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A horizon scan of global conservation issues for 2012

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Our aim in conducting annual horizon scans is to identify issues that, although currently receiving little attention, may be of increasing importance to the conservation of biological diversity in the future. The 15 issues presented here were identified by a diverse team of 22 experts in horizon scanning, and conservation science and its application. Methods for identifying and refining issues were the same as in two previous annual scans and are widely transferable to other disciplines. The issues highlight potential changes in climate, technology and human behaviour. Examples include warming of the deep sea, increased cultivation of perennial grains, burning of Arctic tundra, and the development of nuclear batteries and hydrokinetic in-stream turbines.

Horizon scanning is the systematic search for incipient trends, opportunities, challenges and constraints (henceforth 'issues') that might affect the probability of achieving societal goals and objectives, such as those related to the maintenance of biological diversity, in the longer term [1]. The objectives of horizon scanning are to anticipate issues, accumulate reliable data and knowledge about them, and thus inform policy making and implementation.

Horizon scanning has highlighted both emerging issues and events that have a low probability of occurring but that, if they did occur, would have substantial effects across a range of fields, including medicine [2,3], epidemiology [4], business [5] and criminology [6]. For example, new technologies and developments in medicine are identified using horizon scanning and then presented to the medical profession, so speeding their uptake [2,3]. The method has also been applied to conservation of biological diversity at national [7,8] and global [9–12] scales, and to environmental legislation [13].

Horizon-scanning exercises, together with efforts to identify research questions better aligned with the needs of policy makers, may increase the likelihood that relevant research findings are available when decisions are made [14]. Scientific research may, however, affect policy in at least three different ways [14]. First, conceptual effects change the thinking of policy makers. Second, instrumental effects provide information that directly affects a policy, regulation, or decision about resource allocation. Third, symbolic effects provide new information that reinforces existing policy positions. However, there is likely to be

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little agreement on ecological, economic, or social objectives when scientific knowledge is limited and policy issues are poorly specified [14]. If scientific knowledge increases but clarity of policy issues does not, then the results of research may be used symbolically to meet partisan objectives. Horizon-scanning exercises have the potential to encourage further research and to open the debate over options. In this way, they may be expected to increase conceptual effects and the probability of instrumental effects [14].

Here, we present 15 emerging issues that could affect biological diversity (i.e. the full range of life on Earth, and the ecological and evolutionary processes that support it). The issues were identified during a third annual horizon-scanning exercise. Several of the 15 issues identified for 2010 and 2011 have already become prominent in policy and industry, but their potential effects on biological diversity are not yet apparent. For example, hydraulic fracturing, highlighted in the scan for 2011 [11], has now been banned in France. Dutch scientists hope to produce sausages and burgers from synthetic meat, identified in the scan for 2010 [9], within a year (http://www.telegraph.co.uk/science/science-news/8733576/First-artificial-burger-to-cost-250000.html). A research team in Britain is planning the first major empirical test in the world of a method for injecting particles into the stratosphere (i.e. stratospheric aerosols [9]; http://www.guardian.co.uk/environment/2011/aug/31/pipe-balloon-water-sky-climate-experiment?CMP=NECNETTXT8187). Additionally, the city of Melbourne (Australia) is building a commercial biochar plant [9] to convert organic and wood waste into energy and to sequester carbon dioxide (http://www.smh.com.au/national/melbourne-to-get-first-biochar-plant-20110905-1ju9m.html#ixzz1YhKikE00).

Participants in each horizon scan have grappled with identifying issues that are poorly known and yet may have substantial future effects on biological diversity. In practice, the primary criterion for excluding an issue was that it was well known. For example, Hölker *et al.* [15] suggested that light pollution should have been identified as an issue for 2010 [9]. In fact, participants in the scan for 2010 discussed light pollution, but did not include it in the final set of 15 issues because 94% of the 23 participants were aware of it.

Identification of issues

Twenty-two individuals participated in the scan for 2012. These included professional horizon scanners, conservation scientists and a journalist. Many of the conservation scientists have specialised expertise, whereas some of the participants are employed by large organisations with broad missions and, therefore, have ready access to colleagues who could assist with identification of a diverse suite of issues.

We followed a democratic and transparent process to identify issues [10]. Each participant, independently or after consulting colleagues, identified and summarised one to five emergent issues that might affect the probability of maintaining species or ecosystems. We estimate that at least 253 people contributed to the identification of issues. The resulting set of 80 issues was circulated among the 22 participants. Each participant indicated whether they were aware of each issue and independently scored each issue from 1 (unlikely to have a substantial effect on biological diversity or considered well known) to 1000 (might have a substantial effect on biological diversity but not well known) and were asked not to give more than one issue the same score. Each participant's scores were converted to ranks. The 35 issues with the lowest mean ranks were retained.

