CellPress

Feature Review

A 2017 Horizon Scan of Emerging Issues for Global Conservation and Biological Diversity

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We present the results of our eighth annual horizon scan of emerging issues likely to affect global biological diversity, the environment, and conservation efforts in the future. The potential effects of these novel issues might not yet be fully recognized or understood by the global conservation community, and the issues can be regarded as both opportunities and risks. A diverse international team with collective expertise in horizon scanning, science communication, and conservation research, practice, and policy reviewed 100 potential issues and identified 15 that qualified as emerging, with potential substantial global effects. These issues include new developments in energy storage and fuel production, sand extraction, potential solutions to combat coral bleaching and invasive marine species, and blockchain technology.

Trends

This is the eighth such annual horizon scan.

An international team with expertise in horizon scanning, science communication, and conservation research, practice, and policy identified 15 issues, following widespread consultation and a Delphi-like scoring process to identify the most important.

The issues were wide ranging, and include sand extraction, blockchain technology, use of robotics to combat invasive species, and new developments in energy storage and fuel production.

Aims of Horizon Scanning

We have conducted an annual horizon scan of global conservation issues since 2010 with the aim of highlighting, by consensus, emerging topics that are not yet widely known in the conservation community but could have substantial effects on biological diversity worldwide in the medium to long term. Our iterative, transferable process of horizon scanning, which is designed to be both transparent and democratic, is carried out by a team with a wide range of experiences and areas of expertise.

Our aim has been to focus attention and stimulate debate about these subjects, potentially leading to new research foci, policy developments, or business innovations. These responses should help to facilitate better-informed forward-planning. It is difficult to gauge the direct effects of our horizon scans on the research, policy, or business communities, except through personal communication and hearsay. However, several topics recognized in our previous horizon scans

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received international attention during 2016. For example, we identified microplastics as an emerging issue in 2010 [1]. There is now substantial action on this issue internationally, with several governments, including those of the USA and the UK, introducing legislative bans on microbeads in cosmetics and detergents, and many cosmetics companies voluntarily committing to halt their use of microplastics by 2020 [2,3]. New research on the effects of microbeads has revealed biological responses in both terrestrial and aquatic environments, with evidence demonstrating that microplastics reduce the survival and fitness of earthworms *Lumbricus terrestris* [4] and facilitate the accumulation of sorbed organic pollutants in fish [5]. Discussion of the use of gene editing to control invasive species or disease vectors, raised in our 2014 horizon scan [6], has increased dramatically over the past year, with a range of developments using clustered regularly interspaced short palindromic repeats (CRISPR). This approach is already being focused towards controlling diseases such as malaria, Zika, and dengue, by removing disease-carrying female mosquitoes [7] or reducing reproduction in female mosquitoes [8].

The consumption, production, and marketing of plant-based proteins and meat substitutes (synthetic meat), another issue identified in 2010 [1], gained traction in 2016. Several companies produced molecules found in meats, either from stem cells or by fermentation. More recently, we raised the issue of changes in the legal status of nonhuman animals [9] and in 2016 legislation was introduced by the New Zealand Parliament [the Te Awa Tupua (Whanganui River Claims Settlement) Bill] that, if passed, will legally recognize the Whanganui River as an indivisible and living whole, with both physical and metaphysical elements.

The examples above demonstrate that our process has accurately identified issues that have since become more well known and significant; we look forward to further assessing the trajectories of topics identified in past horizon scans. For these issues, the time lag between our identification of an issue and it resulting in practical or policy consequences has been up to 6 years; clearly this is likely to be a lower bound as the first issues were identified only 6 years ago. At the same time, we recognize that not all identified issues will materialize: new innovations may be quickly superseded by others, initial promise may not be realized, risks may curtail adoption, or an unexpected development may shift the course of a trend. The length of time between an issue being raised and its consequences being felt demonstrates the value of our commitment to horizon scanning as a long-term project, and the importance of regularly revisiting issues.

Identification of Issues

The methods used to identify issues were consistent with our previous annual horizon scans [1,6,9–13]. The 25 core participants in the horizon scan (the authors) applied an inclusive, transparent, and repeatable process that is a modification of the Delphi technique [14,15].

Each participant proposed two or more topics, either alone or following consultation with members of their networks within and beyond their organizations. Several participants used social media to canvass followers for issues. Proposed topics were required to meet the criteria of global relevance and limited recognition among conservation professionals. The 99 topics that were submitted reflected the input of an estimated 430 individuals.

