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Supplementary Materials for

Biodiversity redistribution under climate change: Impacts on ecosystems and human well-being

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Table S1.

Details of the impacts associated with each of the changes in distribution documented in Figure 1, according to the numbered key.

  **1-Moose** Northward expansion of Alaskan moose associated with an increase in shrub habitat and warming. Moose are likely to affect ecosystem functioning through grazing on shrubs and slowing down the greening of the Arctic, potentially impacting climate feedbacks. Hunting practices from indigenous communities and prey-predator dynamics are also affected (*118*).	  **2- Bark beetles** Northward and elevational shift of bark beetles in North America driven by warming climate. The combined effects of increasing temperatures and droughts predispose trees to defoliators and to bark beetles, thus contributing to the severity of pest outbreaks, which in turn may impact climate through increasing fuel loads and fire frequency at high latitudes (72).	  **3- Bumblebees** Southern range contraction and elevational shift for southern species of bumblebees in North America and Europe due to climate change. While species have experienced significant losses from equatorward range boundaries, there has been no corresponding expansion of range limits northwards for these important pollinators. Shifts to higher elevations have been restricted to southern species (*119*)
  **4- Coffee** Decrease in climate suitability for coffee cultivation in low elevation areas of Mexico, Guatemala, El Salvador, Nicaragua, and Costa Rica. New growing regions will need to be developed upslope. Local producers and rural communities that crucially depend on the coffee industry will be greatly affected, and upslope natural areas may be impacted (52).	  **5- Mangroves** Northward shift of mangroves in Florida, USA, correlated with less extreme cold events. The changing distribution of mangroves will affect carbon sequestration and as a consequence, climate feedbacks (29).	  **6- Malaria** Upslope shift in malaria distributions. The median elevation of malaria cases has increased in warmer years in both Ethiopia and western Colombia. In Ethiopia, high-elevation locations previously free of Malaria are now within the viable range for this disease. In Colombia, temperatures have fluctuated without a consistent trend of warming, and Malaria cases at high elevations have fluctuated very closely with the temperature change (*60*).
  **7- Tropical plants** Upslope shift of tropical plants in Ecuador consistent with patterns of warming. This reshaping of tropical plant distributions is consistent with Humboldt's proposal that climate has primary control on the altitudinal distribution of vegetation (*120*).	  **8- Marsupials** Range shifts under climate change scenarios for 55 marsupial species in Brazil. Projection forecasts indicate a range shift to the south east (*121*).	  **9- Skipjack tuna** Skipjack tuna is projected to become less abundant in western, and more abundant in eastern, areas of the Western and Central Pacific Ocean (WCPO). Several Pacific Island countries in the WCPO depend heavily on skipjack tuna for economic development, government revenue, and food security (*48*).

  **10- King crab** Poleward range expansion in the king crab. For millions of years cold water conditions had excluded crustaceans from the continental shelf around Antarctica. In 2010, a population of king crabs was discovered next to the continental shelf, suggesting an expansion of the range as a result of warming seas (*26*).	  **11- Antarctic vegetation** Rapid increase in moss growth rates, microbial productivity, and plant range expansion as ice melts (*122*).	  **12- Mackerel** Expanded distribution of mackerel into Icelandic waters in the recent warm period since 1996. This expansion initially supported a bycatch fishery, which then developed into a direct fishery within the Icelandic EEZ, increasing from ~1700 t in 2006 to ~120 000 t in 2009 and 2010. Negotiations over new quotas for mackerel were key to discussions of Iceland and the Faeroe Islands joining the EU (63).
  **13-Demersal fish** Movement to deeper water by demersal fish in the North Sea as temperatures have increased. Abundant thermal specialist fish have shifted northward, while less abundant, small southerly species have shifted southward (*18*).	  **14- Atlantic salmon** Decline in Atlantic salmon, an anadromous cold water fish, while the northern pike expanded its range in response to warmer water temperatures in Finland. The pike preys on juvenile salmon. Indigenous Skolt Sámi co-management measures have increased harvests of pike and have documented important sites (such as lost spawning beds), so that ecological restoration can provide additional habitat and increase salmon reproduction (*7, 56*).	  **15- Vibrio** Unexpected emergence of *Vibrio* infections, a bacterial waterborne disease, in northern Europe. Changes in sea surface temperature in the Baltic are thought to be responsible (*123)*.
  **16- Freshwater fish** Upstream shift in freshwater fish. Since the 1980s, freshwater fish in France's river systems have moved upwards in elevation; traditionally low-reach species have moved to higher reaches. On average, these fish tracked the direction of warming, but the shifts were not as fast as climate warming (*124*).	  **17- Mountain birds** Upslope shift in suitable areas for mountain birds in Italy due to warmer temperatures. These areas are projected to overlap with suitable areas for ski-industry development, creating challenges for the conservation of these bird species (*64*).	  **18- Sahel vegetation** Changes in Sahel vegetation. Over past decades, vegetation in the Sahel region has changed, affecting the livelihood and culture of people in the region. Pastoralists have increasing difficulties finding dry-season grazing areas for their livestock and suffer from lack of security of tenure over land and resources (*125*).
 	  **20- Reptiles & amphibians**	 

