Improves air quality	Sm			130;
	Provides urban cooling, heat-island mitigation	Sm		131;	**34**;
	Buffers noise	Sm			**34**
	Reduces and delays water run-off and flooding	Sm			**149**; 54; 53
	Improves and restores mental health and well-being	Sm		81; 82	32; **161**
	Reduces economic losses from disaster and recovery	Sm	153	153	153; 52; **162**
	Contributes to sense of place and cultural value	Sm	**154**;	**154**; 155; **156**	**154**; **156**
	Provides sacred areas	Sm		**157**	**157**; 163
	Promotes health and well-being in cities	Sm		**158**	**158**
	Provides green areas in cities	Sm		159; **160**	159; **160**
Goal 12: Ensure sustainable consumption and production patterns	Enables sustainable management	Sm		42	**44**; 42
	Provides biodegradation and decontamination	Sm		**68**; **85**; **164**; **86**	
Goal 13: Take urgent action to combat climate change and its impacts	Sequesters and stores carbon and thereby mitigates climate change	La		**87**	**39**; 40; **41**; **43**
	Reduces climate vulnerabilities and increases resilience	Sm	127; 93; 165	166	91; **44**; **45**

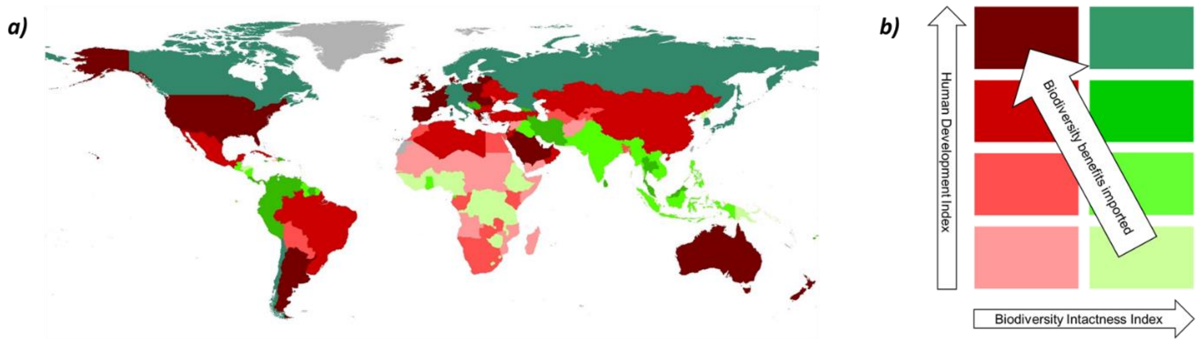

***Figure 1: Country groupings by relative levels of biodiversity intactness and development. a)** Many countries ranked by UNDP as highly developed have low biodiversity. Countries are identified as having low (shades of red) or high (shades of green) biodiversity intactness relative to the global mean of national values of the Biodiversity Intactness Index[122], and as belonging to one of four tiers defined by the Human Development Index[25] – the more developed a country the deeper the shade of colour (for details see Supplementary Information 1). Base map credits: Esri, DeLorme Publishing Company, Inc. **b)** More developed countries may sustain a high level of development by importing biodiversity benefits from less developed countries (illustrative large white arrow).*

