

Feature Review

A Horizon Scan of Global Conservation Issues for 2016

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This paper presents the results of our seventh annual horizon scan, in which we aimed to identify issues that could have substantial effects on global biological diversity in the future, but are not currently widely well known or understood within the conservation community. Fifteen issues were identified by a team that included researchers, practitioners, professional horizon scanners, and journalists. The topics include use of managed bees as transporters of biological control agents, artificial superintelligence, electric pulse trawling, testosterone in the aquatic environment, building artificial oceanic islands, and the incorporation of ecological civilization principles into government policies in China.

Introduction to Horizon Scanning

Horizon scanning is a systematic process that aims to identify potential threats and opportunities relative to a given set of objectives or phenomena to improve societal preparedness [1]. In the horizon scan described here, we sought to identify environmental threats and opportunities that are on the margins of mainstream investigation or discussion, but may merit increased attention within the conservation community, either because they have a high likelihood of occurrence or because they could have substantial effects on the world's species, ecosystems, and ecological and evolutionary processes (i.e., biological diversity). In previous years, we identified many issues related to drivers of environmental change such as climate change, food production, energy generation, and toxicants.

Issues that are identified in a horizon scan vary with regard to their probability of emergence, pace of transformation from a horizon scan issue into a reality, the time over which they are likely to occur, and the likely extent of their effects. We considered these factors, and the familiarity of environmental professionals with each issue, in our identification process. We aimed to identify issues that previously were known to less than half of the participants. Some may be on the distant horizon whereas others already may be affecting biological diversity.

We hope that heightened awareness of these threats and opportunities will encourage researchers, policy makers, and practitioners to consider them, potentially improving the alignment of environmental research and science with policy and practice [2]. Indeed, horizon scanning is

Trends

This is the seventh annual horizon scan.

A team of 24 horizon scanners, researchers, practitioners, and journalists identified 15 issues following widespread consultation and a Delphi-like process to select the most suitable.

The issues were wide ranging but included artificial superintelligence, changing costs of energy storage and consumptive models, and ecological civilization policies in China.

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now an increasingly accepted early stage exercise in policy making within entities such as the UK government and the Australasian Joint Agencies Scanning Network. In the 6 years since we conducted the first of this series of annual horizon scans, horizon scanning has been widely applied to ecological issues, polar issues, and environmental decision-making [3–6].

Identification of Issues

The methods we used to identify issues were consistent with those used in our preceding horizon scans [7–12]. The 24 core participants in the horizon scan (the authors) were affiliated with organizations with diverse research, management, and communications mandates. They included professional horizon scanners and experts in a range of disciplines relevant to conservation.

We used a modified version of the Delphi technique that is inclusive, transparent, and repeatable [13–15]. At the start of the process, each participant, either alone or in consultation with others within and beyond their organizations (including scientific specialist groups affiliated with conservation organizations), proposed and described at least two topics that met the criteria of global relevance and limited awareness within the community of scientists, policy makers, and practitioners engaged in conservation and restoration of biodiversity. A total of 422 individuals were consulted. We also monitored a range of environmental and technological Twitter accounts, as recommended by Pang [16] and Amanatidou *et al.* [17]. Two participants, who collectively have more than 12 000 Twitter followers, used Twitter to solicit issues, and one person used Facebook to invite issues. These search efforts collectively led to the identification of 89 topics, which were circulated to the participants.

Participants scored each topic on a scale from 1 (well known, or poorly known but unlikely to have substantial environmental effects) to 1000 (poorly known and likely to have substantial environmental effects). From these scores, we produced a ranked list of topics for each participant, and then calculated the median rank for each topic. The 35 topics with the highest median ranks, plus two others that participants thought warranted further consideration, were retained. One additional topic was identified at this stage of the process and retained. Two participants, neither of whom had proposed the topic, further researched the technical details, potential likelihood of realization, and potential effects of each of the 37 original topics that were retained. Three participants researched the additional topic.

The participants convened in Cambridge, UK, in mid-September 2015. We discussed each of the 38 topics in turn, with the constraint that the individual who suggested a topic was not among the first three people to contribute to its discussion. The focus and emphasis of some topics were modified during discussion. After each topic was discussed, participants again independently and confidentially scored it as described earlier. The full process, from submitting topics to the final selection of topics, took approximately 4 months. Here, we present the 15 topics that received the highest median ranks after discussion at the meeting. The topics are grouped by subject area rather than presented in rank order.