19- Coastal fish Poleward range shift in the coastal fish species, *Argyrosomus coronus*, from Angola into Namibia. This shift crosses Economic Exclusive Zones, complicating fishery management, particularly in light of a lack of congruence in the fisheries policies between nations (*126*).	Upslope range shift in 30 species of reptiles and amphibians in Madagascar. These species have moved uphill from 10 to 51 meters, as climate warmed (*127*).	**21- Tropical and temperate fish** Southward shift of tropical fish and range contraction of temperate fish associated with ocean warming in South Africa. These changes in species composition and abundance have impacted the spear-fishing sector (*128*).
  **22- Arctic vegetation** Altered distribution, composition, and density of terrestrial vegetation in the Arctic, driven by climate warming, through both increasing average temperatures and a longer growing season. These changes in vegetation affect the albedo, vegetation biomass, and evapotranspiration, exacerbating climate warming (*68*).	  **23- Kelp & abalone** The loss of temperate canopy-forming macro algae in Tosa Bay, Japan, associated with recent warming. There has been local extinction of the kelp *Ecklonia cava*, loss of other temperate *Ecklonia* and *Sargassum* species, and an increase in a tropical *Sargassum*. An associated decline of commercial abalone has been attributed to the loss of Ecklonia (*129*).	  **24- Reef coral** Reef coral species range shifts. These species have shifted at rates up to 14 km/yr northward along the coastline of Japan, consistent with climate warming (*130*).
  **25- Oil sardine** Northward shift in the range of the oil sardine. Historically, the sardine had a restricted distribution between 8°N to 14°N, but in the past two decades, it has increased in abundance to the north: the region 14°N - 20°N now makes up 15% of the catch. The range shift of the species is a boon for coastal fishing communities in this region in India (*131*).	  **26- Moths** Upslope shift in tropical moth species. 102 montane moth species in Borneo have increased in elevation by a mean of 67 m over 42 years, driven by climate warming (*17*).	  **27- Birds & possums** Upslope shift of 13 bird and 4 ringtail possum species as a result of climate warming in the wet tropics of Australia (*132*).
  **28-Kelp, fish & invertebrates** Range contraction of 100 km in kelp forests and other habitat-forming seaweeds in Western Australia. Increases in warm-water fish and invertebrates associated with ocean warming, leading to increased herbivory, loss of kelp and replacement of by seaweed turf (eastern and western Australia). These changes in ecosystem structure could impact Australia's most valuable single-species fishery (rock lobster) (*30, 31*).	  **29- Sea urchin** Poleward range shift in the sea urchin, *Centrostephanus rodgersii*, into Tasmania, tracking the pattern of warming in this region. Through grazing this species has converted kelp forests into urchin barrens, affecting the regional lobster and abalone fisheries (*55*).	  **30-Adelie penguins** Increase in numbers and poleward range expansion in Adelie penguins. In McMurdo Sound (the Ross Sea) the breeding range of Adelie penguins has expanded 3 km southwards. The population size has also increased markedly (from 1983 to 1987) (*133*).

Table S2.

Influence on achieving the Global Sustainable Development Goals (*134*) of observed or predicted climate-driven changes in the distribution of species. Secondary effects and consequences of changing distributions of species will ultimately impact most of the Sustainable Development Goals. Here, we highlight those that, based on our collective knowledge and informed by an analysis of links between Aichi Biodiversity targets and SDG's (*135*), will likely be most significantly and immediately affected.