Short descriptions of the full list of topics were circulated to all participants in July 2016. Participants then scored each topic on a scale from 1 (well known, or poorly known but unlikely to have substantial effects on conservation of biological diversity) to 1000 (poorly known and likely to have substantial effects on the conservation of biological diversity and the environment). Each participant also indicated whether they had heard of each issue; the percentage of participants that were aware of each issue was considered in the final scoring process as a relative measure of the novelty of an issue. Each participant's scores were converted to ranks, and we calculated the median rank of each topic. Given the time available for discussion, we

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retained the 35 topics with the highest median ranks and three topics that one or more participants thought warranted further discussion, and one additional topic that was not included in the original 99. Two participants, neither of whom had proposed the topic, researched the feasibility, novelty, and likely effects of each topic if realized (three participants examined the newly added topic).

The participants convened in Cambridge, UK, in mid-September 2016. Each of the 39 topics was discussed in turn, with the constraint that the individual who suggested a given topic, if present, was not among the first three people to comment on it. The focus of some topics was modified during discussion. After each topic was discussed, participants independently and confidentially rescored the issue from 1 through 1000 as described above. The 15 topics that received the highest median ranks after discussion at the meeting are reported below. The topics are not presented in rank order, but are instead grouped by approximate subject area. We present each topic as objectively as possible, and acknowledge that many topics, if realized, could present either risks or opportunities for global biological diversity, the environment, and conservation efforts in the future.

The Topics

Manipulating Coral Symbionts to Avoid Mass Coral Bleaching

Bleaching, a stress response of corals to high ocean temperature, has recently led to mass coral mortality over extensive areas. The incidence and magnitude of bleaching is strongly influenced by a symbiotic dinoflagellate (*Symbiodinium*) held within coral tissues. *Symbiodinium* strains vary greatly in heat tolerance, but recent studies have identified strains that are particularly tolerant to very high temperatures [16]. These studies are unraveling the physiological and transcriptional responses of genetically different strains to thermal stress and exploring how these responses translate into bleaching [17]. This step increase in our understanding of the molecular basis of *Symbiodinium* thermal tolerance raises the possibility of manipulating symbiont populations in the wild as a means of improving the survival of multiple coral species in warming seas, either through the transfer and release of natural strains of *Symbiodinium* outside their current geographical range, or through more direct genetic manipulation. With recurring mass mortality of corals, the possibility of such 'assisted evolution' is receiving serious consideration [18]. The risks associated with engineering *Symbiodinium* in the wild, such as disease transfer or unexpected biological responses, have not yet been evaluated.

The Use of Robots to Target Invasive Marine Species

Non-native invasive and native irruptive species can have marked detrimental effects on ecosystems. The eradication and control of such species can be particularly challenging in marine environments, and managers often rely on time- and labor-intensive manual removal. Robotics could provide a means of accelerating such interventions, with prototype robots intended to cull two of the most damaging marine species now being tested. The COTSbot is an autonomous robot that can search a reef for 4–8 h, accurately recognize irruptive crown-of-thorn seastar *Acanthaster planci* (responsible for 40% of coral mortality on the Great Barrier Reef over the past three decades: [19]), and administer a lethal injection of bile salts [20]. In the Caribbean, remotely operated underwater vehicles are targetting invasive lionfish *Pterois volitans*, an Indo-Pacific species that has reduced the biomass of native reef fishes by up to 80% [21]. The vehicles stun the lionfish with an electric shock, and retrieve them for human consumption, creating a revenue stream. Customized robots can work more hours per day and at greater depths than human divers and, hence, might more effectively control species considered to be marine pests at a local level. Therefore, robotic technologies could significantly increase our ability to tackle the growing range of problematic invasive species across the world in the future. However, the costs of this approach are currently high and might be prohibitive in many circumstances, particularly for developing nations. Spatially extensive application might

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depend on future developments that make this technology more accessible. Nevertheless, the use of robots may be feasible in popular tourist destinations or to protect high-priority areas for conservation.