The Topics

Artificial Superintelligence

In the past 5 years, the field of artificial intelligence has become much more sophisticated. Developments include high-level pattern recognition, natural language processing that makes sense of conversational speech, architectures inspired by human brains, and machine learning: programs that extrapolate principles, evaluate mistakes, and rewrite their own code. Artificial intelligence already has many applications in ecology and conservation. For example, machine-learning methods can identify butterfly species with 98% accuracy on the basis of texture features of butterfly images [18], raising the possibility of automated identification or verification

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of photographic biological records. Other established intelligent technologies have proven successful for early detection and control of pests and diseases [19] and for conserving energy in buildings [20]. Artificial intelligence potentially could be applied to management of complex systems, such as regulation of floods and other environmental flows. Although humans initially would direct these applications, management could become more complicated if artificial intelligence overtakes that of humans. Some artificial intelligence experts predict that computers will surpass humans in a variety of cognitive domains, including the ability to improve their function, by 2050. This projection has triggered a call to regulate the directions of artificial superintelligence to ensure that human values are carefully articulated and embedded in the software to prevent societally undesirable outcomes, such as the development of autonomous weapons [21]. However, it is not clear whether and how environmental considerations are being incorporated into these discussions. The development of artificial superintelligence could have substantial and currently unanticipated effects on biological diversity and conservation.

Changing Costs of Energy Storage and Consumption Models

Although the ability to store energy in batteries is not new, it has become increasingly prominent as use of renewable energy increases, consumers seek energy independence, and grid operators strive to increase the predictability of the energy supply provided by renewable technologies. Battery costs are expected to decrease as the market for energy storage grows [22]. For example, construction of a gigafactory worth US\$5 billion is being planned in the USA. Although challenges remain, including managing battery recycling to prevent pollution and ensuring that resources are used sustainably, the widespread commercial availability of reliable home energy storage units may facilitate a substantial increase in renewable energy use. Rapidly changing regulations [23], rate structures, and incentives may affect the rate of consumers' uptake. Other tools may be required to stimulate a transformation, such as software that can control when batteries are charged, or the use of certain appliances during periods of excess energy production [24]. Electricity suppliers are considering how they can transform their once-predictable market and business models to meet evolving consumer demands. Ultimately, this technology could remove a significant obstacle to large-scale renewable electricity generation. Whilst storage of energy in batteries may reduce the magnitude of future climate change and its effects on biological diversity [25], there may be undesirable ecological effects of comprehensive deployment of wind power and other renewable energy technologies (e.g., [26]). In addition, enhanced battery technologies may also provide opportunities for environmental monitoring: the range of unmanned aerial vehicles, currently limited in flight time in no small part by the weight of their batteries, could become significantly greater. In general, cheaper and longer-lasting energy storage for terrestrial, marine, and aerial observation systems could lead to increased and improved data collection.

Ecological Civilization Policies in China

The principle of ecological civilization is now formally incorporated in Chinese government policy [27]. China's economy is currently the world's second largest, accounting for US\$10 trillion of a \$77 trillion global gross domestic product (GDP). Although China's domestic population is relatively stable at 1.36 billion, per capita consumption patterns have changed rapidly and now converge on those of affluent countries [28]. In many of these countries, conventional economic growth has brought costly environmental externalities that affect public health and economic welfare [29]. China has higher than mean per capita carbon dioxide emissions (5 t CO₂ per person; world mean 4.4 t), accounts for 50% of worldwide pesticide use, and has serious desertification and high levels of air and soil pollution. It is also home to 420 threatened vertebrate species. Nevertheless, between 1980 and 2008, efficiency and technology advances reduced China's energy intensity from 8 kg to 3 kg carbon dioxide per \$GDP [28]. Since 2000, the Chinese government has invested \$100 billion in financial incentives for reforestation and water management. It supports 150 ecological demonstration villages countrywide; identified over

8 million agricultural hectares (35% of the land area) that are also intended to meet conservation objectives; instituted so-called Ecosystem Function Conservation Areas, where biological diversity and ecosystem services such as flood and soil retention are protected; and will report ecosystem service metrics in addition to GDP [30]. If successful, the adoption of ecological civilization principles may have substantial positive effects on environmental protection and conservation in China, and encourage other nations to support and implement the 2015 Sustainable Development Goals, particularly if these principles are promoted through China's investments overseas.

Electric Pulse Trawling

Electric pulse trawling uses electricity to flush flatfish or shrimp from seabed sediments, and is claimed by proponents to use less fuel, catch more selectively, and cause less seabed damage than traditional beam trawls. It also provides higher catch and profits per trip. However, there is evidence of injury and mortality to some nontarget species of fishes (e.g., cod *Gadus morhua*) [31], and some have questioned how the method may affect benthic species and population sizes of diverse aquatic animals [32]. The use of electric pulse trawling for shrimps in the East China Sea was banned by China in 2001 as a result of evidence of damage to benthic fauna (including juvenile shrimp) and unsustainable harvest levels; these effects were linked to poor regulation and selection of pulse settings [33]. Electric fishing in general was banned in European Union sea waters in 1988, but since 1999 the European Union has issued dispensations that permit electric pulse trawling for scientific research. These licenses first were issued to operators in The Netherlands and then to operators in Germany, Belgium, and the UK. Currently, 97 European fishing boats are practicing electric pulse trawling in the North Sea. Use of electric pulse trawling is growing ahead of a full understanding of its ecological effects and with limited regulation and enforcement.

