Review

A 2018 Horizon Scan of Emerging Issues for Global Conservation and Biological Diversity

William J. Sutherland,[1,*] Stuart H.M. Butchart,[1,2] Ben Connor,[3] Caroline Culshaw,[4] Lynn V. Dicks,[5] Jason Dinsdale,[6] Helen Doran,[7] Abigail C. Entwistle,[8] Erica Fleishman,[9] David W. Gibbons,[10] Zhigang Jiang,[11,12] Brandon Keim,[13] Xavier Le Roux,[14,15] Fiona A. Lickorish,[16] Paul Markillie,[17] Kathryn A. Monk,[18] Diana Mortimer,[19] James W. Pearce-Higgins,[1,20] Lloyd S. Peck,[21] Jules Pretty,[22] Colleen L. Seymour,[23,24] Mark D. Spalding,[1,25] Femke H. Tonneijck,[26] and Rosalind A. Gleave[1]

This is our ninth annual horizon scan to identify emerging issues that we believe could affect global biological diversity, natural capital and ecosystem services, and conservation efforts. Our diverse and international team, with expertise in horizon scanning, science communication, as well as conservation science, practice, and policy, reviewed 117 potential issues. We identified the 15 that may have the greatest positive or negative effects but are not yet well recognised by the global conservation community. Themes among these topics include new mechanisms driving the emergence and geographic expansion of diseases, innovative biotechnologies, reassessments of global change, and the development of strategic infrastructure to facilitate global economic priorities.

Trends

This is the ninth such annual horizon scan.

Twenty-four experts in conservation research and practice, ecology, economics, policy, and science communication identified 15 topics following a wide consultation. They followed a Delphi like process to score and identify the most important.

The issues highlighted span a wide range of fields and include thiamine deficiency in wild animals, the geographic expansion of chronic wasting disease, genetic control of invasive mammal populations and the effect of culturomics on conservation science, policy and action.

Introduction and Aims of Horizon Scanning

We present the outcomes of our ninth annual horizon scan. Our aim is to highlight systematically both risks and opportunities to the conservation of biological diversity that are not widely known by conservation scientists and decision makers. Collectively, our horizon scanning team has considerable expertise, experience, and perspectives on conservation science and allied disciplines. These disciplines encompass economics, policy, journalism, ecology, microbiology, conservation practice, and professional horizon scanning. Horizon scanning allows users, including but not limited to policy makers, researchers, innovators, educators, investors, and practitioners, to identify future political, environmental, technological, and societal changes and consider their possible effects. Horizon scanning can help reduce the degree for conservation biology to be a crisis discipline [1], and to be a proactive rather than a reactive science.

It is now well established that horizon scanning can support and shape local, national, and international decision making. For example, a foresight study on the detection and identification of infectious diseases by the UK Government Office for Science drove investment into new approaches [2]. We cannot easily track whether the issues we identified previously affected decisions by policy makers or conservationists because the issues are embedded within extensive political, social, and environmental changes such as urbanisation, human migration, and population growth. The potential opportunities and threats associated with each issue, and the response of the global conservation community will be affected considerably by the trajectory of these global drivers. In some scenarios, the issues are likely to mature into trends, whereas in others they are not. However, several issues that we highlighted in previous scans

[1]Conservation Science Group, Department of Zoology, Cambridge University, The David Attenborough Building, Pembroke Street, Cambridge, CB2 3QZ, UK
[2]BirdLife International, The David Attenborough Building, Pembroke Street, Cambridge, CB2 3QZ, UK
[3]British Ecological Society, Charles Darwin House, 12 Roger Street, London, WC1N 2JL, UK
[4]Natural Environment Research Council, Polaris House, North Star Avenue, Swindon, SN2 1EU, UK
[5]School of Biological Sciences, University of East Anglia, UEA, Norwich, NR4 7TJ, UK
[6]Environment Agency, Horizon House, Deanery Road, Bristol, BS1 5AH, UK
[7]Natural England, Eastbrook, Shaftesbury Road, Cambridge, CB2 8DR, UK

gained broader attention that resulted in action, suggesting at the least that some of our issues were at the cusp of emergence.

In 2015, we discussed the underground gasification of coal and its potential to contaminate groundwater and produce greenhouse gases [3]. After publication of the scan, the UK Government commissioned an independent review of underground gasification of coal [2]. In November 2015, that review suggested that the technology could be responsible for a substantial increase in greenhouse gas emissions. Scotland banned underground gasification of coal in October 2015 [4] and the UK Department for Business, Energy and Industrial Strategy stated that it was 'minded not to support' the technology in 2016. In 2017, we noted that the growing demand for sand and gravel was outstripping sustainable supply [5]. This same issue since has been the subject of media investigation and reporting in major outlets in the US, Europe, and Asia [6], and an editorial on this issue [7] referenced our scan when identifying this topic as an emerging issue.

As the basis for the scan reported here, we compiled 117 issues. Participants and their colleagues suggested the issues on the basis of at least 444 sources that were referenced in descriptions of the issues: 178 articles from a total of 109 scientific journals, 138 online news articles, and an assortment of web pages, press releases, reports, surveys, blogs, videos, and radio programmes. Most references were in English, but some were written in Chinese, Spanish, Icelandic, or Portuguese. Content producers were affiliated with, among others, universities, government, research institutions, national newspapers, and agricultural or industrial sectors.

Identification of Issues

The methods we used during this horizon scan were consistent with those used during our previous annual scans [3,5,8–14]. The 24 core participants in the horizon scan (the authors) used a modified version of the Delphi technique that is repeatable, inclusive, and transparent [15–17].

We consulted our professional networks by person-to-person communication and through targeted Facebook groups, Twitter (e.g., six participants tweeted the same message to their 22 377 followers), the BiodivERsA network, and a project on ResearchGate. We communicated directly with 357 people in person, electronically, or via social media. Each coauthor then submitted at least two issues. Criteria for consideration of these issues by the group were that they must be related to conservation of nature or natural resources, relevant at regional or global scales, and emergent among the global community of researchers, practitioners, and policy makers. The resulting list of 117 issues was circulated to the participants.

