A Horizon Scan of Global Conservation Issues for 2015

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This paper presents the results of our sixth annual horizon scan, which aims to identify phenomena that may have substantial effects on the global environment, but are not widely known or well understood. A group of professional horizon scanners, researchers, practitioners, and a journalist identified 15 topics via an iterative, Delphi-like process. The topics include a novel class of insecticide compounds, legalization of recreational drugs, and the emergence of a new ecosystem associated with ice retreat in the Antarctic.

Aims and methods of horizon scanning

Horizon scanning is the systematic search for, and examination of, potentially significant medium- to long-term threats and opportunities within a given field or discipline (Sutherland and Woodroof 2009, Amanatidou et al. 2012). A key objective of horizon scanning is to reduce the probability that society will be confronted with unexpected social, technological, or natural changes. An additional core objective is to allow time for policy and technological responses to those changes (Konnola et al. 2012, Sutherland et al. 2012a). This is the sixth annual assessment of emerging global environmental or conservation issues (e.g., Sutherland et al. 2010, 2014).

Horizon scanning is becoming more prevalent and policy-relevant. A prominent example of its use in environmental policy is inclusion of horizon scanning in the 2013–2015 work plan of the scientific and technical review panel of the Ramsar Convention (Ramsar 2013). Horizon scanning also is employed by the Australasian Joint Agencies Scanning Network, which convenes members from approximately 20 Australian and New Zealand environmental and other government agencies (Delaney and Osborne 2013). A horizon scan for zoos and aquariums conducted in 2013 (Gusset et al. 2014) illustrates the potential to apply horizon scanning to specific environmental sectors. Moreover, horizon scanning is used by some governments to anticipate emerging issues across a broader set of sectors, such as health, energy, security, business, and technology. For example, a cross-departmental horizon scanning programme was established by the UK government in 2013, and two teams within the government-funded Korean Institute of Science and Technology Information are dedicated to identification of emerging trends (Kim *et al*. 2013).

Since our annual horizon scans began, scanning methods have been recognised as a central element of general futures research (Bengston *et al*. 2012). Different methods to identify and select issues have been tested, including automated web-crawlers (Palomino et al. 2012), text-mining, and Bayesian network models (Amanatidou et al. 2012; Kim *et al.* 2013). The output from such automated searches still must be classified, analysed and prioritised by experts. Amanatidou*et al*. (2012) identified focused expert review and Twitter as the only two highly useful and appropriate tools for the initial scanning stage. Our horizon scan identified weak signals (warnings, events, and developments for which effects or responses cannot yet be estimated accurately) or emerging issues (conceptions of the future that are relevant to political debate) (Amanatidou et al. 2012) on the basis of scanning carried out by experts across professional networks, followed by expert review. We did not attempt further clustering or processing of these issues.

The main purpose of our horizon scans is to alert policy-makers and researchers to possible future environmental or conservation issues, thus enabling them to prepare their policy responses or begin preliminary research. It is difficult to trace responses directly to our horizon scans given that emerging trends tend to become apparent from many sources simultaneously. Additionally, it is likely that our identification of topics coincides with, rather than instigates, political and public awareness of those topics. Nonetheless, there are examples of policy responses to various issues in the years following our identification of the topic in a horizon scan. In 2010, we raised the issue of the potential environmental effects of nanosilver. In 2014, the European Commission's Scientific Committee on Emerging and Newly Identified Health Risks published an opinion on the health and environmental effects of nanosilver, including possible environmental risks and suggestions for further research (SCENIHR 2014). In the 2011 horizon scan, we discussed the increasing atmospheric concentrations of nitrogen trifluoride (NF_3), a new and powerful greenhouse gas. In 2013, $NF_3$was added to the Greenhouse Gas Protocol as the seventh gas for which emissions should be reported (World Resources Institute 2013).

Issues that are identified during future scans may contribute to the priorities of the International Platform on Biodiversity and Ecosystem Services. This platform, an independent intergovernmental body open to all member countries of the United Nations, aims to facilitate communication among the scientific community, governments, and other stakeholders on biological diversity and the services it provides to humans.

Identification of issues

As in previous years, we used a modified Delphi technique to identify topics. This method was developed for systematic forecasting and is inclusive, transparent, and repeatable (Rowe & Wright 1999, Sutherland et al. 2011b).