Osmotic Power

Mixing water with two different salinities creates energy known as salinity gradient power or blue energy. A method for harnessing this energy produced where a river meets the sea was developed in the 1970s [34], when the global power-generating potential of blue energy was estimated to be sufficient to meet the world's then 2 TW electricity needs [34,35]. The first blue energy plant operated in Norway from 2009 to 2013, but closed because it was not economically viable. Technology is now overcoming the previously limited generation capacity, with approaches including the use of supercapacitors and heating the fresh water [36]. Power generation capacity may be further boosted with the use of nanotubes [37]. Although blue energy is renewable and relatively clean, the brackish byproduct may lead to salinity fluctuations that exceed natural variability in the surrounding environment, affecting salt-intolerant aquatic species [38]. The construction of infrastructure in estuaries could also have detrimental environmental effects. Furthermore, it is possible that in the future climate change and increased water extraction will reduce the flow of rivers into the sea, reducing opportunities to generate blue energy.

Managed Bees as Vectors

Use of managed bees as transporters (vectors) to deliver microbiological control agents (i.e., bacteria, viruses, or fungi) directly to the flowers of agricultural plants is emerging as a method for crop protection. The vector is usually either the honeybee *Apis mellifera* or a commercially managed bumblebee species *Bombus* sp. There is evidence that this can control a range of fungal diseases or insect pests on many flowering crops in field or glasshouse conditions [39,40]. At least one company is marketing this technology, in which individual bees pick up the control agents by walking through a patch of powder as they leave their colony to forage. The microbial control agents are registered plant protection products, so their potential effects on the environment, including effects on soil and leaf microbiota, have been evaluated [41]. However,

microbes are easily transferred between insects and flowers during foraging [42]. Therefore, the use of bees as vectors, as opposed to application of biological controls via spraying or application to the soil, may harm both the bee vectors and other wild insects (e.g., hoverflies, solitary bees, butterflies, and moths) that visit the same flowers. The insect pathogens that are being distributed by managed bees have sublethal and, in some cases, lethal effects on bumblebees [43]. The effects of delivering microbiological control agents directly to flowers on nontarget wild insects and plants have not been evaluated.

Unregulated Fisheries in the Central Arctic Ocean Threaten Expanding Fish Stocks

The high seas of the central Arctic Ocean cover 2.8 million km². This area is beyond the jurisdiction of its five coastal states (Canada, Denmark, Norway, Russia, and the USA). For most of the year, the central Arctic Ocean is covered in sea ice, although the extent of the sea ice is expected to decline as climate continues to change. If sea ice recedes as projected, some fishes, including commercial species such as Atlantic cod *Gadus morhua* and yellowfin sole *Limanda aspera*, may extend their ranges into the area [44]. Because the high seas are beyond national jurisdiction, unregulated fishing could have considerable effects on these stocks, as seen in the collapse of pollock *Gadus chalcogrammus* stocks in the Bering Sea during the 1980s [45]. In recognition of this potential, the five Arctic Ocean coastal states signed a declaration in July 2015 to prevent unregulated commercial fishing until mechanisms are established to manage fishing in accordance with international standards. However, the development of an international, legally binding instrument under the UN Convention on the Law of the Sea may be protracted given disagreement between member states, including three with coasts along the Arctic Ocean [46]. Meeting these challenges will require strong actions by the Arctic Council, ensuring the provision of substantive information to all parties and encouraging the payment of compensation to resolve conflict [47]. If international agreements fail, there is a high likelihood of the development of a new commercial fishery in the Arctic, with uncontrolled and unsustainable levels of harvest.

Increasing Extent of Construction of Artificial Oceanic Islands

Although the construction of oceanic artificial islands is not new (e.g., Japan built extensively upon the Okinotori islands from 1987 until 1993), the scale of construction has grown markedly in recent years. For instance, since 2014 China has been creating a group of at least seven artificial islands that collectively cover more than 13 km². These islands are being built in part on the Spratly Island group of coral atolls and reefs that lie in a disputed part of the South China Sea. Artificial land was created by pumping sand onto live coral reefs and paving the sand with concrete, while wide areas have also been dredged in the development of harbors and shipping lanes [48]. These practices compound the effects of coastal development, pollution, and fishing that have led to an estimated decline of coral cover on offshore atolls and archipelagos in the South China Sea from greater than 60% to approximately 20% since about 2000 [49]. The ecological effects are locally intense, and may interrupt larval supplies throughout the region. Furthermore, it is possible that the degraded reefs will erode more quickly and will no longer buffer wave action. In this case, the artificial islands will be highly likely to erode and collapse during typhoons, especially as sea levels continue to rise. The construction of usable landmass far from a country's shoreline may also set a precedent for creation of new land to increase national territorial claims in disputed waters or international waters, whether for military purposes or for access to natural resources ranging from fish stocks to seabed minerals.