Participants gave each issue a unique score in the range from 0 to 1000, with higher scores for issues that were not well known and likely to have considerable environmental effects. The scores were converted to ranks. Separately, participants also indicated whether they had heard of the issue, and the proportion of participants' awareness was used to indicate wider awareness or novelty of the issue, and hence to influence the final scoring. To counteract the possibility of scoring fatigue, or unconscious differences in scoring of issues near the start and end of a long list [18], we developed two versions of the list in which the order of issues was changed, and distributed each version to half of the participants. We retained the 35 issues with the highest median ranks across all participants for further consideration.

Next, two or occasionally three participants were assigned to each of 35 issues to investigate further their novelty, apparent likelihood of occurrence or implementation, and likely magnitude

[8]Fauna & Flora International, The David Attenborough Building, Pembroke Street, Cambridge, CB2 3QZ, UK
[9]Department of Fish, Wildlife and Conservation Biology, Colorado State University, Fort Collins, CO 80523, USA
[10]RSPB Centre for Conservation Science, Royal Society for the Protection of Birds, The Lodge, Sandy, SG19 2DL, UK
[11]Institute of Zoology, Chinese Academy of Sciences, Beijing, 100101, China
[12]University of Chinese Academy of Sciences, Beijing, 100049, China
[13]721 Ohio Street, Bangor, ME 04401, USA
[14]Fondation pour la Recherche sur la Biodiversité, 195 rue Saint Jacques, 75005 Paris, France
[15]Microbial Ecology Centre, INRA, CNRS, Université Lyon 1, Université de Lyon, 43 Boulevard du 11 Novembre 1918, 69622 Villeurbanne, France
[16]Cranfield Institute for Resilient Futures, Cranfield University, Cranfield, MK43 0AL, UK
[17]The Economist, 25 St James's Street, London, SW1A 1HG, UK
[18]Natural Resources Wales, Cambria House, 29 Newport Road, Cardiff, CF24 0TP, UK
[19]Joint Nature Conservation Committee, Monkstone House, City Road, Peterborough, PE1 1UA, UK
[20]British Trust For Ornithology, The Nunnery, Thetford, IP24 2PU, UK
[21]British Antarctic Survey, Natural Environment Research Council, High Cross, Madingley Road, Cambridge, CB3 0ET, UK
[22]School of Biological Sciences, University of Essex, Colchester, CO4 3SQ, UK
[23]South African National Biodiversity Institute, Private Bag X7, Claremont, 7735, South Africa
[24]Percy FitzPatrick Institute of African Ornithology, DST/NRF Centre of Excellence, Department of Biological Sciences, University of Cape Town, Rondebosch, 7701, South Africa
[25]Global Marine Team, The Nature Conservancy, Department of Physical, Earth and Environmental Sciences, University of Siena, Pian dei Mantellini, Siena 53100, Italy
[26]Wetlands International, PO Box 471, 6700 AL Wageningen, The Netherlands

*Correspondence:
w.sutherland@zoo.cam.ac.uk (W.J. Sutherland).

of positive or negative effects. The participants then convened in Cambridge, UK, during September 2017 and discussed each of the 35 issues. The proponent of each issue was not one of the first three people to contribute to discussion on that topic. During our discussion, the emphasis of some issues was adjusted. Following discussion, participants again independently and confidentially ranked the issues, and the 15 with the highest median ranks across all participants were selected for inclusion in the scan. During our subsequent research on these issues, it became clear that two were substantially better known than we originally thought. We removed these two issues and replaced them with the next two highest-ranked issues. The duration of the formal process, from original submission to final selection of the 15 issues with the highest ranks, was ~4 months, although participants gather issues throughout the year. The issues below are grouped thematically rather than presented in rank order.

Emerging Issues

Thiamine Deficiency as a Possible Driver of Wildlife Population Declines

Evidence is increasing that a range of taxonomic groups, including bivalve molluscs, ray-finned fish, and birds across the Northern Hemisphere, are deficient in thiamine (vitamin B1) [19,20]. Thiamine is required for basic cellular metabolism and functioning of neuronal membranes. Thiamine deficiency rarely is a direct cause of mortality, but impairs health and can cause immunosuppression or leads to behavioural and reproductive problems that ultimately could cause population decline or extirpation. Days of thiamine deficiency may present long-lasting sublethal effects, which makes recognition of the extent of thiamine deficiencies more complex. The deficiencies likely are caused by insufficient dietary intake, which may be related to shifts in thiamine-producing algal populations. A recent and extensive survey along the northwest coast of the US found evidence of thiamine depletion in the water column [21]. Additionally, exposure to environmental pollutants may interfere with thiamine uptake. The extent to which thiamine deficiency may pose a substantial long-term risk to a range of species remains unclear.

Geographic Expansion of Chronic Wasting Disease

Chronic wasting disease is a progressive and fatal neurodegenerative disease in cervids. It is a prionic disease similar to scrapie and bovine spongiform encephalitis. Transmission appears likely to occur from animal to animal, with the infectious agent being passed in faeces, urine, or saliva and from mothers to offspring. The prions associated with chronic wasting disease are highly resilient, and contaminated pasture soils may become sources of infection. First discovered in mule deer (*Odocoileus hemionus*) in the US in 1967, the disease subsequently was found in other deer species – white-tailed deer (*Odocoileus virginianus*), elk (*Cervus canadensis*), and moose (*Alces alces*) – in 23 US states and two Canadian provinces. Chronic wasting disease may cause annual, population-level mortality of ~10% in white-tailed deer, and may be constraining population growth [22]. There is a risk that chronic wasting disease will become epidemic in other continents, potentially inducing ecological cascades if key herbivore populations suddenly decline. Chronic wasting disease recently was discovered in captive elk in South Korea and in two individual reindeer (*Rangifer tarandus*) in Southern Norway; its first confirmed presence in Europe [23]. Infection later was detected in three additional reindeer in Central Norway, prompting the decision to cull a herd of 2000 animals [24]. Further emergence of chronic wasting disease in Norwegian reindeer may have substantial effects on vegetation structure, ecological succession, and prey availability for top predators in tundra ecosystems [25], and on the culture and livelihoods of Arctic herding communities.