Participants were also invited to identify any of the 45 discarded issues they thought warranted further consideration; six such issues were identified. Two groups of two and one group of three issues in the retained set of 35 were extremely similar and hence combined. The 37 issues remaining were assessed at a workshop in Cambridge (UK) in September 2011. For each issue, two participants were asked to review the literature and use expert judgment before the workshop to assess novelty and potential effects of the issue on biological diversity. If a participant had proposed the issue, they were not asked to conduct its review and were not among the first two people to discuss it. At the end of discussion, each participant again scored each issue from 1 to 1000. At this stage, the proportion of participants who had heard of each issue was considered in the scoring process. Scores were converted to ranks, and the 15 issues with the lowest mean ranks were retained.

The 15 issues for 2012 are listed below, but not in rank order. We do not specify all of the potential effects on biological diversity because possible effects are often unknown. We aim to present each issue as neutrally as possible, and acknowledge that most issues may have positive or negative effects on biological diversity as a function of, for example, how a new technology is deployed.

The issues for 2012

Warming of the deep sea

The mean temperature of several of the abyssal ocean basins of the world (i.e. those below 4000 m) and in the deep Southern Ocean (1000–4000 m) is increasing substantially, while also making a measureable contribution to sea-level rise of 0.1 mm per year globally and 1 mm per year in the Southern Ocean through thermal expansion [16]. The change in temperature is poorly monitored in time and space because even the newest observational instruments, such as robotic profiling floats and gliders, cannot operate below 2000 m. Detailed mechanisms for the increase in temperature are unknown and, therefore, future changes in temperature cannot be projected reliably. Strengthening inferences will require observations and modeling of interactions between ocean ice and the atmosphere in the Antarctic, and of processes that control the export of dense waters from relatively high to low latitudes. The actual changes in temperature have been small to date, but there is little information on the response of deep-sea organisms to such temperature changes. Additionally, more rapid transfer of surface waters to deeper oceans may lead to more rapid acidification of the deep ocean waters than had been projected. Shallow marine systems worldwide could also be affected by responses of surface or shallow currents to temperature-induced changes in deep-sea circulation.

Mining in the deep ocean

Global demand for rare-earth elements is increasing rapidly because they are necessary to produce electronic equipment, including relatively novel products, such as solar cells. It has been suggested that limits on the export of rare-earth elements imposed by the Chinese Government will lead to a global market shortage, which in turn may result in prospecting for deposits in the deep oceans. Exploratory drilling in deep-sea mud on the floor of the eastern, south and central North Pacific Ocean at depths of between 3500 and 6000 m has revealed extensive deposits of rare-earth elements, such as lanthanum and yttrium, and other metals [17]. One location was estimated to contain sufficient quantities that 1 km^2 could provide one-fifth of the current annual global demand for these elements. Additionally, hydrothermal vents may have economically viable reserves of metals, such as copper and gold [18].

Methane venting from beneath the ocean floor

Large volumes of methane, a powerful greenhouse gas, are trapped in high-latitude sediments in both terrestrial and marine environments. Their release, linked to the melting of surface layers of permafrost and of deeper ocean marine hydrates, could be a potential driver of irreversible changes in climate [19]. Several sources of evidence now suggest that methane is being vented from beneath the sea in response to increases in global temperature [20]. Rather than being held beneath the deep sea at high pressure, this source of methane has been trapped by permafrost under relatively shallow water. Plumes of methane have also emerged from the sea floor at depths of 150–400 m around the Svalbard archipelago, where the temperature of the West Spitsbergen current has increased [21]. Much of the methane is likely to be derived from methane hydrate in extensive sediments beneath the seabed; hydrate is being destabilised by increases in the temperature of bottom waters. Beyond the potential effect on climate, mass destabilisation of hydrate reservoirs and subsequent increases in methane concentrations could cause widespread regional ocean deoxygenation, particularly in circumpolar basins.