Increasing Aquatic Concentrations of Testosterone

Increasing numbers of men in affluent countries appear to be taking testosterone supplements to maintain or increase physical fitness or sexual desire or function. The extent to which testosterone supplements achieve those objectives varies substantially among populations [50], and they may also have unintended health side effects. Testosterone supplements may

increase the likelihood of cardiovascular adverse events in men 65 years of age or older with low testosterone levels and limited mobility [51]. Testosterone has also been associated with increases in lean body mass [52] but decreases in short-term verbal memory [53] of healthy, elderly men. Nevertheless, in the USA prescription sales of testosterone alone increased by 25–30% annually between 1993 and 2002, and from US\$18 million in 1988 to \$1.6 billion in 2011 [50]. Increasing use of testosterone supplements is likely to increase testosterone concentrations in natural water bodies. The effects on aquatic organisms are uncertain, but some hypothesize that the effects may be similar to those of estrogens. Within a week after hatching, intersex gonadal morphology was observed in medaka *Oryzias latipes* (a common aquarium fish and model organism in toxicology) that were exposed to testosterone, but sex ratios did not change significantly [54]. It is unclear whether human use of testosterone supplements will persist and, ultimately, how such use may affect the condition and population dynamics of species throughout the aquatic food chain.

Effects of Engineered Nanoparticles on Terrestrial Ecosystems

Engineered nanoparticles are increasingly being incorporated into consumer and agricultural products, and can be released into the environment during the manufacture, use, and disposal of such products. Much of the research associated with unintended biological effects of nanoparticles over the past decade has focused on the aquatic environment. However, contamination of terrestrial ecosystems has received much less attention, despite estimates of exposure suggesting that soil could be a major sink for nanoparticles, through the use of sewage sludge in agriculture, atmospheric deposition, landfills, or accidental spillage [55]. It is estimated that concentrations of titanium dioxide nanoparticles, widely used in products such as toothpaste and sunscreen, are currently increasing in European sewage sludge-treated agricultural soils by 0.9–3.6 mg/kg annually [55]. There is increasing evidence that nanoparticles can have considerable effects on soil microbial activity [56]. At least some of these compounds, such as silver nanoparticles, substantially reduce enzyme and respiratory activities at low concentrations and therefore appear highly toxic [57]. Little is known about the potential effects of engineered nanoparticles on fungal and archaeal biota. Although the potential effects of metal contamination of agricultural soils from sewage sludge are well known and regulated, any risks associated with nanoparticles may create an additional burden for disposal of solid biological waste. These burdens are likely to affect fertilizer costs and biological diversity in and around agricultural areas.

Satellite Access to Shipborne Automatic Identification Systems

Rapid advances in systems to track vessels at sea offer substantial opportunities to strengthen environmental protection. Automatic identification systems were originally intended to assist ship operators and maritime agencies in monitoring vessel movements for safety purposes, but their use has since become widespread. Under the Convention for the Safety of Life at Sea it has been mandatory for very large vessels and all passenger vessels to carry these systems since 2004; since May 2014, all fishing vessels over 15 m in length in European Union waters must carry such systems [58]. Accurate, real-time, berth-to-berth monitoring of vessel movements at sea is becoming a transformative technology. It is possible, for example, to differentiate fishing activities from ordinary vessel transit [59], and an application of the technology may be to decrease the incidence of illegal, unreported, and unregulated fishing [60]. Satellite-tracked automatic identification systems, in combination with other remotely sensed images, could also be used to identify illegal transits, dumping, or spillage. Even if automatic identification systems are turned off, satellite-based synthetic aperture radar can detect the position of a vessel. As access to ship-tracking data increases, there will be greater potential to regulate market access for goods on the basis of their source vessels' compliance with emissions or fishing regulations, and to inform consumers about the provenance and environmental footprint of different products.

Passive Acoustic Monitoring to Prevent Illegal Activity

Passive acoustic monitoring has long been used to monitor wildlife on land and at sea, and now can be used for detecting illegal activities. Technological advances in low-cost digital recorders, coupled with the ability to download data from remote locations, are increasing the potential for relatively cheap and efficient passive acoustic monitoring over large extents [61]. Passive acoustics can be used to detect not only species and some forms of environmental change [62] but also several types of illegal activity, such as logging and hunting, although there are substantial analytical challenges to using and interpreting the volume of data collected [63]. If these challenges can be overcome, then, in combination with cloud computing, close to real-time information on such illegal activities may be available to enforcement agencies. For example, ‘Rainforest Connection’ has converted recycled mobile phones to solar-powered listening devices for the detection of illegal logging in Sumatra, triggering action by local rangers. If integrated with public, web-based data outputs, information from passive acoustic monitoring could also be used to inform consumer behavior and citizen action. Underwater acoustic monitoring is already highly advanced in sectors from defense to ecological observation. Active use of underwater acoustic monitoring to detect and intercept blast fishing, and to conduct surveillance of illegal fishing and vessel transit in remote ocean areas with autonomous vessels, is also possible [64].