Breaks in the Dormancy of Pathogenic Bacteria and Viruses in Thawing Permafrost

Some viruses and bacteria can survive freezing for thousands of years [26]. Permafrosts (frozen soils usually held together by ice) that have persisted for millennia are now thawing because of recent and continuing climate changes. As permafrosts thaw, embedded viruses and bacteria, some of them pathogens of humans or other living organisms, may be released and break dormancy, with cascading ecological effects. During the 2016 heat wave in Siberia, for example, a release of anthrax bacteria (*Bacillus anthracis*) led to infections that resulted in one human fatality, the hospitalisation of 20 people, and the death of 2000 reindeer [27]. The anthrax bacterium is thought to have emerged from the thawing carcass of a reindeer that died some 75 years previously. Pathogen viability may be far longer than 75 years, however. Following thawing in a laboratory, a virus (*Pithovirus sibericum*) that had been frozen in Siberian permafrost for 30 000 years was able to infect and kill amoebae [28]. If the pathogens are released in a given area from which they have been absent for a long period, then the pathogens could result in population-threatening epidemics. The extent and speed of fast-thawing permafrost may be further increased by mining for minerals and drilling for oil and gas that is facilitated by melting of Arctic Sea ice.

RNA-Based, Gene-Silencing Pesticides

Topical application of double-stranded RNA (dsRNA) is emerging as a novel method to control insects and viruses considered to be plant pests. The ingested dsRNA triggers enzymes within insect cells, stopping production of proteins that correspond to the dsRNA sequence. This process mimics the natural defence mechanism of RNAi; consumption of dsRNA sequences alters genetic expression in some species [29] and halts expression of genes that strongly affect survival or reproduction of the pests. dsRNA delivered via the vascular system of several crop plants killed sap-feeding insects [30] and a single application of dsRNA protected tobacco plants against a virus for 20 days [31]; albeit both studies were laboratory based. Diverse applications of dsNRA are being developed. For example, one company is developing an RNAi spray that kills *Varroa destructor*, a mite that threatens some honey bee populations (*Apis cerana* and *Apis mellifera*). Because gene silencing does not result in a heritable change, this approach may be more publicly acceptable than others that modify organismal genomes. Similarly, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services pollinator report identified RNAi gene silencing specifically as a promising technology for controlling viruses in honey bees [32]. In addition, dsRNA could be regulated as a chemical pesticide rather than a genetically modified product. Little is known about the potential effects of gene silencing on nontarget organisms with the same gene sequences. Although some studies [33,34] found no measurable effects on survival, condition, or gene expression of nontargeted organisms, these studies were conducted on relatively few species. Ensuring the species specificity of gene-silencing methods is challenging, as is creation of effective, integrated pest management with fewer undesirable environmental effects [35].

Genetic Control of Mammal Populations

Gene editing and self-replicating gene drive technologies, which can spread a deleterious allele to provoke a population crash, are developing rapidly [36]. A global partnership of scientists from diverse organisations, including the governments of the US and New Zealand, is fostering development of the technologies, and their accompanying regulations and ethics, to control non-native invasive rodents on islands. The programme aims for applications within 10 years (Genetic Biocontrol of Invasive Rodents; http://www.geneticbiocontrol.org/). Controlling or eradicating invasive mammals on islands could reduce the likelihood of projected future extirpations of threatened vertebrates by 41–75% [37]. New Zealand aims to eradicate rats, possums, and stoats on all its land by 2050, and is investing NZ$6 million (~US$ 4.3 million) per year in this effort (Predator Free 2050; http://www.doc.govt.nz/predator-free-2050). Laboratories worldwide are developing gene drive systems in mice (*Mus musculus*), although rats are responsible for a greater proportion of extinctions on islands than mice. The projections of individual-based models [38] suggest that some methods based on CRISPR-Cas9 (clustered regularly interspaced short palindromic repeats) gene editing could reduce the mouse population of an island from 50 000 to zero in 4–5 years [38]. Larger populations of mice, and populations of black rats (*Rattus rattus*) or rabbits (*Oryctolagus cuniculus*), also could be eradicated with these methods, although more slowly. Widespread use of these methods to manipulate the demography of mammal populations, however, raises ethical and ecological questions, such as the cascading effects of the eradication of the targeted populations and the potential consequences if an eradication trait spreads into nontarget regions or species within their native range.

Use of Lasers in Commercial Deep Water Fishing

An alternative to bottom trawling has been developed by the Innovation Center Iceland and Icelandic Marine Research Institute [39]. Currently one-third of the value of wild seafood landed in Europe is caught by bottom trawling, a fishing method that generates considerable bycatch [40], causes extensive and enduring damage to benthic ecosystems [41], and results in substantial carbon emissions [42]. Emissions of greenhouse gases and bycatch generated by trawling for shrimp, for example, are especially high; fuel use may approach 4 l of oil per kilogram of edible catch. The new method replaces the conventional trawl with a rigid frame and a small tapered net that corresponds to the cod end of a traditional trawl. Automated height control allows the frame to glide above the sea floor, and target species are herded with directed laser beams, leaving nontarget species and other elements of the benthic ecosystem undisturbed. Lasers also can be used to extend the effective size of the trawl without introducing additional drag [39]. Tests on caridean shrimp (*Pandalus borealis*) indicated that the volume of catch from the laser-based gliding trawl is greater than from bottom trawling. If the new technology proves viable, it may be a realistic alternative to traditional bottom trawls, causing much less sea-bed damage and substantially reducing the volume of fossil fuel used per catch. However, the potential for unsustainable catch levels and other undesirable effects have not yet been widely discussed.

Use of Metal–Organic Frameworks (MOFs) for Harvesting Atmospheric Water

A new technique is being developed to capture atmospheric water in a wide range of ambient conditions, including in low humidity. It involves MOFs (a form of porous crystals) [43,44] or use of solar power. MOFs capture 2–5 l of water daily per kilogram of MOF. MOFs currently use expensive metals such as zirconium, but frameworks that are based on other materials are under development [45]. MOFs could reduce the time necessary to collect water and reduce displacement of humans or wildlife from arid ecosystems or during drought, increasing well-being of humans and reducing ecological effects of environmental migration or land abandonment. Conversely, capture of atmospheric water might make farming in marginal lands feasible, with adverse environmental and social effects. Future refinements might allow collection of sufficient water for plant growth in semi-arid areas, perhaps focusing on drought-tolerant species. Whilst this technique creates new opportunities for human and wildlife communities, its implementation across large areas could lead to major land-use or land-cover changes, with potentially widespread effects on local ecological communities. Effects of capture of atmospheric water in areas with low humidity are unclear, but across extensive areas, further reduction in local atmospheric humidity might exacerbate existing water stress in nonirrigated plant communities in arid areas.