The 18 core participants in the horizon scan (the authors) included professional horizon scanners, experts in a range of disciplines relevant to conservation science and a journalist. Participants were affiliated with organisations with diverse research, management, and communications mandates. Each participant proposed and described at least two topics, either alone or following consultation with others, that met the criteria of global relevance and limited awareness within the conservation community. Two of the core participants monitored a range of environmental and technological Twitter accounts as part of their scanning strategy, as recommended by Pang (2010) and Amanatidou*et al*. (2012). A total of 270 individuals was consulted in the identification of 83 topics, which then were circulated to the core participants. Each participant 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 the scores we produced a ranked list of topics for each participant and then calculated the average rank for each topic across participants. We retained the 35 topics with the highest mean ranks plus one additional topic that participants thought warranted further consideration. For each of those 36 topics, two participants, neither of whom had proposed the topic, further researched the technical details and the potential that the topic would become prominent.

The core participants gathered at a meeting in Cambridge, UK, in September 2014. We discussed each of the topics in turn, with the constraint that the individual who suggested a given topic was not among the first three people to contribute to its discussion. After each topic was discussed, participants independently and confidentially re-scored the topic as described above. Here, we present the 15 topics that had the highest mean ranks after the discussion. Related topics are grouped rather than presented in rank order.

The topics

Compounds that disrupt insects' capacity to sense airborne compounds

Rapid progress has been made in identifying new insect repellents and attractants. Within the past few years, it has become feasible to screen the effects on insect behavior and physiology of thousands of candidate compounds relatively quickly. Although a primary purpose of the screening has been the identification of mechanims to control agricultural pests, there may be many other applications, including development of insect repellants for human use. One such new repellent, Vanderbilt University Allosteric Agonist (VUAA1), represents a new class of compounds that activates all of an insect's olfactory receptors simultaneously. This stimulation would disrupt typical behavior and make it highly challenging for insects to detect food sources. Compounds such as VUAA1 may be thousands of times more potent than N,N-Diethyl-meta-toluamide (DEET), the main repellent now in use (Jones et al. 2011). VUAA1 is highly effective, but indiscriminate, and thus is likely to affect non-target species. Similar screening processes could lead to the development of species-specific repellants, and interest in such processes has been reported from some agrochemical companies (Doughton 2013). These repellents could markedly reduce agricultural reliance on broad-spectrum insecticides that may be environmental toxicants. However, the potential environmental effects of widespread use of compounds that stimulate insects'olfactory systems remain to be explored. Because some insects rely on smell to reproduce, locate food, and avoid predators, the biological effects may be substantial.

Bioplastics from waste

Plastics derived from renewable, plant-based feedstocks (*bioplastics*) offer an alternative to petrochemical-based plastics. Current production of bioplastics largely relies on agricultural production of feedstocks such as sugar cane, maize, and switchgrass (*Panicumvirgatum*). Rising demand for these products may affect the global pattern of crop production or, as a result of competition for land, lead to conversion of natural ecosystems (Colwill et al. 2012), with potential effects on the viability of ecological processes and individual species. Bioplastics produced from bacteria that feed on carbon dioxide and methane recently have been developed. These bioplastics include the biodegradable polyhydroxybutyrate (van der Ha 2012) and high-density durable polyhydroxyalkanoates suitable for toys and mobile-telephone cases (Fruth et al. 2014). Durable bioplastic from waste methane is already available, marketed by one firm as carbon negative furniture (see http://www.usatoday.com/story/news/nation/2013/12/30/plastic-from-carbon-emissions/4192945/). Polyhydroxyalkanoate technologies may not yet be economic relative to technologies that derive plastics from fossil fuels (Tan *et al*. 2014), but the commercial feasibility may improve if biological waste streams can be used as feedstock. The industrial sector predicted a 25% annual growth in global demand for bioplastics by 2017, driven in part by high oil prices (SmithersRapra 2012). Cheap supplies of oil and gas may hamper substantial growth in the market share for bioplastics, but market factors rapidly could be affected by policy interventions. A bioplastics industry independent of fossil fuel feedstocks and agricultural land could grow rapidly.