Synthetic Body Parts of Endangered Animals

Innovation in the synthesis of complex biological materials has made it possible to replicate rhinoceros horn. The resulting product, which incorporates engineered keratin and is extruded on a 3D printer, is almost indistinguishable from authentic horn, and the addition of rhinoceros DNA could make it effectively identical [65]. The companies developing this process hope the availability of a horn substitute will reduce pressure on wild rhinoceros, which have been driven to near extinction by poaching and the black market in rhinoceros body parts. Synthesis of rhinoceros horn could thus play a major role in destroying markets that are based on rarity of the commodity. However, some conservation groups have questioned whether the synthesis could expose new markets to legal synthetic horn and increase the demand for real horn, ultimately increasing poaching. Evidence suggests that counterfeit luxury consumer goods inflate the price of authentic products [66]. Real horn might also be presented as synthetic, confounding efforts to curtail trafficking of horn procured from the wild. Although the synthetic replication technique has so far been limited to rhinoceros horn, it could be used to produce elephant ivory, pangolin scales, and tiger bone [67].

Artificial Glaciers to Regulate Irrigation

Artificial glaciers have been created in the cold, arid western Himalayas as a mechanism to increase the supply of water for agricultural irrigation in response to climate change (e.g., [68,69]). Historically, communities in these high-elevation regions relied on glacial melt and winter snowfall for crop irrigation and drinking water. However, increased winter temperatures and decreases and changes in the timing of snowfall have resulted in earlier snow melt, while glacial retreat has delayed glacial melting, affecting meltwater availability during the growing season. To construct an artificial glacier, channels are built to divert winter water to a shaded depression, where it freezes. Recorded volumes in single artificial glaciers can reach 370 000 m³ within 15 years [69]. Because they are built at lower elevations, artificial glaciers melt earlier than natural glaciers, increasing the period during which crops can be irrigated. Other reported effects of the glaciers were decreases in surface runoff and replenishment of aquifers and natural springs, along with reductions in the number of water-sharing disputes and increased social cohesion [69]. Artificial glaciers could increase household income through enhanced agricultural yields, shifts to more profitable crops, increases in the area of tree plantations, pasture development, and cattle rearing. These land-use changes may affect the cold desert ecosystems in the surrounding areas [70]. Because artificial glaciers rely on natural glaciers, they are a temporary adaptation measure and the longer-term effects are not well understood.

Invasive Species as Reservoirs of Genetic Diversity

Many species introduced outside their natural range have become invasive and threaten native biological diversity [71]. Their control can be expensive, long term, and often unsuccessful. Populations of introduced species generally are assumed to have lower genetic diversity than their source populations [72]. However, introduced populations can retain diversity that has been lost from their native range and, in some circumstances, their genetic diversity may exceed that of extant populations in the original range. For example, the stoat *Mustela erminea* population in New Zealand, which was introduced from Britain in the late 1800s, now has higher genetic diversity than the remaining native stoat population in Britain [73], which suffered a major genetic bottleneck in the 1950s in response to collapse of the rabbit population after the introduction of myxomatosis. By contrast, the introduced population in New Zealand retained mitochondrial haplotypes lost from the original British stoat population. Other examples of introduced populations retaining genetic diversity lost from native populations include voles *Microtus arvalis* in the Orkney Islands [74] and invasive tammar wallabies *Macropus eugenii* in New Zealand [75]. More examples are likely to become evident as conservation of genetic diversity becomes a higher priority, and if reintroduction of introduced species to their native range to restore lost genetic diversity becomes more common. This could be controversial, however, in the context of the control or eradication of such species in areas where they have become invasive pests.

Discussion

The topics identified here are diverse, ranging from energy production and storage to environmental contamination to the rapid rate and global effects of political and environmental change in one nation or union. As in previous years, our horizon scan reflects issues that are relevant to both terrestrial and aquatic ecosystems, with marine-focused topics including fishing in the high Arctic, monitoring the locations and activities of ships, and electric pulse trawling. Inevitably, the selection of issues is influenced by the participants' backgrounds, interests, knowledge, and connections. We thus convened participants with varied experiences and encouraged wide geographic and subject area consultation.

Social media is increasingly used to exchange scientific ideas, and can considerably diversify and increase the size of the group that is consulted in the search for issues. Of the original 89 issues, six that are not described here, and two that are (use of managed bees as vectors and changing costs of energy storage), were contributed through requests for issues via social media. It seems likely that continued use of social media will expand the number, themes, and sources of issues that are submitted. The sources, content, and volume of social media on a given topic may also affect scientists' and public perception of the salience, novelty, and credibility of ideas or technologies.

Some of the topics identified here reflect new applications of technologies or new developments of issues we highlighted in previous scans. For example, 3D printing of animals' body parts expands on two previously identified issues: 3D printing, identified in 2013, and the extinction of rhinoceroses and elephants, identified in 2014. Desalination of seawater with solar energy, a topic we discussed this year but did not rank among the top 15, is another example. This technology has the potential to produce potable water and food-grade salt with renewable energy. Ultimately, however, we felt that solar-powered desalination was too similar to the 2012 issue of electrochemical seawater desalination.