Aquaporins Engineered to Increase Plant Salt Tolerance

While certain plant species, including some crops, have high salt tolerance [46], increasing salinity of agricultural soils threatens crop production in many locations worldwide [47]. Recent advances in understanding of plant responses to salt stress suggest possible methods to increase salt tolerance in crops and thus expand their possible cultivation ranges. Aquaporins, for example, are proteins in the plasma membrane that transport water, and can transport solutes and ions in plants and animals. Rarely has transport of ions by aquaporins been reported in plants [48]. Nevertheless, it is becoming apparent that certain aquaporins in plants, such as AtPIP2;1, may transport sodium ions. Accordingly, genetic engineering of aquaporins may increase salt tolerance in plants [49]. Treatment of plants with silicon may increase tolerance of salt further through regulation of aquaporin gene expression [50]. If plants with these aquaporins can be selectively bred or engineered, it may be possible to increase the agricultural capacity of soils that currently are relatively saline or that may become more saline due to subsidence related to ground water extraction or sea level rise. The extent to which salt tolerance in native plants or crops might be increased via such aquaporins remains unclear. Should this, or other methods of increasing plant salt tolerance, become commercially viable, the positive or negative effects on biological diversity may be considerable. Increases in the extent of arable land may lead to loss or fragmentation of habitat for native species. Additionally, salt-tolerant agricultural plants may colonise natural ecosystems and out-compete native plants. An increase in salt-tolerant crops, however, may allow use of abandoned croplands, and reduce food shortages and human displacement, reducing pressure to convert presently nonfarmed land to agriculture or settlements.

Effect of Culturomics on Conservation Science, Policy, and Action

Culturomics analyses word frequencies and associations in large, digital sets of data to better understand human culture and behaviour. The methods are not new, but their applications to conservation are emerging [51]. Culturomics may affect the success of conservation strategies that depend on public support and the demonstration of societal and cultural impacts of conservation. Proposed applications of culturomics in conservation science, practice, and policy include identification of conservation-oriented constituencies, demonstration of public interest in nature, understanding the drivers of such interest, and assessing the effects of conservation interventions. Internet searches, Twitter and WeChat traffic can, for instance, be used to quantify public perception and interest in wetlands or bird species [52,53], or changes in public interest in biological diversity over time [54]. Culturomics could inform efforts to enhance conservation and guide decision-making. While originally applied exclusively to text-based sources, culturomics is becoming feasible for analysing video and audio files [55] and sentiments [56]. Advances in machine learning may enable the classification and use of new information sources, thus allowing further characterization of human–nature interactions that may increase support for conservation. It is probable, however, that culturomics also will be applied by organisations seeking to counteract or prevent conservation policy and actions.

Changes in the Global Iron Cycle

The global iron cycle is changing in response to accelerating ocean acidification, stratification, warming, and deoxygenation and is predicted to change further [57]. Changes in the iron cycle affect the aqueous chemistry, sources and sinks, recycling, particle dynamics, and bioavailability of iron [58]. Iron limitation constrains productivity of phytoplankton in many open ocean areas, which may affect entire ocean ecosystems. Iron is supplied to the oceans by wind-deposited particulates, anthropogenic sources, biological recycling, hydrothermal and riverine inputs, and upwelling. In polar regions, major sources include glacial runoff from scoured rock, resuspension of sediments from iceberg scour, and sea-ice cycles; all of which are predicted to change substantially as climate changes [57]. Available iron may increase in the short-term as a result of increases in iceberg scour. However, in the longer term, as glaciers retreat to their grounding lines, a considerable decrease is likely to occur. The trade-off between iron bioavailability and use also is likely to change as the oceans warm and phytoplankton growth rates increase [58]. Increasing levels of iron limitation might further be used to justify ocean-fertilisation efforts, either simply to enhance or to maintain previous CO_2 draw-down from the atmosphere, or possibly to support offshore fisheries [59].

Underestimation of Soil Carbon Emissions

Soil organic carbon contains most of the terrestrial carbon. The decomposition of this carbon stock as global temperatures increase represents a potentially large climate feedback mechanism, and is a major source of uncertainty in climate models. The loss of carbon from the upper soil layer in response to warming is well recognised [60], but emissions of soil carbon from deeper layers have not yet been systematically considered. A deep-warming (to 100 cm) experiment detected a previously unobserved response at all depths, with CO_2 production increasing by 34–37% given a 4°C increase [61]. Kauffman and colleagues reported losses in mangrove soil carbon stocks at depths >1 m following conversion to pasture [62]. Other research has indicated that soil volume change has been underestimated as a soil forming process, leading to errors of up to −87% to +54% in calculations of soil carbon change over longer time frames [63] and reinterpretation of soil organic matter transport between layers [64]. If a substantial proportion of the soil carbon, emitted through a feedback mechanism in response to increased temperatures, is missing from current climate projections, global warming could be more rapid than expected, with substantial effects on ecosystems, humans, and other species.

Rapid Climatic Changes on the Qinghai–Tibet Plateau

The Qinghai–Tibet plateau in Asia covers 2.5 million km^2, with an average elevation of more than 4000 m, and contains the third largest reservoir of ice in the world. From 1980 to 1997, temperatures on the plateau increased by an average of 0.21°C per decade, accelerating to 0.25°C per decade since 1997; precipitation has increased by 3.8 mm per decade since 1961 [65,66]. Glacial melt and increasing plateau temperatures will cause lakes on the plateau to overflow; the loss of permafrost will increase emissions of soil carbon and also have substantial effects on vegetation, hydrology, and species throughout and beyond the plateau [67]. Changes in the climate of the plateau also may affect Eurasian weather systems. Summer snow cover on the Qinghai–Tibet plateau affects atmospheric winds that modulate the El Niño–Southern Oscillation and in turn influence the East Asian Monsoon, which generates summer rain between the Yangtze and Yellow River basins [68,69]. Snow cover on the Qinghai–Tibet plateau also has been linked to the onset of the summer monsoon on the Indian subcontinent and Indochina, and to heat waves in Southern Europe and Northern China [70,71]. As the plateau continues to warm and snow cover decreases or becomes more variable, its effects on climate and hydrology in Asia and Europe may become more pronounced, with potentially major effects on species and ecosystems.