Algae as a replacement for palm oil

In recent years there has been much interest in the possible applications of oils produced by genetically modified algae (Harun et al. 2010).Initial interest focused on biofuels produced from algae and the environmental consequences of this technology (Slade & Bauen 2013), but these biofuels still may be years away from commercial realisation. Meanwhile, other applications for algal oils, most notably as a substitute for palm oil, have begun to emerge. Growing pressure to reduce dependence on unsustainably produced palm oil has led to a market for replacement products; some forms of algae have been genetically modified to produce such substitute oils. The algae are grown in a bioreactor, fed with sugar, and pressed to produce oil that can be used in products such as cosmetics, foods, and detergents. Unilever has made large investments in a company that is developing algal oils for diverse uses, and a detergent containing algal oil also has been brought to market. Although substitution of palm oil with algal oil may avoid the undesirable effects associated with production and use of palm oil, there has not been a life-cycle analysis of the environmental and social effects of management of algal-oil production vats, or of land-use changes that may result from changes in the demand for palm oil and sugar cane (Yee et al. 2009, Biello 2013).

Adoption of electric vehicles

Many governments worldwide are promoting accelerated adoption of electric vehicles (IEA 2013). The market for electric vehicles is currently constrained by the high purchase prices, limited range, long recharging time, and limited infrastructure for high-density recharging (Bakker *et al*. 2014). However, these difficulties gradually are being addressed. Considerable expansion of the market share for electric vehicles could occur in the next five to ten years with supportive policies, and is likely over the longer term. Global projections of the market expansion include an intergovernmental target of 2% of passenger cars worldwide by 2020 (IEA 2013) and 16-42% of light duty vehicles (cars and vans) by 2050, depending on oil price (Babaee*et al*. 2014). Positive effects on human health and reduction of greenhouse gas emissions associated with increased adoption of electric transport are frequently discussed (e.g., Babaee*et al*. 2014), but potential effects on species and ecological processes have not been analysed. Deposition of nitrogen, generated mainly by vehicle exhausts, has long-term effects on species richness of plants in ecosystems, such as in meadows and upland grasslands, as well as provides a free input to farming (Sutton *et al*. 2011). Reduced emissions of nitrogen oxides, especially near roads with high traffic volumes, could increase the competitive advantage of plants associated with nitrogen-poor environments and will require farming to use more nitrogen fertilizer. In addition, quieter electric vehicles may reduce levels of anthropogenic sound associated with deleterious effects on populations of songbirds (e.g.

McClure *et al*. 2013), particularly species with low-frequency vocalizations (Francis *et al*. 2011).

Legalisation of recreational drugs

Government institutions at local, national, and international levels are considering, and in some cases implementing, legalisation of some recreational narcotics. The motivations for legalisation range from increasing public health and public revenue to decreasing violent crime. The potential environmental effects are diverse and difficult to predict, and may depend on the location where the drugs are produced. For example, legalisation of cocaine could reduce the power of drug cartels and hence increase access of citizens and governments to tropical forests (Reyes 2014). In some cases, the prevalence of drug production and associated lack of law enforcement is deterring logging and other forms of forest exploitation. In other cases, drug production and forest exploitation occur simultaneously (McSweeney et al. 2014), and the actions of drug-control agencies may contribute to forest conservation. Discharges of toxicants into waterways also might be reduced by legalisation of cocaine (Young 1996). It has been suggested that legalisation of marijuana in the United States will increase regulators'ability to control use of biocides that kill non-target wild animals (Gabriel et al. 2012). However, legalisation of marijuana could lead to an increase in energy use. Indoor production of *Cannabis* in the United States, both legal and illegal, was estimated to account for 1% of national energy use (Mills 2012). In Washington state, where recreational use of marijuana became legal in 2012, it has been estimated that energy demand for indoor production will more than double by 2035 (Northwest Power and Conservation Council 2014).

Underground gasification of coal

Coal can be gasified underground by injecting air or concentrated oxygen via a borehole, igniting the underground coal seam, and allowing the resulting gases to flow to the surface via a second borehole. This process of underground gasification recently became commercially viable and may enable the exploitation of up to 15 trillion tonnes of previously inaccessible coal deposits, extending the lifetime of global coal reserves by several hundred years (Self et al. 2012). Underground coal gasification also is less expensive than traditional coal mining and does not require miners to work underground (Bhutto et al. 2013). Industrial experts recommend that targeted coal seams be deep (typically under 300 m), far from groundwater sources, and hydrologically sealed (Lavis et al. 2013). Nevertheless, groundwater pollution remains a potential risk. Various waterborne toxicants have been identified, with long-term groundwater contamination observed in some locations (Kapusta & Stanczyk 2011). Although underground coal gasification has the potential to emit less fly ash and oxides of sulphur and nitrogen into the atmosphere than some other coal-mining technologies, the process produces greenhouse-forcing gases. It has been suggested the carbon dioxide emitted by underground gasification could be captured and stored (Self et al. 2012) via techniques that are in development.