The realization of a horizon scan topic sometimes may occur quickly, leaving a short window of time in which the issue can be identified as both novel and credible. This transformation may occur within a year. An illustration of this might be the omission of the construction of the Nicaraguan canal, a topic that is now well known but was not identified in last year's scan.

Conversely, in some cases topics may remain dormant for a long time (and in that sense seem well known) before they suddenly materialize, often in a slightly different form. One example is artificial intelligence, a concept that has existed for decades, but which has matured to the extent that it may now start to have real-world effects. Additionally, some horizons may never materialize because circumstances change. Therefore, we encourage development of methods for determining the success of horizon scanning.

Three of the 15 issues identified this year (satellite access to shipborne automatic identification systems, passive acoustic monitoring to prevent illegal activity, and synthetic body parts of endangered animals) represent technological advances that may increase the likelihood of achieving global conservation objectives. Three other issues (ecological civilization policies in China, changing costs of energy storage and consumption models, and artificial glaciers to regulate irrigation), if realized, may also have substantial and societally desirable effects. Horizon scanning does not only identify phenomena that may have undesirable effects but may also identify phenomena that may help meet conservation aims.

Acknowledgments

This is an exercise of the Cambridge Conservation Initiative and was funded by the UK Natural Environment Research Council and the Royal Society for the Protection of Birds. We thank the large number of individuals who suggested issues or responded to questions. For suggesting issues that in some form are included in this paper, we thank Jeremy Clifford (changing costs of energy storage and consumption models), Jason Dinsdale (increasing aquatic concentrations of testosterone), Annewieke Vroom (the idea on which ecological civilization policies in China was based), Victoria Price (passive acoustic monitoring), Jean-Louis Ecochard (one of those who suggested artificial superintelligence), and Jennifer Wickens and Victoria Wickens (use of managed bees as vectors). Nibedita Mukherjee documented and made useful contributions to the meeting discussion. W.J.S. is funded by Arcadia.

References

1. Sutherland, W.J. and Woodrooff, H.J. (2009) The need for environmental horizon scanning. *Trends Ecol. Evol.* 24, 523–527
2. Rudd, M.A. (2011) How research-prioritization exercises affect conservation policy. *Conserv. Biol.* 25, 860–866
3. Cook, C.N. et al. (2014) Strategic foresight: how planning for the unpredictable can improve environmental decision-making. *Trends Ecol. Evol.* 29, 531–541
4. Roy, H.E. et al. (2014) Horizon scanning for invasive alien species with the potential to threaten biodiversity in Great Britain. *Glob. Change Biol.* 20, 3859–3871
5. Kennicutt II, M.C. et al. (2014) Antarctic and Southern Ocean science in the 21st century. *Nature* 512, 23–25
6. Fox, A.D. et al. (2015) Current and potential threats to Nordic duck populations – a horizon scanning exercise. *Ann. Zool. Fennici* 52, 193–220
7. Sutherland, W.J. et al. (2010) A horizon scan of global conservation issues for 2010. *Trends Ecol. Evol.* 25, 1–7
8. Sutherland, W.J. et al. (2011) A horizon scan of global conservation issues for 2011. *Trends Ecol. Evol.* 26, 10–16
9. Sutherland, W.J. et al. (2012) A horizon scan of global conservation issues for 2012. *Trends Ecol. Evol.* 27, 12–18
10. Sutherland, W.J. et al. (2013) A horizon scan of global conservation issues for 2013. *Trends Ecol. Evol.* 28, 16–22
11. Sutherland, W.J. et al. (2014) Horizon scan of global conservation issues for 2014. *Trends Ecol. Evol.* 29, 15–22
12. Sutherland, W.J. et al. (2015) Horizon scan of global conservation issues for 2015. *Trends Ecol. Evol.* 30, 17–24
13. Rowe, G. and Wright, G. (1999) The Delphi technique as a forecasting tool: issues and analysis. *Int. J. Forecast.* 15, 353–375
14. 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
15. Mukherjee, N. et al. (2015) The Delphi technique in ecology and biological conservation: applications and guidelines. *Methods Ecol. Evol.* 6, 1097–1109
16. Pang, A.S.K. (2010) Social scanning: improving futures through Web 2.0; or, finally a use for twitter. *Futures* 42, 1222–1230
17. Amanatidou, E. et al. (2012) On concepts and methods in horizon scanning: lessons from initiating policy dialogues on emerging issues. *Sci. Pub. Policy* 39, 208–221
18. Kaya, Y. et al. (2014) Evaluation of texture features for automatic detecting butterfly species using extreme learning machine. *J. Exp. Theor. Artif. Intell.* 26, 267–281
19. Fedor, P. et al. (2009) Artificial intelligence in pest insect monitoring. *Syst. Entomol.* 34, 398–400
20. Dounis, A.I. (2010) Artificial intelligence for energy conservation in buildings. *Adv. Build. Energ. Res.* 4, 267–299
21. Bostrom, N. (2014) *Superintelligence: Paths, Dangers, Strategies*, Oxford University Press
22. AECOM Australia Pty Ltd (2015) *Energy Storage Study*, Australian Renewable Energy Agency (<http://arena.gov.au/files/2015/07/AECOM-Energy-Storage-Study.pdf>)
23. Anuta, O.H. et al. (2014) An international review of the implications of regulatory and electricity market structures on the emergence of grid scale electricity storage. *Renew. Sust. Energ. Rev.* 38, 489–508
24. Kahn, G. (2015) Renewable energy's potential may be understated. *Wall Street J.* 13 September (<http://www.wsj.com/articles/renewable-energys-potential-may-be-understated-1442197711>)
25. Warren, R. et al. (2013) Quantifying the benefit of early climate change mitigation in avoiding biodiversity loss. *Nat. Clim. Change* 3, 512–519
26. Schuster, E. et al. (2015) Consolidating the state of knowledge: a synoptical review of wind energy's wildlife effects. *Environ. Manage.* 56, 300–331
27. Oswald, J.P.F. (2014) What does eco-civilization 生态文明 mean? *The China Story* (Australian Centre on China in the World) 4 September. (<https://www.thechinastory.org/2014/09/what-does-eco-civilization-mean/>)