International Collaborations to Encourage Marine Protected Area Expansion in the High Seas

Areas beyond any national jurisdiction (the high seas) cover 44% of surface of the Earth, and <1% are protected. New designations and advances in international policy frameworks suggest that the expansion of marine protected areas (MPAs) in the open ocean is increasingly possible. The challenges of legally protecting biological diversity in the high seas are considerable [72]. The first high seas MPAs included the South Orkney Islands Southern Shelf MPA (2009) and several sites in the North Sea (from 2010). These MPAs sometimes are criticised because they are in areas with few other human demands [73] or because regulatory controls are insufficient to achieve conservation objectives [74]. The Ross Sea MPA in the Southern Ocean, was scheduled to come into force in December 2017 as the largest MPA (1.55 million km^2) in the world. Members of the Commission for the Conservation of Antarctic Marine Living Resources (which include most of the G20 Group of nations) unanimously agreed to establishment of the MPA. In parallel, a preparatory commission established by the United Nations General Assembly in 2015 has drafted key elements of potential legislation to protect the biological diversity of the high seas, including novel mechanisms for establishing MPAs. This legislation would be managed under the International Convention for the Law of the Sea [75]. The lack of permanence of the Ross Sea MPA, which will expire after 35 years, has been regarded as a core weakness. However, the foundational agreement for the MPA, and the potential for a clearer international framework for management intervention, could lead to rapid increases in high seas conservation.

Belt and Road Initiative in China

In 2013, Chinese President Xi Jinping unveiled a strategic infrastructure programme that would support development of six major land transport corridors across central Asia. The corridors would link China to Europe (the belt) and link Chinese ports to Indonesia, ports around the Indian Ocean, and, through the Red Sea, Southern Europe (the road). The cost of completing the corridors, estimated to be $1.25 trillion by 2025 [76,77], will deliver economic development, supported by considerable scientific and technological development, across Eurasia to Africa. Nearly 70 countries have agreed to cooperate in the plan [78]. Given the growth of ecologically informed policies in China [14], it may be possible to develop the corridors in an environmentally sustainable manner [79]. President Xi stated his ambition to create a big-data service platform for environmental protection, and to support climate change adaptation projects internationally [78]. However, official documents currently do not appear to emphasise environmental assessment, and there are concerns that the investors may push such big infrastructure projects through quickly at the expense of safeguards, with a cascade of negative environmental impacts [80]. For example, the proposed routes overlap protected areas supporting snow leopards (*Panthera unica*), Amur tigers (*Panthera tigris altaica*), and Far Eastern leopards (*Panthera pardus orientalis*) [81]. The anticipated and extensive industrial and infrastructure development across central Asia, exacerbated by resulting human immigration to the region, would compound the undesirable ecological changes that are anticipated as climate changes [79]. Furthermore, any growth in trade throughout the region is likely to increase the risk of trade in endangered species and transport of non-native invasive species.

Potential Effects on Wildlife of Increases in Electromagnetic Radiation

Understanding the potential effects of nonionising radiation on wildlife could become more relevant with the expected adoption of new mobile network technology (5G), which could connect 100 billion devices by 2025. During use, mobile telephones and other smart devices generate radiofrequency electromagnetic fields (RF-EMFs), a form of nonionising radiation, which may change biological processes such as neurotransmitter functions, cellular metabolism, and gene and protein expression in certain types of cells, even at low intensities [82]. The notion of risk to human health remains controversial, but there is limited evidence of increased tumour risk in animals [83]. 5G uses the largely untapped bandwidth of the millimetre wavelength, between 30 and 300 GHz on the radio spectrum, which uses smaller base stations than current wireless technology. As a result, wireless antennae may be placed densely throughout neighbourhoods on infrastructure such as lamp posts, utility poles, and buildings. This could expose wildlife to more near-field radiation. Although some studies reported negative associations between electromagnetic field strength (radiofrequencies and microwaves: 1 MHz–3 GHz range) and species, for example the density and abundance of house sparrows (*Passer domesticus*) [84,85], these studies have not yielded clear empirical evidence that the observed effects are due to RF-EMFs. The potential effects of RF-EMFs on most taxonomic groups, including migratory birds, bats, and bees, are largely unknown. The evidence to inform the development of exposure guidelines for 5G technology is limited, raising the possibility of unintended biological consequences [86].

Discussion

Identifying issues that are truly on the horizon of current scientific thinking entails trade-offs. If there is little evidence that a phenomenon is emerging, it is difficult to gauge whether it is likely to become a major threat or opportunity. If there is considerable evidence, an issue no longer is novel. RF-EMFs are an example of the former. Discussions about the potential effects of RF-EMFs are unresolved and controversial [83]. However, the likely considerable global expansion in the use of RF-EMFs, and recognition that new technologies may allow radiation to use higher frequencies of the electromagnetic spectrum than previously were feasible, led us to include this issue among our 15. In contrast, we also discussed the impending global hydropower boom, but later decided it was no longer an emerging issue [87–89].

Another challenge in horizon scanning is evaluating the degree to which the possible influence of an issue is exaggerated by news media, commercial interests, or individual scientists. Emerging environmental issues that are controversial are typically characterised by active campaigning voices, which can report or reference biased or misleading sets of research results and inferences [90]. When there is little evidence, the quality and provenance of that evidence is crucial to deciding whether an issue plausibly is emerging or whether it more likely represents a campaign mounted by one or more interest groups. We had discussions of this nature about EMFs, thiamine deficiency, and laser light trawling. We also debated the timeline along which we should judge emerging issues, and in many cases, we agreed that some required short-term action.

This year, two of our issues relate to emerging or returning disease. Previous horizon scans highlighted the re-emergence of rinderpest [9], snake fungal disease [13], and coral diseases [3]. These issues reflect growing evidence that emerging, or returning diseases are affecting native species and populations around the world, and, in some cases, leading to population declines or extirpations in once-common species [91,92]. Animal and plant diseases pose a serious and continuing threat to food security, food safety, national economies, biological diversity, and the environment (UK Animal and Plant Health Agency and Department for Environment, Food & Rural Affairs; Protecting plant health: topical issues; https://www.gov.uk/guidance/protecting-plant-health-topical-issues). For example, plant health is a growing focus for governments and country risk registers [93]. Horizon scans can contribute substantially to focused research and its effects on government actions. Given the continued global transport of biological material and cumulative effects of stressors that increase the susceptibility of wild animals and plants to disease [94], we suspect that future horizon scans will continue to highlight novel, emerging, or returning pathogens and diseases.