Electronic Noses to Combat Illegal Wildlife Trade and Improve Biosecurity

Electronic sensors that analyze the chemistry of odors have been used commercially since the early 1990s [22]. Recent rapid technological developments have improved both their sensitivity and portability, and a range of new uses is emerging [23]. One such application is the detection of illegally traded wildlife, a multibillion-dollar sector that attracts organized crime and drives unsustainable levels of harvest of wild animal and plant species. Illegal trade often has far-reaching ecological, security-related, and economic effects. Standard approaches for the detection of illegal wildlife goods along transport routes, such as targeted inspections by enforcement officials and trained sniffer dogs, are expensive, and the number of hours that humans and dogs can work are limited. The use of portable, potentially low-cost, electronic 'noses' linked to software operating on readily available mobile devices could greatly increase detection effort, improve border biosecurity, and result in more enforcement action. Efforts to realize the marketability of one such device that aims to identify species and their geographical origin recently received backing from the Commonwealth Scientific and Industrial Research Organization of Australia. The combination of olfactory sensors with detection of rare species via environmental DNA [12,24] could markedly increase the amount of information available to improve wildlife protection and biosecurity.

Bumblebee Invasions in New Regions

Bumblebees (*Bombus*) inhabit most ecosystems worldwide, with the notable exceptions of Australia and sub-Saharan Africa. The rapid growth in the international trade in bumblebee colonies for crop pollination has resulted in major invasions by *Bombus terrestris* and other *Bombus* species into New Zealand, Japan, and southern South America. Invasion of non-native *Bombus* can lead to declines in local or regional species richness or in the abundance of native pollinators, such as *Bombus dahlbommii* in Argentina, and can increase pollination of non-native invasive plants [25]. As the global bumblebee trade continues to grow, often without regulation, bumblebees are being sent to, and released in, new locations. Models have identified several regions in which *B. terrestris* is not yet present but where habitat quality for the species is high, including mainland Australia, Brazil, Uruguay, China, and areas of South Africa and Namibia [26]. There are currently no records of bumblebee invasions in South Africa, yet the import of bumblebee colonies for agricultural use has been promoted, despite non-native bumblebees posing a substantial risk to native South African species, including carpenter bees (*Xylocopa* spp.). Bumblebees can also act as vectors, introducing novel infectious diseases as they spread to new regions [27].

Extensive Use of Bacteria and Fungi to Manage Agricultural Pests

Biological pest control is currently widely used in forestry, horticulture, and intensive glasshouse production of fruits and vegetables, but it has been successfully used on outdoor field crops in relatively few cases (e.g., control of cassava mealybug *Phenacoccus manihoti* in Africa [28]). Recent advances in genetic screening and engineering are now enabling the widespread use of biological pest control or growth stimulation treatments based on bacteria or fungi. The agrochemical industry views the use of these microbial treatments as an alternative to synthetic compounds and as an area of potential commercial growth in the face of increasingly stringent regulation of synthetic chemicals. Spatially extensive crops, such as cereals and oilseeds, are now targets for the research and development of biological control and the use of biostimulant microbial mixtures (which improve plant growth and yield; [29]). The potential effects on species and ecosystem function from extensive manipulation of soil microbial communities, key to biogeochemical cycling, have not been assessed. Additionally, there may be thresholds beyond

which substantial changes in the microbiota have the potential to affect gas exchange between the soil and the atmosphere, although the mechanisms are not well understood [30].

Sand Becoming a Scarce Resource

Globally, sand and gravel comprise 68–85% of the 47–59 billion tons of material mined annually, and this percentage is increasing rapidly [31]. Sand is used in diverse sectors, particularly the manufacture of concrete and in land reclamation, as well as in the production of glass, asphalt, and electronics; beach creation; and hydraulic fracturing. Hence, as human populations, urbanization, and wealth increase, demand for sand continues to grow, with potentially large, but uncertain, risks and opportunities for biological diversity. Sand and gravel are generally mined from land quarries, rivers, lakes, seabeds, and coasts, and the properties of sand from different sources vary considerably, affecting their utility. Impacts of sand mining include loss of species, loss or degradation of habitats, and social conflict, and the local scarcity of certain types of sand is driving an extensive, and often illegal or unregulated, trade. However, opportunities for restoration after mining and the ecosystem-based design of mining sites are emerging (e.g., [32]). Alternatives, such as the use of desert sand, previously deemed to have little economic value or potential [33], use of mud for land reclamation, or recycling of construction material, are also being explored.