Pharmaceutical-induced loss of aquatic biofilms

Biofilms, the algal, bacterial, and fungal mats that form on rocks in streamsmaking the rocks slippery,recycle nutrients and are a primary food source for invertebrates and fishes. However biofilms are sensitive to toxicants (Tiam*et al*. 2014), including pharmaceuticals (Corcoll*et al*. 2014). A study in New York, Maryland, and Indiana (USA) (Rosi-Marshall *et al.* 2013) assessed the effects of six pharmaceuticals commonly detected in surface waters in the United States on stream biofilm respiration and photosynthesis. Across all sites and seasons, biofilm respiration was suppressed by several of these chemicals, most notably by the antibiotic ciprofloxacin (91% reduction) and the antihistamine diphenhydramine (63%). In autumn in New York, exposure to diphenhydramine reduced photosynthesis and respiration of biofilms by 99.8% and 89%, respectively (Rosi-Marshall et al. 2013). Diphenhydramine also changed the bacterial species composition of the biofilms, increasing the species richness of a group that degrades toxic compounds and reducing the species richness of a group that digests compounds produced by plants and algae. These changes in species composition may affect the amount and quality of food for fishes and invertebrates. Given that the release of pharmaceuticals into waterways, via either discharge waters of production facilities or human excretion, is now common and likely to increase as the human population ages (Depledge 2011), effects on biofilms and higher trophic levels may become pervasive.

Sustainable intensification of high-yielding agriculture

Sustainable intensification of agriculture refers to the goal of increasing food production from existing agricultural areas without causing undesirable environmental side-effects (Garnett *et al* 2013). Sustainable intensification is a response to the growth and rapidly changing consumption patterns of the global human population, and has become a policy goal for a number of national and international institutions. Although it long has been clear that sustainable intensification is feasible in parts of the world where yields are generally low (for example, Pretty *et al.* 2011), research is starting to demonstrate that sustainable intensification also is possible in areas with high crop yields or animal productivity (Davis et al. 2012; Firbank et al. 2013; Pretty and Bharucha 2014). The sustainable-intensification concept does not dictate or prioritise a given vision or method of agricultural production, nor does it specify technologies, species composition, or design components. Rather, it emphasises accounting for environmental and social effects as part of the growth and profitability of agricultural businesses. In both cropped and livestock systems, it seeks to increase the supply of ecosystem services such as carbon sequestration (by conservation agriculture and management-intensive rotational grazing systems), water free of pollutants (by integrated pest management) or reduced energy-intensive fertilizer (by precision agriculture and rotations with legumes). Rapid uptake will arise as farmers increasing expand their role from solely food producers to beneficiaries of natural capital. The Water-Land-Ecosystems programme of the CGIAR and FAO aims for a paradigm shift in agricultural research towards sustainable intensification (http://wle.cgiar.org/), thus transforming farming systems from carbon sources to carbon sinks (Rockström and Karlberg, 2010).

Increases in coral disease in the Indo-Pacific

The substantial biological effects of diseases that affect corals and consequently coral reef structure, such as white band disease, are well established in the Caribbean (Alvarez-Filip et al. 2009). A growing number of publications and field observations suggest that the extent, frequency, and effects of coral-disease outbreaks in the Indo-Pacific region are increasing (e.g. Weil et al. 2012). These outbreaks may be exacerbated by human-induced changes in water quality (Pollock et al. 2014) and by stress from increasing temperatures (Harvell et al. 2007). Outbreaks have been reported from the Great Barrier Reef (Haapkyläet al 2013), and even from more remote areas, such as Palmyra Atoll (Williams et al. 2010) and the northwestern Hawaiian Islands (Aeby et al. 2011), that largely are isolated from effects of human activity. Despite the absence of long-term data, these observations raise the possibility that coral diseases may be becoming more prevalent in the Indo-Pacific, and that growth in the incidence and extent of these diseases could result in structural changes to reefs at a level previously observed only in the Caribbean (Weil and Rogers 2011).