Climate-driven colonisations in Antarctic waters

For as long as 14 million years, Antarctic continental shelf waters have been colder than the deeper waters of the Southern Ocean, and shell-crushing predators have been absent from the continental shelf [22]. However, mean ocean surface temperatures around Antarctica have increased by 0.6 °C since 1950 and the temperature of shelf waters on the Antarctic Peninsula is increasing at a rate of 0.01 °C yr^{-1} [23], increasing the probability that cold water-intolerant species will occupy shallow Antarctic waters. A few red king crabs *Paralomis birsteini*, typically found at depths of 2000–3000 m off the continental slope, were discovered at a depth of approximately 1900 m in 2003 [24] and approximately 1100 m in 2007 [25]. In 2010, densities of king crabs *Neolithodes capensis* exceeding 10 000 crabs km^{-2} (densities similar to those of commercial fisheries around Alaska and South Georgia) were observed on the continental slope above 850 m [23]. These predators, and other future colonists, could affect the distinct assemblages of Antarctic molluscs that have evolved in the absence of shell-crushing predators. High crab densities could also attract interest from fishing industries and create pressure to reduce protection of the Southern Ocean.

Increases in pharmaceutical discharges as human populations age

The demographic trend towards ageing populations in many countries is resulting in marked increases in the quantity and diversity of pharmaceuticals and their metabolites released into the environment. In the UK, the quantity of pharmaceuticals used by humans is expected to more than double by 2050 [26]. The quantity of veterinary medicines required to support increases in food production for a growing human population is also expected to rise. Increasing wealth and economic development in many parts of the world, coupled with ready availability of low-cost generic pharmaceuticals, also are likely to increase drug use and subsequent discharge [27]. Early concerns regarding pharmaceuticals in the environment focused on the feminisation of fish by components of oral contraceptives [28]. More recently, the presence of antibiotics in freshwater and coastal environments has been linked to the spread of antibiotic resistance [29]. An increasing range of pharmaceuticals is currently detectable in the environment. These include statins, anti-hypertensives and cancer chemotherapy agents, reflecting treatments administered to an increasing number of people over 50 years of age. The effects on non-human species of increasing concentrations of current and new pharmaceuticals (e.g. nanomedicines), particularly in complex mixtures, have yet to be assessed.

Sterile farming to increase food safety

Following the 2006 outbreak of *Escherichia coli* O157:H7 caused by consumption of raw spinach in California, food and farming industry representatives developed the California Leafy Green Products Handler Marketing Agreement (LGMA), a series of operating procedures intended to reduce microbial hazards to humans [30]. Although grower participation is voluntary, buyers of 99% of the volume of leafy greens, such as lettuce and spinach, produced in California now require LGMA-adherent practices. Produce buyers in Arizona implemented a similar agreement. Although the role of wild animals as vectors in the 2006 outbreak is unknown [31] and their significance as vectors of crop-borne zoonoses is debated [32–34], reducing the number of wild animals present in agricultural fields is an LGMA focus. Recommended LGMA practices include bare-ground field buffers, non-crop vegetation removal, poisoning of water sources for wild animals, poisoned bait stations, traps and animal-impenetrable fencing. Some growers have abandoned, or plan to abandon, previously adopted measures to conserve species and watersheds, such as riparian restoration and reuse of irrigation water [30]. The US Department of Agriculture is currently drafting a national voluntary standard for the production of leafy greens, and similar measures may be adopted by other countries.

Transferring nitrogen-fixing ability to cereals

Synthetic fertilisers played a major role in increasing agricultural productivity during the 1900s, but had substantial undesired effects on terrestrial and aquatic ecosystems [35]. Projections suggest that, unless alternative production systems are developed, these effects will increase as a consequence of meeting the global food demand expected by 2050 [36]. For cereals, a possible alternative to synthetic fertilisers that is actively being developed is genetically engineered crop plants that are able to fix their own nitrogen through symbiosis with nitrogen-fixing bacteria [37,38]. Reduced fertiliser application is likely to reduce the eutrophication of terrestrial, aquatic and marine ecosystems. It is unclear whether the ability to plant cereals that fix nitrogen will increase or decrease rates of conversion of land to agricultural use. On the one hand, the technology may allow farming to resume or continue on agricultural land with depleted nutrients. On the other hand, the technology might allow the expansion of agriculture into areas with nutrient-poor soils. Widespread cultivation of nitrogen-fixing cereals will almost certainly affect soil biota and function in ways that currently are difficult to predict.

Increased cultivation of perennial cereals

Although a range of perennial crops exist (e.g. apples and bananas), agriculture is dominated by annual crops, especially cereals (e.g. wheat, rice, maize and sugar cane). There is, however, increasing interest in the development of perennial cereals to increase food security [39,40]. Although yield is lower than that of conventional annual varieties, perennial cereal crops have considerable potential on marginal land, especially in arid and semi-arid ecosystems. Compared with annual cereal crops, perennial cereals can provide a stable yield, generate biomass for fuel or livestock feed, increase carbon sequestration and species richness, and reduce costs of seeds, fertilisers and herbicides [40]; perennial crops may be a target for pests and pathogens. Replacing annual with perennial cereals may also reduce soil erosion and water contamination, for example from leached nitrates [41]. The extensive cultivation of perennial cereal crops in arid and semi-arid ecosystems has the potential to reduce desertification and water demand, and to use soil nutrients more efficiently compared with annual crops; it may lead to expansion of agriculture to areas that were previously unsuitable. Although many of the potential effects of increased cultivation of perennial cereals on ecosystem services can be identified, those on species are less clear.