Effects of Border Fences on Wild Animals

The use of fences to stake ownership, secure borders, control livestock, or prevent vehicle collisions has long constrained the movements of animals. The fencing of international boundaries between the Soviet Union, China, and Mongolia during the 1950s, for example, limited the movements of numerous migratory species. New political trends are leading to an acceleration of fencing around national boundaries in the USA and Europe. Such fences and associated infrastructure affect the daily movements, migration, and survival of animals ranging from large carnivores to gallinaceous birds [34,35]. Thus, these fences may present a new threat to the viability of wild animal populations. For example, Slovenia has built a razor-wire fence along much of its border with Croatia that may reduce connectivity among transboundary animal populations, including grey wolf *Canis lupus*, a protected species with a regional population size estimated to be less than 100 [36]. The extent to which species can traverse new border fences, and resulting population-level effects, will depend on how fences are constructed and maintained, and on surrounding land use and cover.

Effects of Changing Waste Management on Animal Movements and Populations

Changes in waste management may affect the abundance and behavior of scavenging species, with effects potentially cascading to lower trophic levels [37]. Recently, the availability of food at rubbish dumps has been shown to drive sedentary behavior in previously migratory European white stork *Ciconia ciconia* [38] and brown bear *Ursus arctos* in Turkey and Romania [39], contributing to increases in the abundance of the stork and fragmentation of bear populations. There is strong policy pressure for the closure or covering of open landfill sites in the European Union (under the Landfill Directive 1993/31/EC), Turkey, and other parts of the world. Such closures may alter the abundance and behavior of avian and mammalian scavengers. For example, it is unclear whether scavenging European white storks would resume winter migrations to sub-Saharan Africa in response to closure of landfill sites. Such changes in the behavior and distribution of scavengers may have unpredictable short- and long-term effects on species, ecological processes, and the incidence of human–wildlife conflict [39].

Increasing Wind Speeds at the Sea Surface

Over the past two decades, there has been a slow but steady increase in the average air speed above the oceans and a corresponding increase in frequency of gales [40]. Average sea-surface wind speed increased considerably between 1988 and 2011, from 24.8 km h^{-1} to 27.4 km h^{-1}

[41]. This was associated with increased wave height and increased frequency of very large waves. It has not yet been determined whether these changes are part of a long-term trend or simply reflect long-term oscillations, but they would be consistent with some projections of climate change. Strong winds (more than force 5 on the Beaufort scale) have become more common. Coastal and inshore ecosystems, such as beaches, dune systems, coastal forests, benthos affected by polar icebergs, and reefs, could increasingly be affected by wind or waves, including storm surges. Coastal dynamics may also be altered by the formation or removal of sediment-driven structures, such as dunes, islands, windward lagoon margins, and shallow subtidal sediments. The distribution and behavior of oceanic bird species or transoceanic migrants could be affected, potentially increasing their likelihood of collision with wind turbines [42]. Increases in the speed of oceanic winds could also drive human actions that could affect wildlife, such as the construction of highly engineered coastal defences or changes in the locations of shipping routes, offshore windfarms, or fishing areas.

Development of Floating Wind Farms

Commercial offshore windfarms currently comprise bottom-fixed wind turbines that cannot be installed at depths exceeding 50 m [43]. Most potential wind energy is associated with areas above deeper waters, and so is not currently utilized. As distance offshore increases, winds become more consistent and the visual effects of windfarms to land-based observers decrease. The concept of floating offshore wind turbines was proposed during the 1970s, but prototypes were not deployed until 2008. The floating structure needs sufficient buoyancy to support the turbine weight and to restrain pitch, roll, and heave motions. Consequently, the floats are tethered to the seabed with mooring lines. The main barriers to installation have been high capital and operating costs. Nonetheless, in 2016, Statoil was granted a seabed lease to develop the largest floating windfarm in the world (five 6-megawatt turbines) off the Scottish coast. Globally, more than 40 similar schemes are in development. Potential ecological effects of floating windfarms are not well understood, and are likely to depend on where they are sited [44]. Floating structures in deep water often attract fish, but fishing would be likely to be prohibited in close proximity, which could provide a *de facto* reserve effect. However, floating windfarms could also lead to bird strikes and entanglement of marine mammals and fish in cables. It has been suggested that there is substantial potential for reducing costs and providing other benefits by siting multiple offshore ventures in close proximity [45], but the potential effects of such ventures on highly mobile oceanic species has not been assessed.