Effects on krill of marked decline in Antarctic sea ice

Krill (*Euphausiasuperba)* is a key species in the Southern Ocean food web, and summer krill densities are positively correlated with sea-ice extent during the previous winter (Atkinson *et al.* 2004). To overwinter in sufficient abundance and condition to support higher taxonomic groups, such as fishes, squid, seals, penguins, and whales, krill are dependent on epontic algae that grow in sea ice. The largest krill populations occur along the Antarctic Peninsula and extend to the South Shetland and South Orkney Islands, where the extent and duration of sea ice has declined markedly in recent decades (Ducklow *et al.* 2013). These declines in sea ice, which could affect krill productivity, contrast with the significant increase in sea ice in the Ross Sea and a small increase in the total extent of Antarctic sea ice in recent years. Hatching rates of krill eggs also are reduced by ocean acidification (Kawaguchi *et al*. 2013). Changes in the composition of the Antarctic Treaty Nations are resulting in concomitant changes in scientific and economic priorities, including more pressure to increase the exploitation of fishes, squid, and krill in the Southern Ocean. The combination of increases in ocean temperature, acidification, loss of sea ice, and increased fishing effort may lead to substantial decreases in krill populations, with considerable effects on the Southern Ocean food web.

Novel coastal ecosystems associated with ice retreat

Permanent or seasonal ice-cover, ice scour, and battering by glacial or free-floating ice historically limited biotic colonization of the intertidal and shallow subtidal zones of the Antarctic (Bick and Arlt 2013). However, rapid decreases in the extent of glaciers and sea ice in many locations are markedly increasing coastal productivity (Peck et al. 2010). Around the Antarctic Peninsula, where changes are fastest, 87% of glacial termini have retreated in recent decades and some 28,000 km^2 of floating ice-shelves have melted (Cook and Vaughan 2010). As a result, the extent of permanently ice-free intertidal seabeds and open water is increasing. These new ecosystems could be colonised by species that have been virtually absent from Antarctica since the last interglacial (about 400,000 years b.p.), and possibly for millions of years. In time,potential colonisers could include South American limpets and bivalve molluscs,such as mussels. Some Diptera, including chironimids, may colonise the edge between aquatic and terrestrial ecosystems. Initial colonisation of intertidal benthos may be dominated by organisms already present in the region. Subsequent colonisation is likely to be affected by other processes including migration from deeper waters and from warmer areas such as sub-Antarctic Islands and southern South America (Clarke 2008). Visiting vessels and floating marine debris also will function as sources of colonists (Lee and Chown 2007). The coastline of the Antarctic Peninsula alone is 1,300km long and highly complex, representing a considerable space for development of novel ecosystems. Similarly extensive ice-dominated Arctic regions, such as Ellesmere Island and the coastline of northern Greenland, also might become targets for colonists as ice extent changes.

Increasing the legal status of non-human species

Public and scientific awareness of consciousness in animals is growing, as is the literature on sentience and welfare of vertebrates (Proctor et al. 2013, Walker et al. 2014) and invertebrates (e.g. Magee and Elwood 2013). This awareness is reflected in pressure to change the legal status and associated rights of some animal species (Miller 2011) and recently inspired lawsuits in New York State to recognize captive chimpanzees as legal persons (Siebert 2014).

Acknowledgment of the individuality and personality of animals also has led to deeper recognition of the function of culture in nonhuman societies. For example, a 2014 meeting of the Convention on the Conservation of Migratory Species of Wild Animals proposed that cultural transmission and social interactions within groups of cetaceans should be reflected in agreements and recommendations affecting these species (CMS 2014). A new perspective on animals as conscious individuals could change the ways in which many decisions relating to farmed and wild species and their habitats are made (Bekoff 2013). Increased status, whether granted legally or acknowledged in cultural norms, could lead to changes in welfare standards for domestic species, but also could lead to a rise in objections to lethal methods of controlling invasive or pest animals, as illustrated by protests over culling of mute swans (*Cygnus olor*) and Canada geese (*Branta canadensis*) in the eastern United States (Blackburn *et al*. 2010). Although this perspective may hinder pest control for broader ecological purposes, it also might increase the engagement of a large and potentially growing community of people who value animals as individuals rather than species units or functional providers of services to humanity.

Impact investing

Impact investments, a class of financial instruments intended to benefit both the financial sector and society, have grown rapidly over the last decade, and now represent an estimated US$40 billion in private-sector capital (Drexler & Noble 2013). The magnitude of investments currently focused on the environment is small, but the unmet demand for conservation finance among investors may be considerable (Vellacott & Meister 2014). If one percent of total institutional capital were directed to conservation finance, an estimated $200 to $300 billion could be raised, meeting much or even most of the global need (Huwyler*et al*. 2014).