28. Pretty, J. (2013) The consumption of a finite planet: well-being, convergence, divergence and the nascent green economy. *Environ. Resour. Econ.* 55, 475–499
29. Pretty, J. et al. (2015) Improving health and well-being independently of GDP: dividends of greener and prosocial economies. *Int. J. Environ. Health Res.* 11, 1–26
30. Guerry, A.D. et al. (2015) Natural capital and ecosystem services informing decisions: from promise to practice. *Proc. Natl. Acad. Sci. U.S.A.* 112, 7348–7355
31. Soetaert, M. et al. (2015) Electrotrawling: a promising alternative fishing technique warranting further exploration. *Fish Fish.* 16, 104–124
32. WWF (2014) Sustainable Brown Shrimp Fishery – Is Pulse Fishing A Promising Option? WWF Germany (<http://www.wwf.de/fileadmin/fm-wwf/Publikationen-PDF/Technical-Report-Sustainable-Brown-Shrimp-Fishery.pdf>)
33. Yu, C. et al. (2007) The rise and fall of electrical shrimp beam trawling in the East China Sea: technology, fishery, and conservation implications. *ICES J. Mar. Sci.* 64, 1592–1597
34. Loeb, S. (1975) Osmotic power plants. *Science* 189, 654–655
35. Norman, R.S. (1974) Water salinization: a source of energy. *Science* 186, 350–352
36. Janssen, M. et al. (2014) Boosting capacitive blue-energy and desalination devices with waste heat. *Phys. Rev. Lett.* 113, 268501
37. Siria, A. et al. (2013) Giant osmotic energy conversion measured in a single transmembrane boron nitride nanotube. *Nature* 494, 455–458
38. Montague, C. and Ley, J.A. (1993) Possible effect of salinity fluctuation on abundance of benthic vegetation and associated fauna in Northeastern Florida Bay. *Estuar. Coast.* 15, 703–717
39. Mommaerts, V. and Smagghe, G. (2011) Entomovectoring in plant protection. *Arthropod Plant Interact.* 5, 81–95
40. Reeh, K.W. et al. (2014) Potential of bumble bees as bio-vectors of *Clonostachys rosea* for Botrytis blight management in lowbush blueberry. *J. Pest Sci.* 87, 543–550
41. Brimmer, T.A. and Boland, G.J. (2003) A review of the non-target effects of fungi used to biologically control plant diseases. *Agric. Ecosyst. Environ.* 100, 3–16
42. Ushio, M. et al. (2015) Microbial communities on flower surfaces act as signatures of pollinator visitation. *Sci. Rep.* 5, 7
43. Mommaerts, V. et al. (2009) A laboratory evaluation to determine the compatibility of microbiological control agents with the pollinator *Bombus terrestris*. *Pest Manage. Sci.* 65, 949–955
44. Wisz, M.S. et al. (2015) Arctic warming will promote Atlantic-Pacific fish interchange. *Nat. Clim. Change* 5, 261–265
45. Bailey, K.M. (2011) An empty donut hole: the great collapse of a North American fishery. *Ecol. Soc.* 16, 28
46. Hubert, A.-M. (2015) UN General Assembly Resolution to Develop a New Legally Binding Instrument on the Conservation and Sustainable Use of Marine Biological Diversity of Areas beyond National Jurisdiction, The JCLOS Blog (<https://site.uit.no/jclos/2015/08/17/un-general-assembly-resolution-to-develop-a-new-legally-binding-instrument-on-the-conservation-and-sustainable-use-of-marine-biological-diversity-of-areas-beyond-national-jurisdiction/>)
47. Cole, S. et al. (2014) Games in the Arctic: applying game theory insights to Arctic challenges. *Polar Res.* 33, 233357
48. Larson, C. (2015) China's island building is destroying reefs. *Science* 349, 1434
49. Hughes, T.P. et al. (2012) The wicked problem of China's disappearing coral reefs. *Conserv. Biol.* 27, 261–269
50. Spitzer, M. et al. (2013) Risks and benefits of testosterone therapy in older men. *Nat. Rev. Endocrinol.* 9, 414–424
51. Basaria, S. et al. (2010) Adverse events associated with testosterone administration. *N. Engl. J. Med.* 363, 109–122
52. Emmelot-Vonk, M.H. et al. (2008) Effect of testosterone supplementation on functional mobility, cognition, and other parameters in older men: a randomized controlled trial. *JAMA* 299, 39–52