	Targets likely to be impacted *(134)*	**Rationale**	**Example & reference in Table S1**
1. No Poverty	By 2030, ensure that all men and women, in particular the poor and the vulnerable, have equal rights to economic resources, as well as access to basic services, ownership and control over land and other forms of property, inheritance, natural resources, appropriate new technology and financial services, including microfinance.	Access to natural resources will change as species move into or out of particular areas. Health of plants and animals that human societies depend on for food may be affected by changes in the distribution of pollinators, pathogens and parasites. Forests, wetlands, and coastal areas are particularly important as sources of food and income during times of stress for the most marginalized and vulnerable people living in rural areas.	Moose (1) Bumblebees (3) Coffee (4) Skipjack tuna (9) Atlantic salmon (14) Sahel vegetation (18) Coastal fish (19) Tropical and temperate fish (21) Oil sardine (25)
2. Zero Hunger	By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment. By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production,	Some ecosystems may no longer support productive agriculture, aquaculture, subsistence hunting or fisheries. Food production systems may be subject to new pathogens, pests, or other disruptive species (e.g. jellyfish or harmful algal blooms).	Moose (1) Bumblebees (3) Coffee (4) Skipjack tuna (9) Atlantic salmon (14) Sahel vegetation (18)

	that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality. By 2020, maintain the genetic diversity of seeds, cultivated plants and farmed and domesticated animals and their related wild species, including through soundly managed and diversified seed and plant banks at the national, regional and international levels, and promote access to and fair and equitable sharing of benefits arising from the utilization of genetic resources and associated traditional knowledge.	Poleward and elevational movement of species could result in increased production costs or jurisdictional issues, as species move across borders or decrease in abundance due to lack of suitable habitat. Genetic diversity could be compromised because "successful movers and colonisers" may require a specific set of traits.	Coastal fish (19) Tropical fish (21) Oil sardine (25)
3. Good Health and Well-Being	By 2030, end the epidemics of AIDS, tuberculosis, malaria and neglected tropical diseases and combat hepatitis, water-borne diseases and other communicable diseases.	Many diseases, such as malaria, are expected expand in distribution both in elevation and to higher latitudes. . Mental health and well-being of farmers and fishers, and indigenous or rural communities, may be impacted as their lands or fishing grounds can no longer support the same ecosystems or traditional practices and subsistence activities. These consequences are more likely as the rate of species movements increases.	Malaria (6) Vibrio (15)
5. Gender Equity	Undertake reforms to give women equal rights to economic resources, as well as access to ownership and control over land and other forms of property, financial services, inheritance and natural resources, in accordance with national laws.	The natural resources that women harvest may decline in abundance, be impacted by pests or pathogens, or shift to other places, creating increased tensions for women participating in the provision of adequate food or other resources.	Sahel vegetation (18)
6. Clean water and sanitation	By 2030, achieve universal and equitable access to safe and affordable drinking water for all.	The capacity of water-related ecosystems such as mountains, forests, wetlands, rivers, aquifers and lakes, to ensure sustainable supply of clean freshwater, is	Bark beetles (2) Mangroves (5)

	By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity. By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate. By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes. Support and strengthen the participation of local communities in improving water and sanitation management.	dependent upon healthy ecosystems and therefore impacted by changes in the distribution of associated species. Ecosystem services impacted by changes in species distribution also includes the reduction or removal of pollutants. Natural ecosystems, e.g. mangrove belts, can be effective in reducing the flooding impacts of storm surges occurring during cyclones, typhoons and hurricanes on the quality of drinking water in low-lying coastal areas.	Vibrio (15)
8. Decent work and Economic Growth	Improve progressively, through 2030, global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation, in accordance with the 10-year framework of programmes on sustainable consumption and production, with developed countries taking the lead.	Sustainable production may be harder to achieve or require new methods, as the distribution and relative abundance of species changes and conditions become less suitable for common crops and forms of animal production and aquaculture.	Skipjack tuna (9) Mackerel (12) Atlantic salmon (14) Mountain birds (17) Sahel vegetation (18) Coastal fish (19) Kelp and abalone (23) Oil sardine (25)
10. Reduced inequities	By 2030, progressively achieve and sustain income growth of the bottom 40 per cent of the population at a rate higher than the national average.	Many lower-income populations are dependent on harvesting natural resources, which may no longer be supported in their regions as species abundances and distributions change.	Skipjack tuna (9) Mackerel (12) Mountain birds (17) Sahel vegetation (18) Coastal fish (19) Oil sardine (25)
11. Sustainable cities and communities	Strengthen efforts to protect and safeguard the world's cultural and natural heritage. By 2030, significantly reduce the number of deaths and the number of	Human culture and attachment to place can be closely associated with particular species and thus can be affected when existing species move out of a local area	Moose (1) Mangroves (5) Vibrio (15)