To raise such a sum, conservation finance must mature as an asset class, much as mainstream impact investing did a decade ago. Accordingly, it will be necessary to offer investable, large-scale projects in which both financial returns —from carbon credits, ecosystem service valuations, agriculture, tourism, and other revenue-generating activities —and ecological effects are clearly defined (Vellacott& Meister 2014). Simultaneously, the success of impact investing will require financial managers and brokers to develop new types of investments, and to include conservation in the client advisory process. New regulatory policies also may be needed to value natural areas and processes (Huwyler*et al.* 2014). Additionally, conservation finance may need to navigate the tensions of mainstream impact investment, particularly over expectations of the amount of financial return, and whether non-financial benefits are a primary goal or secondary outcome (Keim 2014).

Reproducibility in Environmental Science

Many disciplines, including psychology, cancer biology and other forms of biomedicine, economics, political science, and some fields of chemistry, have difficulty replicating experimental results. Challenges to replication include a bias toward publication of statistically significant results, low statistical power, and widespread use of poor research practices, such as running many different tests until a low *p*-value is achieved (i.e., *p*-hacking; see Nuzzo 2014). Under these conditions, false positives become prevalent in the literature. For example, 47 of 53 landmark pre-clinical trials in cancer research could not be replicated (Begley & Ellis 2012). Similarly, preliminary results suggested that just 33% of published results in psychology are replicable (Nosek et al 2014). Environmental science is among the disciplines that remain dominated by null-hypothesis significance testing (Fidler et al. 2006). Less than 10% of environmental science articles reported statistical power, and more than 75% of publications included statistically significant results (Fanelli 2010). Unless the average power also was over 75%, which is unlikely, published results reflect statistical bias. In other disciplines, lack of reproducibility has received widespread media attention and reduced the perceived credibility of those disciplines. Decreases in the apparent reliability of the scientific evidence base for environmental decision-making could undermine efforts to increase the application of science to policy and practice (Dicks *et al*. 2014).

Investor-state dispute settlements in free trade negotiations

A new free-trade agreement, the Transatlantic Trade and Investment Partnership, is being negotiated by the United States and the European Union. This agreement complements the Trans-Pacific Partnership, which is in the final stages of negotiation among the United States, Japan, Mexico, Canada, Australia, Malaysia, Chile, Singapore, Peru, Vietnam, New Zealand and Brunei Darussalam. Both agreements include provisions for investor-state dispute settlement. Under certain conditions, these provisions allow foreign investors to initiate claims against a government for profits lost due to legal or regulatory changes, including those concerning the environment or public health. Such dispute-settlement mechanisms already exist in many bilateral and multilateral agreements. However, investor-state dispute settlement litigation grew globally from fewer than four cases per year before 1997 to 40 cases in 2013 (World Bank 2014). Two notable environmental investor-state dispute settlement cases are underway. The first challenges Germany’s decision to phase out nuclear power (Vattenfall AB and others v. Federal Republic of Germany (ICSID Case No. ARB/12/12)). The second, in which the Canadian government is being sued for CD$250 million, challenges Quebec’s moratorium on unconventional hydraulic fracturing of natural gas (Lone Pine Resources Inc.

v. The Government of Canada (UNCITRAL)). These cases may lead governments to avoid formulating new environmental regulations given the associated political and financial risks.

Discussion

We believe that this year's range of topics is unusually diverse. We excluded some topics because they were closely related to topics identified during previous horizon scans or because they already are well known, albeit their effects are expanding. Examples of topics we excluded are the increasing use of the chemical diclofenac in Europe (which can cause mortality of vultures and some eagle species that feed on the carcasses of livestock treated with the drug), the extension of microplastic pollution from the aquatic to the terrestrial environment (with evidence of microplastic particles in honey and rainwater), and new genetic methods and species-specific toxins to eradicate pests. Although we identified the use of algae to produce oil in a previous horizon scan (Sutherland et al. 2014), the use of algae as a replacement for palm oil (rather than as a biofuel) is novel.

Political decisions and the behaviour of economic markets are likely to be critical in determining which phenomena ultimately have substantial effects on the environment. For example, political interventions are likely to drive demand for electric vehicles or the pursuit of unconventional fossil fuels or the market for drugs. However, future policy is difficult to predict, and thus the relative effects of these developments are only theoretical at this stage.

During discussions of several technological topics, we considered trade-offs between the search for novelty and the probability of a given environmental effect. These trade-offs were particularly relevant for topics in which new innovation is frequent, such as further development of solar voltaics or car batteries. These developments could have marked environmental effects, but it is difficult to project which one of these developments that might have global relevance.

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