As we discussed in our 2017 horizon scan, biotechnology continues to yield transformational developments, many enabled by new and relatively cheap gene editing methods such as CRISPR-Cas9 [5]. Two of the issues we identified this year, gene-silencing pesticides based on RNAi and genetic biocontrol of mammals, are being considered as solutions to the challenges of invasive non-native species and the need for increased food production. Both technologies may have major, positive effects on species and ecosystems through highly targeted control of unwanted species. However, both also represent technological interventions in natural populations and ecosystems that previously have not been attempted across extensive areas and could have long-term and unintended ecological or environmental consequences. As new biotechnologies develop, ethical considerations and careful assessment of possible negative effects are usually given a high profile in the scientific literature and by regulators and governments (e.g., [95,96] on CRISPR-Cas9). Nevertheless, these processes do not always stop the development of promising technologies that indeed have unintended consequences that are considered unacceptable by some sectors of society.

The horizon scanning process is not intended to draw attention to phenomena that are widely understood to affect societal needs or values, including those related to all aspects of biological diversity. Instead, it is intended as an early awareness and alert system drawing attention to novel issues that, if realised, may create pivotal opportunities or threats and thus warrant further analysis in the near future. It supports the capabilities of organizations to deal better with an uncertain and complex future [97]. We hope that our annual scans highlight issues of relevance not only to biological conservation but also to the wider environment and, by extension, to human well-being.

Acknowledgements

This is an exercise coordinated by the Cambridge Conservation Initiative, funded by both the Natural Environment Research Council (NERC) and the Royal Society for the Protection of Birds (RSPB). We are grateful to the large numbers of people who engaged with this process and submitted issues. For suggesting issues that appeared in this paper, we thank Ricardo Correia (culturomics), Silviu Petrovan (chronic wasting disease), Lewis Spurgin (RNAi pesticides), Steffen Oppel (electromagnetic radiation) and Nancy Ockendon (genetic control of mammals). W.J.S and R.A.G are funded by Arcadia. L.V.D is funded by The Natural Environment Research Council (NE/N014472/1).

References

1. Soulé, M.E. *et al.* (1985) What is conservation biology? *Bioscience* 35, 727–734
2. Hunt, D. (2015) *Underground Coal Gasification – Evidence Statement of Global Warming Potential*, DECC. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/575940/Underground_Coal_Gasification___Evidence_Statement_of_Global_Warming_Potential.pdf
3. Sutherland, W.J. *et al.* (2015) A horizon scan of global conservation issues for 2015. *Trends Ecol. Evol.* 30, 17–24
4. Carrell, S. (2016) Scotland bans controversial gas extraction technique. *The Guardian* 6 October. https://www.theguardian.com/environment/2016/oct/06/scotland-bans-underground-coal-gasification-ugc
5. Sutherland, W.J. *et al.* (2017) A 2017 horizon scan of emerging issues for global conservation and biological diversity. *Trends Ecol. Evol.* 32, 31–40
6. *The Times of India* September (2017). Why even Arab nations are buying sand. https://timesofindia.indiatimes.com/world/middle-east/why-even-arab-nations-are-buying-sand/articleshow/60492513.cms
7. Torres, A. *et al.* (2017) A looming tragedy of the sand commons. *Science* 357, 970–971
8. Sutherland, W.J. *et al.* (2010) A horizon scan of global conservation issues for 2010. *Trends Ecol. Evol.* 25, 1–7
9. Sutherland, W.J. *et al.* (2011) A horizon scan of global conservation issues for 2011. *Trends Ecol. Evol.* 26, 10–16
10. Sutherland, W.J. *et al.* (2011) Methods for collaboratively identifying research priorities and emerging issues in science and policy. *Methods Ecol. Evol.* 2, 238–247
11. Sutherland, W.J. *et al.* (2012) A horizon scan of global conservation issues for 2012. *Trends Ecol. Evol.* 27, 12–18
12. Sutherland, W.J. *et al.* (2013) A horizon scan of global conservation issues for 2013. *Trends Ecol. Evol.* 28, 16–22