	people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations. By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities. Support positive economic, social and environmental links between urban, peri-urban and rural areas by strengthening national and regional development planning. By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015-2030, holistic disaster risk management at all levels.	and 'new' species move in. Natural ecosystems can have an important role in mitigating against disasters. Development planning for positive links between urban and rural areas depends upon knowledge of the distribution of natural resources.	Sahel vegetation (18)
12. Responsible Consumption and Production	By 2030, achieve the sustainable management and efficient use of natural resources.	Agriculture, fisheries and aquaculture that is currently sustainable may be unsustainable in the future as the distributions of food species, and/or pollinators, pathogens and pests shift with global warming.	Bumblebees (3) and other examples involving harvesting
13. Climate Action	Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries. Integrate climate change measures into national policies, strategies and planning. Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning.	Biodiversity conservation and health strategies will require improved education to raise awareness of the impacts and implications of range-shifting species on food production. Appropriate adaptations should be incorporated into species-specific and ecosystem management plans as well as into broader national policies.	Moose (1) Bark beetles (2) Mangroves (5) Arctic vegetation (22)

		Direct and indirect influences of shifting species ranges and associated feedbacks on our climate system need to be more thoroughly accounted for in projections of future climate.	
14. Life below water	By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans. By 2020, effectively regulate harvesting and end overfishing, illegal, unreported and unregulated fishing and destructive fishing practices and implement science-based management plans, in order to restore fish stocks in the shortest time feasible, at least to levels that can produce maximum sustainable yield as determined by their biological characteristics. By 2020, conserve at least 10 per cent of coastal and marine areas, consistent with national and international law and based on the best available scientific information. By 2030, increase the economic benefits to Small Island Developing States and least developed countries from the sustainable use of marine resources, including through sustainable management of fisheries, aquaculture and tourism. Provide access for small-scale artisanal fishers to marine resources and markets.	The movement of marine species will constantly challenge management, as sustainable practices require adjustment to keep pace with alterations in the distribution and abundance of species Restoration of degraded marine areas may not return habitats to their original state, because colonising species may no longer be present or may be unable to become established in these habitats. Marine protected areas established to help conserve species may become ineffective as target species are redistributed.	Skipjack tuna (9) King crab (10) Mackerel (12) Atlantic salmon (14) Coastal fish (19) Kelp and abalone (23) Oil sardine (25) Kelp, fish and invertebrates (28) Sea urchin (29) Adelie penguins (30)
15. Life on land	By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements. By 2020, promote the implementation of sustainable management of all	The restoration of forests, wetlands, mountains and drylands may be compromised by changes in the species that are able to colonise and live in these habitats.	Moose (1) Bark beetles (2) Bumblebees (3) Tropical plants (7)

	types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally. By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world. By 2030, ensure the conservation of mountain ecosystems, including their biodiversity, in order to enhance their capacity to provide benefits that are essential for sustainable development. Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species.	Range expansions of pathogens, pests and disease vectors will reduce the potential to protect biodiversity. As species ranges shift (e.g., up mountains), their habitats may become more fragmented, resulting in increased genetic isolation. For some moving species, there may not be sufficient habitat at the poleward or upslope margins of their distributions to prevent extinctions.	Marsupials (8) Vascular plants (11) Freshwater fish (16) Mountain birds (17) Sahel vegetation (18) Reptiles and amphibians (20) Arctic vegetation (22) Moths (26) Birds and possums (27)
17. Partnerships for the Goals	Significantly increase the exports of developing countries, in particular with a view to doubling the least developed countries' share of global exports by 2020. Realize timely implementation of duty-free and quota-free market access on a lasting basis for all least developed countries, consistent with World Trade Organization decisions, including by ensuring that preferential rules of origin applicable to imports from least developed countries are transparent and simple, and contribute to facilitating market access. Enhance the global partnership for sustainable development, complemented by multi-stakeholder partnerships that mobilize and share knowledge, expertise, technology and financial resources, to support the achievement of the sustainable development goals in all countries, in particular developing countries.	As species cross national borders, partnerships will be essential, and 'who owns what' becomes an issue (see "mackerel wars" in the main text). Developing global partnerships for sustainable management of natural resources will require jurisdictions to manage species as transboundary stocks, rather than on a jurisdiction-by-jurisdiction basis. Addressing the challenges of changes in the distribution of pests, pathogens and pollinators may also require multi-jurisdictional strategic planning and cooperation.	Coffee (4) Skipjack tuna (9) Mackerel (12) Coastal fish (19)

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