Creating Fuel from Bionic Leaves

Energy from the sun can be harnessed with solar panels, but, in the absence of sunlight, the energy must be stored. During photosynthesis, plants deploy catalysts that use sunlight to split water into oxygen and hydrogen to produce the fuel needed to form sugars. Researchers recently developed an artificial leaf [46]: a silicon strip, coated with catalysts and positioned in water, which uses energy from a photovoltaic panel to split water into oxygen and hydrogen. The hydrogen is then fed to *Ralstonia eutropha* bacteria, which convert atmospheric CO_2 into alcohol, completing the photosynthesis cycle. By overcoming some of the limitations of earlier versions of the bionic leaf [47], the new device may create a range of products (biomass, liquid fuel, and even bioplastics) up to ten times more efficiently than natural photosynthesis [46]. There is also scope for such artificial leaves to make other products, such as chemicals currently synthesized from pollutants [48]. Although currently limited by the speed at which bacteria create fuel, the technology serves as a proof of concept and has potential as a local, renewable energy source in regions without an electricity grid.

Lithium-Air Batteries

A substantial constraint to many renewable energy sources is the difficulty of storing energy where supply is unpredictable. Long-lasting energy storage is also key to enabling the mass

market adoption of electric vehicles. To transform the market, a battery with higher energy density than lithium-ion is needed. Such a battery, the lithium-air battery, was recently developed. In theory, lithium-air has a specific energy ten times that of lithium-ion; such a high energy density is comparable to that of petrol. In 2015, researchers announced a laboratory-based demonstration of a lithium-air battery that has higher capacity and stability than previous attempts [49]. While the results are promising, the researchers cautioned that a practical lithium-air battery is unlikely to be available for at least a decade. More recently, a new variation of the lithium-air battery, the nanolithia cathode, was reported that could be used in a conventional, fully sealed battery [50]. The team expects to move from this laboratory-based proof of concept to a practical prototype within a year. These new batteries could transform market demand for renewable energy, with considerable impacts on land use, water quality, species and ecosystems, and geomorphology.

Reverse Photosynthesis for Biofuel Production

The recent development of a process, dubbed 'reverse photosynthesis', has the potential to transform the production of biofuels and plastics [51]. The oxidation of plant biomass by enzyme-catalyzed reactions is a basic mechanism of the carbon cycle. However, a class of oxidative enzymes, lyctic polysaccharide monooxygenases, has been shown to produce 100-fold increases in catalytic activity when combined with oxidizing agents and pigments and exposed to light. The levels of cellulose oxidation achieved with this process are believed by the innovators [51] to be higher than any previously reported results. This method of light-driven oxidation could have industrial applications in the conversion of biomass to fuel and useful chemical compounds. It could increase the rate of production of, for example, methanol, while minimizing pollution and substantially reducing energy consumption through the use of solar energy. Processes that currently take 24 h could take as little as 10 min to complete. Development is still at an early stage, requiring considerable further research and technological advancement to become industrially viable. However, if realized, the efficient conversion of biomass to biofuel and industrial compounds could reduce fossil fuel use and carbon emissions. Such innovations could also precipitate changes in land use, especially towards biofuel production, with many effects on biological diversity [52].

Mineralizing Anthropogenic Carbon Dioxide

Carbon capture and storage could be a viable option to reduce emissions of CO_2 from specific point sources, but, as yet, no safe, long-term mechanism to prevent future leakage has been proposed. Researchers in Iceland have developed a method by which CO_2 is dissolved in water before being injected into basaltic rocks for storage [53]. Injections of pure CO_2 and of a CO_2-H_2S (hydrogen sulfide) mixture, along with carbon-14 and other tracers, were monitored for almost 2 years. By that point, mineralized carbon, in the form of calcite, had been locked in the basalt. The researchers concluded that 95% of the CO_2 had been mineralized, contrasting with the conventional wisdom that such a process would take hundreds to thousands of years. A possible drawback is that this technique requires large amounts of energy and water. This can be minimized if the CO_2 is only injected into reactive fractured rocks, such as basalts and ultramafics [54]. The theoretical carbon-storage capacity of basalt in the oceanic ridges around Iceland is greater than the estimated amount of carbon that would be released by burning all fossil fuels known to be accessible. Although it remains unclear how much of this capacity would be practical to use [55], a net reduction of carbon emissions would have many positive impacts on biological diversity.