53. Maki, P.M. et al. (2007) Intramuscular testosterone treatment in elderly men: evidence of memory decline and altered brain function. *J. Clin. Endocrinol. Metab.* 92, 4107–4114
54. Koger, C.S. et al. (2000) Determining the sensitive developmental stages of intersex induction in medaka (*Oryzias latipes*) exposed to 17 β -estradiol or testosterone. *Mar. Environ. Res.* 50, 201–206
55. Sun, T.Y. et al. (2014) Comprehensive probabilistic modelling of environmental emissions of engineered nanomaterials. *Environ. Pollut.* 185, 69–76
56. Neal, A.L. (2008) What can be inferred from bacterium–nanoparticle interactions about the potential consequences of environmental exposure to nanoparticles? *Ecotoxicology* 17, 362–371
57. Simonin, M. and Richaume, A. (2015) Impact of engineered nanoparticles on the activity, abundance, and diversity of soil microbial communities: a review. *Environ. Sci. Pollut. Res.* 22, 13710–13723
58. International Maritime Organization (IMO) (2014) *Third IMO GHG Study 2014*, IMO
59. Natale, F. et al. (2015) Mapping fishing effort through AIS data. *PLoS ONE* 10, e0130746
60. Hess, D. and Savitz, J. (2015) *Global Fishing Watch. Free Worldwide Information for Citizens Seeking Effective Enforcement of Ocean Conservation Laws*, Oceana (<http://globalfishingwatch.org/oceana-global-fishing-watch-report.pdf>)
61. Farina, A. et al. (2014) The soundscape approach for the assessment and conservation of Mediterranean landscapes: principles and case studies. *J. Landsc. Ecol.* 7, 10–22
62. Farina, A. and Pieretti, N. (2014) Sonic environment and vegetation structure: a methodological approach for a soundscape analysis of a Mediterranean maqui. *Ecol. Inform.* 21, 120–132
63. Servick, K. (2014) Eavesdropping on ecosystems. *Science* 343, 834–837
64. Greene, C.H. et al. (2014) A wave glider approach to fisheries acoustics: transforming how we monitor the nation's commercial fisheries in the 21st century. *Oceanography* 27, 168–174
65. Save the Rhino International and the International Rhino Foundation (2015) *Synthetic Rhino Horn: Will it Save the rhino?* Save the Rhino International and the International Rhino Foundation (https://www.savetherhino.org/rhino_info/thorny_issues/synthetic_rhino_horn_will_it_save_the_rhino)
66. Qian, Y. (2011) *Counterfeits: Foes or Friends? How Do Counterfeits Affect Different Product Quality Tiers?* The National Bureau of Economic Research
67. Nuwer, R. (2015) 3D printed horns may put rhinos at greater risk of extinction. *New Sci.* 1 May (<https://www.newscientist.com/article/dn27459-3d-printed-horns-may-put-rhinos-at-greater-risk-of-extinction/>)
68. Bagla, P. (2001) "Artificial glaciers" aid farmers in Himalayas. *Natl. Geogr. News* 4 September (http://news.nationalgeographic.com/news/2001/08/0830_artglacier.htm)
69. Shaheen, F.A. et al. (2013) Climate change impact in cold arid desert of North-Western Himalaya: community based adaptations and mitigations. In *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change* (Nautiyal, S. et al., eds), pp. 239–256, Springer
70. Tewari, V.P. and Kapoor, K.S. (2013) Western Himalayan cold deserts: biodiversity, eco-restoration, ecological concerns and securities. *Ann. Arid Zone* 52, 225–232
71. Lodge, D.M. (1993) Biological invasions: lessons for ecology. *Trends Ecol. Evol.* 8, 133–137
72. Roman, J. and Darling, J.A. (2007) Paradox lost: genetic diversity and the success of aquatic invasions. *Trends Ecol. Evol.* 22, 454–464
73. Veale, A.J. et al. (2015) An invasive non-native mammal population conserves genetic diversity lost from its native range. *Mol. Ecol.* 24, 2156–2163
74. Martinakova, N. et al. (2013) Divergent evolutionary processes associated with colonization of offshore islands. *Mol. Ecol.* 22, 5205–5220
75. Taylor, A.C. and Cooper, D.W. (1999) Microsatellites identify introduced New Zealand tammar wallabies (*Macropus eugenii*) as an extinct taxon. *Anim. Conserv.* 2, 41–49