13. Sutherland, W.J. *et al.* (2014) A horizon scan of global conservation issues for 2014. *Trends Ecol. Evol.* 29, 15–22
14. Sutherland, W.J. *et al.* (2016) A horizon scan of global conservation issues for 2016. *Trends Ecol. Evol.* 31, 44–53
15. Rowe, G. and Wright, G. (1999) The Delphi technique as a forecasting tool: issues and analysis. *Int. J. Forecast.* 15, 353–375
16. Sutherland, W.J. *et al.* (2011) Methods for collaboratively identifying research priorities and emerging issues in science and policy. *Methods Ecol. Evol.* 2, 238–247
17. Mukherjee, N. *et al.* (2015) The Delphi technique in ecology and biological conservation: applications and guidelines. *Methods Ecol. Evol.* 6, 1097–1109
18. Danziger, S. *et al.* (2011) Extraneous factors in judicial decisions. *Proc. Natl. Acad. Sci. U. S. A.* 108, 6889–6892
19. Balk, L. *et al.* (2009) Wild birds of declining European species are dying from a thiamine deficiency syndrome. *Proc. Natl. Acad. Sci. U. S. A.* 106, 12001–12006
20. Balk, L. *et al.* (2016) Widespread episodic thiamine deficiency in Northern Hemisphere wildlife. *Sci. Rep.* 6, 38821
21. Sañudo-Wilhelmy, S.A. *et al.* (2012) Multiple B-vitamin depletion in large areas of the coastal ocean. *Proc. Natl. Acad. Sci. U. S. A.* 109, 14041–14045
22. Edmunds, D.R. *et al.* (2016) Chronic wasting disease drives population decline of white-tailed deer. *PLoS One* 11, e0161127
23. Benestad, S.L. *et al.* (2016) First case of chronic wasting disease in Europe in a Norwegian free-ranging reindeer. *Vet. Res.* 47, 88
24. Stokstad, E. (2017) *Norway Plans to Exterminate a Large Reindeer Herd to Stop a Fatal Infectious Brain Disease.* http://www.sciencemag.org/news/2017/04/norway-plans-exterminate-large-reindeer-herd-stop-fatal-infectious-brain-disease
25. Forbes, B.C. and Kumpula, T. (2009) The ecological role and geography of reindeer (*Rangifer tarandus*) in Northern Eurasia. *Geogr. Compass* 3, 1356–1380
26. Christner, B.C. *et al.* (2003) Bacterial recovery from ancient glacial ice. *Environ. Microbiol.* 5, 433–436
27. Fox-Skelly, J. (2017) There are diseases hidden in ice, and they are waking up. BBC Earth, 4 May. http://www.bbc.com/earth/story/20170504-there-are-diseases-hidden-in-ice-and-they-are- waking-up
28. Legendre, M. *et al.* (2014) Thirty-thousand-year-old distant relative of giant icosahedral DNA viruses with a pandoravirus morphology. *Proc. Natl. Acad. Sci. U. S. A.* 111, 4274–4279
29. Fire, A. *et al.* (1998) Potent and specific genetic interference by double-stranded RNA in *Caenorhabditis elegans*. *Nature* 391, 806–811
30. Ghosh, S.K. *et al.* (2017) Double strand RNA delivery system for plant-sap-feeding insects. *PLoS One* 12, e0171861
31. Mitter, N. *et al.* (2017) Clay nanosheets for topical delivery of RNAi for sustained protection against plant viruses. *Nat. Plants* 3, 16207
32. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (2016) *The Assessment Report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on Pollinators, Pollination and Food Production*, Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. https://www.ipbes.net/sites/default/files/downloads/pdf/spm_deliverable_3a_pollination_20170222.pdf
33. Tan, J. *et al.* (2016) No impact of DvSnf7 RNA on honey bee (*Apis mellifera* L.) adults and larvae in dietary feeding tests. *Environ. Toxicol. Chem.* 35, 287–294
34. Pan, H. *et al.* (2017) Dietary risk assessment of v-ATPase A dsRNAs on monarch butterfly larvae. *Front. Plant Sci.* 8, 242
35. Pretty, J. and Bharucha, P.Z. (2015) Integrated pest management for sustainable intensification of agriculture in Asia and Africa. *Insects* 6, 152–182
36. Harvey-Samuel, T. *et al.* (2017) Towards the genetic control of invasive species. *Biol. Invasions* 19, 1683–1703
37. McCreless, E.E. *et al.* (2016) Past and estimated future impact of invasive alien mammals on insular threatened vertebrate populations. *Nat. Commun.* 7, 12488
38. Prowse, T.A.A. *et al.* (2017) Dodging silver bullets: good CRISPR gene-drive design is critical for eradicating exotic vertebrates. *Proc. Biol. Sci.* 284, 20170799
39. Hreinsson, E. *et al.* Use of light for guiding aquatic animals, Google Patents, 2010, US09872528
40. Davies, R.W.D. *et al.* (2009) Defining and estimating global marine fisheries bycatch. *Mar. Policy* 33, 661–672
41. Hiddink, J.G. *et al.* (2017) Global analysis of depletion and recovery of seabed biota after bottom trawling disturbance. *Proc. Natl. Acad. Sci. U. S. A.* 114, 8301–8306
42. Groen, E. *et al*. (2013) *Variability in Fuel Efficiency of a North East Atlantic Demersal Trawl Fishery*. http://torskeprogrammet.no/wp-content/uploads/sites/16/2014/03/Extended-summary-LCM-June-13-FINAL.pdf
43. Kim, H. *et al.* (2017) Water harvesting from air with metal-organic frameworks powered by natural sunlight. *Science* 356, 430–434
44. Rieth, A.J. *et al.* (2017) Record atmospheric fresh water capture and heat transfer with a material operating at the water uptake reversibility limit. *ACS Cent. Sci* 3, 668–672
45. Nelson, D.J. (2017) Off-grid devices draw drinking water from dry air. *Scientific American* 26 June. https://www.scientificamerican.com/article/harvesting-clean-water-from-air/
46. Maas, E.V. (1985) Crop tolerance to saline sprinkling water. *Plant Soil* 89, 273–284
47. Assaha, D.V. *et al.* (2017) The role of Na^+ and K^+ transporters in salt stress adaptation in glycophytes. *Front. Physiol.* 8, 509
48. Johansson, I. *et al.* (2000) The role of aquaporins in cellular and whole plant water balance. *Biochim. Biophys. Acta Biomembr.* 1465, 324–342
49. Byrt, C.S. *et al.* (2017) Non-selective cation channel activity of aquaporin AtPIP2;1 regulated by Ca^{2+} and pH. *Plant Cell Environ.* 40, 802–815
50. Rios, J.J. *et al.* (2017) Silicon-mediated improvement in plant salinity tolerance: the role of aquaporins. *Front. Plant Sci.* 8, 948
51. Ladle, R.J. *et al.* (2016) Conservation culturomics. *Front. Ecol. Environ.* 14, 269–275
52. Correia, R.A. *et al.* (2016) Familiarity breeds content: assessing bird species popularity with culturomics. *PeerJ* 4, e1728
53. Do, Y. *et al.* (2015) Using Internet search behavior to assess public awareness of protected wetlands. *Conserv. Biol.* 29, 271–279
54. Keim, B. (2017) Is interest in biodiversity declining? *Anthropocene Magazine* 26 July. http://www.anthropocenemagazine.org/2017/07/google-trends-biodiversity/
55. Sherren, K. *et al.* (2017) Conservation culturomics should include images and a wider range of scholars. *Front. Ecol. Environ.* 15, 289–290
56. Liu, B. (ed.) (2012) *Sentiment Analysis and Opinion Mining Synthesis Lectures on Human Language Technologies*, Morgan & Claypool
57. Peck, L. Antarctic marine biodiversity: adaptations, environments and responses to change. *Oceanogr. Mar. Biol. Annu. Rev.* (in press)
58. Hutchins, D.A. and Boyd, P.W. (2016) Marine phytoplankton and the changing ocean iron cycle. *Nat. Clim. Change* 6, 1072–1079
59. Smetacek, V. *et al.* (2012) Deep carbon export from a Southern Ocean iron-fertilized diatom bloom. *Nature* 487, 313–319
60. Crowther, T.W. *et al.* (2016) Quantifying global soil carbon losses in response to warming. *Nature* 540, 104–108
61. Kauffman, J.B. *et al.* (2016) Carbon stocks of mangroves and losses arising from their conversion to cattle pastures in the Pantanos de Centla, Mexico. *Wetl. Ecol. Manag.* 24, 203–216