Rapid and low-cost genomic sequencing

The technologies for sequencing genetic material are improving rapidly, with costs decreasing by at least 50% every 2 years. When the Human Genome Project was completed in 2003, sequencing 1 Mb of DNA cost approximately US$2500, whereas the cost is now US$0.32. New technologies now allow genomes (i.e. the total genetic material of an individual) to be sequenced in weeks rather than years. It is likely that such technological advances will continue for some time, revolutionising the extent to which genomes can be decoded. Genomic sequencing can be used to estimate the status of populations and species in terms of environmental stress levels and the expression of important genes. In Antarctic marine species, for example, genomic studies demonstrated that expression of genes for heat shock proteins, which protect cells from warming, is absent in many species [42–44]. The number of sequenced genes that affect responses to stress in an Antarctic clam increased from four in 2008 to 300 in 2009, and to 18 500 almost a year later [43,45,46]. New sequencing methods also allow genome-wide genetic variability in populations to be screened, enabling both genetic status and stress levels to be determined at levels from the individual to species.

Electrochemical sea water desalination

Emerging techniques for desalinating brackish and sea water require less energy than the standard techniques of distillation and reverse osmosis, which require energy intensive recirculation systems and high pressure pumps, respectively. A new seawater desalination system has been developed at a demonstration plant in Singapore to produce drinking water to World Health Organisation standards. Electrochemical desalination uses an electric field to draw sodium and chloride ions out of the water across ion exchange membranes. The system uses 50% less energy than current desalination technologies [47] and, therefore, is relatively low cost. This technology may enable some countries with freshwater shortages to increase their delivery of safe drinking water to large population centres. Where large desalination plants are impractical, such as in disaster situations or resource-poor countries, small, portable and even battery-powered desalination systems are possible, given the development of a simple microfluidic device to desalinate sea water with a power consumption of less than 3.5 Wh l^{-1} [48]. Increased access to water could lead to the expansion of agriculture and urbanisation of arid landscapes. There is also the potential for extracting brackish water to supply desalination plants.

Rapid development and extensive application of graphene

Graphene is a crystalline, one atom-thick carbon film. Optically transparent, chemically inert and an excellent conductor, it is the thinnest and strongest material ever tested [49,50]. Graphene has become a focus of research and development in many industries, and synthesis and processing methods are developing rapidly [51]. Materials such as polystyrene, plastic, grass and even insects have been used successfully to obtain high-quality graphene [52]. Because graphene is so light and strong, it could have monitoring applications, such as lightweight tracking devices, improve renewable energy production, and reduce the carbon emissions of industrial products from aircraft and satellites. Given the magnitude of research on the production of graphene and its applications, products might be in the home within 2 to 3 years [53]. As a pure and inert carbon material, industry believes that graphene is non-toxic to animals and that its extensive disposal is safe, but only a handful of studies have focused on its environmental effects, with some indicating that it may be toxic to vegetable seedlings [54] and reduce the viability of animal cells [55,56].

Nuclear batteries

Nuclear batteries, which rely on the continuous decay of radioactive elements, promise to provide safe, cheap and almost limitless energy. Recent developments include a nuclear battery the thickness of a penny (http://news.bbc.co.uk/1/hi/technology/8297934.stm) holding a million times the charge of a standard battery and providing power for hundreds of years, and a refrigerator-sized battery producing 25 MW, enough to power approximately 20 000 homes [57]. Such batteries are currently used for military, aerospace and medical applications, but could also power desalination plants and ships, and provide energy to remote communities, especially in low-income countries that lack energy infrastructure, such as regional or national electricity grids. Although nuclear batteries contain only small quantities of nuclear material, little is known of the potential effects of multiple small sources of radioactive waste. Nuclear batteries could help meet some of the expected increased energy demands [58] with very low greenhouse gas emissions and reduced toxic waste compared with traditional nuclear power plants and without the need to invest in extensive power infrastructure. This increased availability of energy may change some land use patterns. Nuclear batteries could power mobile electronic devices, including those for remote environmental monitoring.