Blockchain Technology

Blockchains can be used as ledger systems that are verifiable, auditable, transparent, and run on a network of personal computers. Although best known as the computational underpinning of Bitcoin, they have applications beyond digital currency. They could transform contexts where

verification of transactions without a central authority is currently a stumbling block. Among the applications being explored are so-called 'smart contracts', reputation systems, intellectual property, asset registers, voting, and the administration of decentralized organizations [56]. There are also applications with environmental relevance. These include land claims registration, especially in regions where property ownership frequently is contested or where administrative institutions are not trusted, including species-rich parts of the developing world; establishment of alternative currencies backed by renewable energy generation, carbon mitigation, and sustainable innovation [57]; supply chain traceability to improve transparency and undermine corruption, particularly in agriculture and fishing; and tracking of illegal wildlife trade. Further applications in fields such as agriculture and land management are likely to arise as this new technology matures.

Discussion

Scanning nascent issues that may, in time, have profound effects on global conservation efforts and biological diversity is necessary to achieve societal and policy objectives for conservation. Our horizon scans have highlighted emerging issues that may warrant further research, investment in risk assessments, and, in some cases, action by policy makers and practitioners. We recognize that there are limitations to any method of horizon scanning. Many issues, particularly those related to new technologies, advance incrementally each year and, in the absence of any clear step-change, are unlikely to be highlighted by our process even if they have substantial environmental effects.

Novelty is subjective; what is considered to be well known in one sector may be unknown in another. The topics we identify often reflect participants' knowledge of emerging research, changes in the spatial extent of potential effects, a rise in media attention, or a new manifestation or response to its potential effects [58]. We have discussed at length concepts for which a range of approaches are being deployed to achieve the same or similar endpoints, for example efficiency of energy production and storage or carbon capture. While we aim to single out those advances that we think may revolutionize an entire field, alternative approaches may ultimately be even more transformational. Hence, the one issue or advance that we highlight in our horizon scan should be interpreted as representative of its field. The greatest regional or global effects on biota often result from widespread adoption of a general technology (e.g., conversion from gasoline-powered to battery-powered automobiles) rather than one manifestation of the technology.

We discussed CRISPR-Cas9, a precise and relatively cheap method of gene editing, in detail during both this year's (2017) and the previous year's (2016) horizon scans. We decided not to include it in our final set of 15 issues because it is a step towards the realization of genetic control of invasive species or disease vectors, a horizon issue identified in 2014. The CRISPR method was first demonstrated for double-stranded DNA in 2013 [59], and is more efficient and less expensive than previously proposed gene drive technologies [60], but we were unaware of its potential at the time of the 2014 horizon scan. The potential conservation risks and opportunities associated with using CRISPR for biological control have been thoroughly discussed [59,60] and, to the best of our knowledge, it has not yet been used as the basis for an actual species control program. However, such use of CRISPR might be considered as a candidate horizon issue, especially if implementation was likely to be extensive and occurred in the absence of a regulatory framework [60].

Four of the issues highlighted this year (creating fuel from bionic leaves, reverse photosynthesis for biofuel production, manipulating coral symbionts to avoid mass coral bleaching, and extensive use of bacteria and fungi to manage agricultural pests and diseases) are products of the rapidly growing field of biotechnology. It has been suggested that the world is at the cusp

of a technological revolution, where increased biological understanding, step changes in access and efficiency, and the widespread adoption of CRISPR, will enable production of self-replicating organisms. Such organisms might be applied to fields and objectives as diverse as energy production, efforts to reduce climate change, and plastic bioremediation [61]. As with gene editing, risk assessment and regulation of such technology is likely to be necessary to avoid unwanted negative effects on biological diversity and the environment.

We also have discussed, but have not highlighted, many of the environmental effects (both positive and negative) that may result from the current dynamic political context in affluent European countries and the USA (border fences being the exception). These political changes may have a greater effect on conservation than would many of the issues presented here. While specific geopolitical events can be unpredictable, we are aware that recent trends, including the rise in nationalism, military conflicts, terrorism, and the mass movements of political or economic migrants and refugees (e.g., [62]), can have considerable effects on biological diversity that we may fail to identify on an annual basis. At the same time, there are global desires and movements to improve living standards in low-income countries and to reduce the disparity between relatively high-income and low-income populations and nations. All of these pressures will continue to have major ramifications for biological diversity, conservation efforts, and other forms of environmental management.

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