62. Sollins, P. and Gregg, J.W. (2017) Soil organic matter accumulation in relation to changing soil volume, mass, and structure: concepts and calculations. *Geoderma* 301, 60–71
63. Hicks Pries, C.E. *et al.* (2017) The whole-soil carbon flux in response to warming. *Science* 355, 1420–1423
64. Tonneijck, F.H. *et al.* (2016) The effect of change in soil volume on organic matter distribution in a volcanic ash soil. *Eur. J. Soil Sci.* 67, 226–236
65. Duan, A. and Xiao, Z. (2015) Does the climate warming hiatus exist over the Tibetan Plateau? *Sci. Rep.* 5, 13711
66. Wan, G. *et al.* (2017) The precipitation variations in the Qinghai–Xizang (Tibetan) Plateau during 1961–2015. *Atmosphere* 8, 80
67. Yao, T. *et al.* (2007) Recent glacial retreat and its impact on hydrological processes on the Tibetan Plateau, China, and surrounding regions. *Arct. Antarct. Alp. Res.* 39, 642–650
68. Wu, Z. *et al.* (2011) Modulation of the Tibetan Plateau snow cover on the ENSO teleconnections: from the East Asian summer monsoon perspective. *J. Clim.* 25, 2481–2489
69. Hu, J. and Duan, A. (2015) Relative contributions of the Tibetan Plateau thermal forcing and the Indian Ocean Sea surface temperature basin mode to the interannual variability of the East Asian summer monsoon. *Clim. Dyn.* 45, 2697–2711
70. Senan, R. *et al.* (2016) Impact of springtime Himalayan–Tibetan Plateau snowpack on the onset of the Indian summer monsoon in coupled seasonal forecasts. *Clim. Dyn.* 47, 2709–2725
71. Wu, Z. *et al.* (2016) Can the Tibetan Plateau snow cover influence the interannual variations of Eurasian heat wave frequency? *Clim. Dyn.* 46, 3405–3417
72. Ban, N.C. *et al.* (2014) Systematic conservation planning: a better recipe for managing the high seas for biodiversity conservation and sustainable use. *Conserv. Lett.* 7, 41–54
73. Brooks, C.M. (2013) Competing values on the Antarctic high seas: CCAMLR and the challenge of marine-protected areas. *Polar J.* 3, 277–300
74. Matz-Lück, N. and Fuchs, J. (2014) The impact of OSPAR on protected area management beyond national jurisdiction: effective regional cooperation or a network of paper parks? *Mar. Policy* 49, 155–166
75. Morgera, E. *et al.* (2017) Summary of the Fourth Session of the Preparatory Committee on Marine Biodiversity beyond areas of national jurisdiction: 10–21 July 2017. *Earth Negot. Bull.* 25, 1–22 http://enb.iisd.org/download/pdf/enb25141e.pdf
76. Shambaugh, D. (2015) China's soft-power push. *Foreign Aff.* 94, 99–107
77. Wang, Y. (2016) Offensive for defensive: the belt and road initiative and China's new grand strategy. *Pac. Rev.* 29, 455–463
78. Normile, D. (2017) China's belt and road infrastructure plan also includes science. *Science* 16 May. http://www.sciencemag.org/news/2017/05/china-s-belt-and-road-infrastructure-plan-also-includes-science
79. Li, P. *et al.* (2015) Building a new and sustainable "Silk Road economic belt". *Environ. Earth Sci.* 74, 7267–7270
80. Laurance, W.F. and Burgués Arrea, I. (2017) Roads to riches or ruin? *Science* 358, 442–444
81. Tracy, E.F. *et al.* (2017) China's new Eurasian ambitions: the environmental risks of the Silk Road Economic Belt. *Eurasian Geogr. Econ.* 58, 56–88
82. Sivani, S. and Sudarsanam, D. (2012) Impacts of radio-frequency electromagnetic field (RF-EMF) from cell phone towers and wireless devices on biosystem and ecosystem-a review. *Biol. Med.* 4, 202–216
83. Hardell, L. (2017) World Health Organization, radiofrequency radiation and health – a hard nut to crack. *Int. J. Oncol.* 51, 405–413
84. Balmori, A. and Hallberg, Ö. (2007) The urban decline of the house sparrow (*Passer domesticus*): a possible link with electromagnetic radiation. *Electromagn. Biol. Med.* 26, 141–151
85. Everaert, J. and Bauwens, D. (2007) A possible effect of electromagnetic radiation from mobile phone base stations on the number of breeding house sparrows (*Passer domesticus*). *Electromagn. Biol. Med.* 26, 63–72
86. Manville (2016) A briefing memorandum: what we know, can infer, and don't yet know about impacts from thermal and non-thermal non-ionizing radiation to birds and other wildlife – for public release. http://www.mainecoalitiontostopsmartmeters.org/wp-content/uploads/2016/07/Manville-7-14-2016-Radiation-Briefing-Memo-Public.pdf
87. Rudd, J.W. *et al.* (1993) Are hydroelectric reservoirs significant sources of greenhouse gases? *AMBIO* 22, 246–248
88. Rosa, L.P. and Schaeffer, R. (1994) Greenhouse gas emissions from hydroelectric reservoirs. *AMBIO* 23, 164–165
89. Rosa, L.P. *et al.* (2004) Greenhouse gas emissions from hydroelectric reservoirs in tropical regions. *Clim. Change* 66, 9–21
90. Dicks, L. (2013) Bees, lies and evidence-based policy. *Nature* 494, 283
91. Skerratt, L.F. *et al.* (2007) Spread of chytridiomycosis has caused the rapid global decline and extinction of frogs. *EcoHealth* 4, 125
92. Robinson, R.A. *et al.* (2010) Emerging infectious disease leads to rapid population declines of common British birds. *PLoS One* 5, e12215
93. Wilkinson, K. *et al.* (2011) Infectious diseases of animals and plants: an interdisciplinary approach. *Philos. Trans. R. Soc. B Biol. Sci.* 366, 1933–1942
94. Ricciardi, A. *et al.* (2017) Invasion Science: a horizon scan of emerging challenges and opportunities. *Trends Ecol. Evol.* 32, 464–474
95. Baltimore, D. *et al.* (2015) A prudent path forward for genomic engineering and germline gene modification. *Science* 348, 36–38
96. Webber, B.L. *et al.* (2015) Opinion: is CRISPR-based gene drive a biocontrol silver bullet or global conservation threat? *Proc. Natl. Acad. Sci. U. S. A.* 112, 10565–10567
97. Khoury, M. and Abouchakra, R. (2015) *Government for a New Age: The Transformation Agenda,* Infinite Ideas