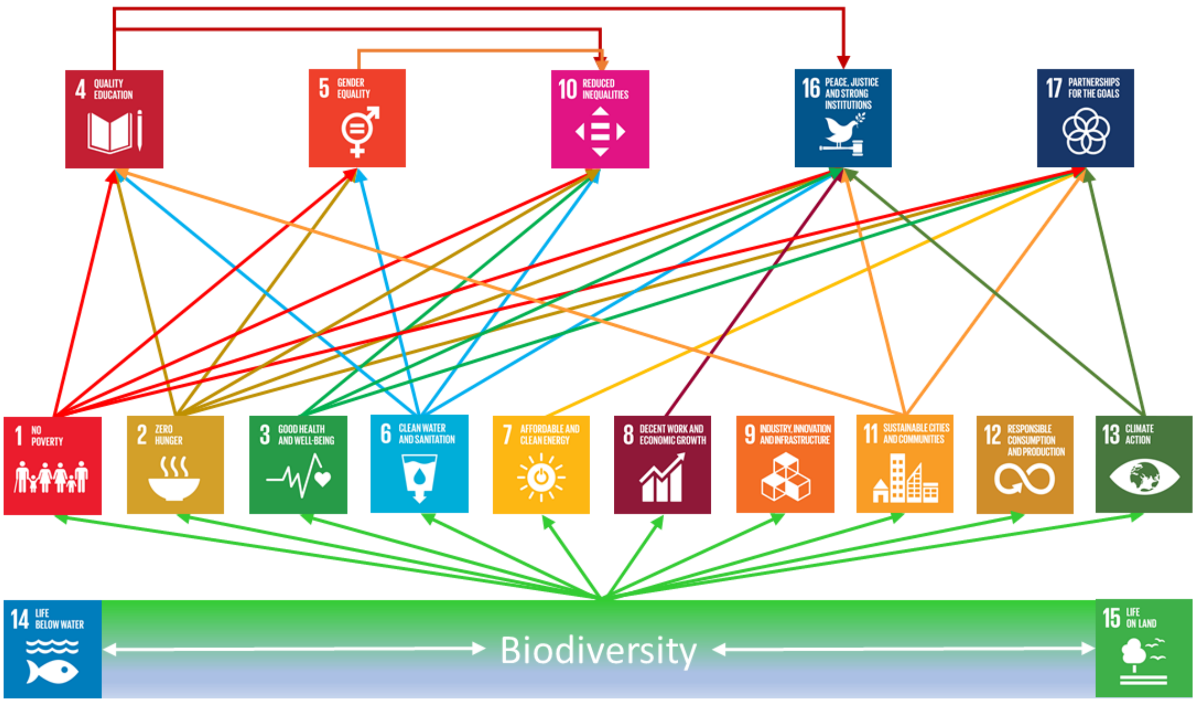

***Figure 2: A summary illustration of our examples of the ways that biodiversity contributes to the SDGs.** Our study demonstrates that biodiversity is not only relevant to SDGs 14 and 15 (lower tier of the figure) but may also directly support fulfilment of ten of the other SDGs (middle tier) and thereby contribute indirectly to achieving the remaining five SDGs (upper tier). We sought to exemplify direct contributions of biodiversity to every SDG. For those SDGs where we were unable to find examples of direct contributions, we sought to exemplify that they are indirectly supported by some SDGs to which biodiversity contributes directly. In reality, there may be many other indirect links between goals within the middle and upper tiers. Credit: United Nations (UN/SDG).*

Box 1. Sustainable development

In this study, we follow the definition of sustainable development first used by the Brundtland Report[1], i.e. development that "meets the needs of the present without compromising the ability of future generations to meet their own needs". Immediate pressures on the poorest people's survival in developing countries may focus attention on meeting their short-term local needs. However, as the Brundtland's definition implies, the challenge posed by sustainable development is to address people's current needs everywhere and in ways that sustain environmental resources for future generations. Actions in one part of the world influence people's abilities to meet their needs there and elsewhere. With the global population already exceeding Earth's carrying capacity[167], and projected to grow substantially, this implies using and developing technologies and social organisation to promote more equitable and reduced consumption of environmental resources, e.g. through development of a circular economy[168]. Hence, sustainable development is a multidimensional concept embracing both spatial and temporal considerations. Accordingly, while the Millennium Development Goals (MDGs) were focused on action in developing countries, the Sustainable Development Goals (SDGs) apply to all nations and seek to address the universal need for development that meets everyone's needs.

Box 2. Biodiversity

The CBD defines "Biological diversity" (biodiversity) as "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems". In contrast, nature is a wider term that for many people encompasses everything that is not man-made; biotic or abiotic. "Biodiversity" has long been recognised in the literature as a value-laden term[169]. It is often interpreted as concerning the relative diversity or richness of species in different places at a local scale (e.g. a "rich" natural wetland as compared with "poor" intensively managed arable land) or at larger scales (e.g. in determining 'global biodiversity hotspots'[170]). However, the CBD and its Aichi Targets also address biodiversity as an entity at a global scale, with the entire "variability among living organisms from all sources… and the ecological complexes of which they are part" contributing to it. In that sense, Antarctica as an ecosystem may be viewed as making an important, unique contribution to biodiversity[171] even though it is not biologically diverse, especially when compared with tropical rainforests or coral reefs. Analogously, 'green' and 'blue' spaces in cities contribute more to biodiversity than the surrounding concrete. Both common and rare species, and the genotypes of horticultural cultivars, crops and livestock are also all integral parts of biodiversity. We focus in this study on biodiversity as a global entity and its three key components (i.e. ecosystems, species and genes), while acknowledging that these components are characterised by attributes, such as diversity, abundance and composition[172,173]. In doing so, we consider that our framing of the paper about biodiversity rather than about nature is reflective of ways in which biodiversity is commonly addressed by researchers and policymakers.

Author contributions

MB and RJS conceived the review and wrote the manuscript. MB undertook the literature search and was supported by RJS in identifying relevant examples. GM undertook the analysis for Figure 1. All authors contributed to ideas and editing.

Competing interests

The authors declare no competing interests.