Effect of increased cement demand on karst forest and cave ecosystems

Global cement demand is projected to increase by 4.1% per annum to 3.5 billion tonnes in 2013 despite the western financial crisis [59,60]. Cement production rates in Southeast Asia are rising the fastest within tropical regions [61]; cement production in China is currently rising at 10% per annum, and consumption in Vietnam grew by 39% in 2008 [59]. Many infrastructure projects, such as the construction and maintenance of dams, bridges, ports, buildings and roads, require the quarrying of limestone for cement. Limestone is the substrate of karst forest and cave ecosystems, which cover approximately 400 000 km^2 in Southeast Asia alone [62]. The fauna and flora of karst ecosystems are adapted to a highly alkaline environment and exceedingly dry soils. The fauna includes diverse, geographically restricted species, such as cave invertebrates and bats [63]; for example, 28 species of obligate, narrowly endemic cave-dwelling invertebrates occupy a single cave in Southeast Asia [64].

In-stream hydrokinetic turbines

Methods for generating in-stream hydrokinetic electricity, such as turbines anchored to a river bottom, were designed to reduce the undesirable environmental effects associated with conventional hydropower dams and reservoirs. In British Columbia, over 8000 potential sites for in-stream turbines with a potential installed capacity of over 12 000 MW and annual energy yield of nearly 50 000 GWh per year have been identified [65]. Hydrokinetic energy may provide renewable energy and is regarded as an important technology for rural communities; it may be more cost-effective to use decentralised systems to deliver energy to people living over 20 km from the electric grid [66]. Although there are over 100 designs for hydrokinetic technologies, few have been developed or tested within rivers [67]. Their potential effects are not fully understood and may include changes in hydraulic regimes, structure of river bottoms, sedimentation, population dynamics of fish, noise levels and electromagnetic fields. The toxicity of chemicals associated with turbine manufacture and maintenance also are poorly understood [68]. A life-cycle assessment of one hydrokinetic energy extraction system, the Gorlov helical turbine, showed that its effects and greenhouse gas emissions were comparable to those of a small hydropower plant [69].

Burning of Arctic tundra

The Arctic permafrost has long been regarded as relatively stable, and stores an estimated 14% of the soil carbon of the world [70]. However, in 2007, the Anaktuvuk River fire burned over 1000 km^2 of tundra in Alaska; lake sediment core analysis indicated that the quantity of soil organic matter consumed during the fire was highly anomalous over the past 5000 years [71]. The frequency and extent of fires in the Arctic tundra may increase during periods of both relatively high summer temperatures and low precipitation, and extensive fires might be linked to a rapid reduction in cover of sea ice in response to increases in air temperature throughout the Arctic [71,72]. One effect of an increase in the frequency and extent of tundra fires is an increase in nutrient availability, which may facilitate the expansion of shrubs and further increase the frequency and severity of fire.

Discussion

The 15 issues identified in this horizon scan highlight potential effects on biological diversity of changes in climate, technology and human behaviour. Inevitably the composition, background and interactions among participants affect the identification of issues in a horizon-scanning exercise. However, we believe convening a diverse group, thoughtfully critiquing the issues and making decisions through two rounds of anonymous scoring, reduced subjectivity.

Potential changes in human uses and abiotic attributes of oceans, particularly in the deep sea, emerged strongly in this horizon scan. This is not explained by a shift in composition of the participants because only two or three marine scientists participate each year. Instead, the rise in the number and range of deep-ocean issues identified may stem from a confluence of circumstances, including the continuously increased technical capacity of humans to monitor, explore and exploit the deep sea. The end of 2010 also saw the conclusion of the decade-long Census of Marine Life (http://www.coml.org/), which facilitated research and discovery of deep-sea environments, such as abyssal plains, hydrothermal vents and mid-ocean ridges, and brought them to the attention of the public. Increased awareness of the deep oceans may have prompted participants to offer the marine issues presented here. Given the importance of oceans for global climate regulation, it is not surprising that issues relating to ocean temperature predominate. Increases in deep-sea temperature and methane venting may affect humans and other species worldwide as, for example, in the colonisation of the continental shelf of the Antarctic by species that have not occurred there for millennia.

Many other issues identified in the horizon scan reflect the emergence and application of new technologies. Graphene, nuclear batteries, perennial grains, modifications to the nitrogen-fixing capability of cereals, hydrokinetic energy and low-cost desalination systems all offer potential benefits to humans. We think that it is likely that their rate of deployment will be determined mainly on the basis of economic criteria rather than their potential effects on biotic and abiotic attributes of the environment.

The rapid development of technologies without concomitant anticipation of their environmental effects is a recurring theme in the issues raised here. Our objective is to explore possible future changes, identify possible effects and provide ideas and track research with the aim of better understanding the effects of the issues identified.

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