Trends in
Ecology & Evolution

CellPress

Review

A horizon scan of global biological conservation issues for 2022

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We present the results of our 13th annual horizon scan of issues likely to impact on biodiversity conservation. Issues are either novel within the biological conservation sector or could cause a substantial step-change in impact, either globally or regionally. Our global panel of 26 scientists and practitioners identified 15 issues that we believe to represent the highest priorities for tracking and action. Many of the issues we identified, including the impact of satellite megaconstellations and the use of long-distance wireless energy transfer, have both elements of threats and emerging opportunities. A recent state-sponsored application to commence deep-sea mining represents a significant step-change in impact. We hope that this horizon scan will increase research and policy attention on the highlighted issues.

Highlights

Our 13th annual horizon scan identified 15 emerging issues of concern for global biodiversity conservation.

A panel of 26 scientists and practitioners submitted a total of 80 topics that were ranked using a Delphi-style technique according to the novelty and likelihood of impact on biodiversity conservation.

The top 36 issues were discussed at an online meeting held in September 2021 during which issues were ranked according to the same criteria.

Our 15 issues cover impacts ranging from satellite megaconstellations to deep-sea mining.

Other emerging issues include floating photovoltaics, long-distance wireless energy, and ammonia as a fuel source.

Horizon scanning for conservation

This year, 2021, marks a particularly challenging time for a horizon scan, given the global impacts of the coronavirus disease 2019 (COVID-19) pandemic and the timing of global conventions tasked with charting humanity's path to a more sustainable future. Because COVID-19 and the global conventions are subject to considerable thought and analysis, we did not consider them as issues for this 13th annual horizon scan despite their undisputed and compounded effects on society and environmental governance. Instead, we used them as a backdrop for our scan.

The COVID-19 pandemic has already had substantial impacts on natural, social, and economic systems worldwide. Many of these impacts are known, and others will become clearer over the coming years [1]. The indirect impacts of the social effects of COVID-19 will become apparent as the next generation of conservation practitioners and academics emerges. For example, it will become evident in the coming years whether the loss of laboratory, field, or other training time has hampered research or disrupted long-term monitoring, and whether more than a year of online or suspended instruction and professional interaction has reduced practical skills and connections to nature. Societies worldwide will also be affected by the compounded effects of COVID-19, including reduced capacity building, as well as social and economic inequalities such as poverty, lack of access to education, and poor internet connections.

Human-forced climate change and losses of biological diversity are already the focus of extensive intergovernmental, investor, third-sector, and corporate initiatives. However, society did not meet any of the global biodiversity targets established by the Parties to the Convention for Biological Diversity in 2010, and it is unlikely that climate targets set in 2015 by the Paris Agreement will

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be met. The risks of insufficient action are substantial: the 2020 World Economic Forum estimated that over half of global GDP – US$44 trillion – depends on nature and is at risk from operational disruptions and devaluation of environment-dependent commodities [2]. As a positive response, various central and development banks have started to enact adaptation measures. The European Central Bank has called on states to implement a swift transition to a climate-neutral European economy to avoid the considerable costs of climate change [3]. Proposed targets include these dimensions and the drivers of biodiversity loss, and may herald greater success in meeting future targets.

Nevertheless, many realised or potential drivers of climate change, losses of species, and disrupted ecosystem function are unabated. For instance, oil fields continue to be discovered in the Arctic, where oil extraction could increase 20% by 2026 [4]. One oil company has even installed giant coolers to stabilise the permafrost to ensure that rigs remain stable while extending their efforts to extract fossil fuels [5].

Furthermore, the implementation of multilateral processes sometimes discredits them in the eyes of global society. For example, the United Nations Food Systems Summit did not account substantively for the interests of local communities and small organisations [6]. By contrast, there is growing awareness and engagement in the conservation of natural systems, with an ever-increasing gap between people's expectation of action to address climate change and loss of biodiversity, and the ambition of political decisions [7].

We anticipate a step-change in the ambition of targets for species and climate in the next several years as advocated, for example, by the Global Goal for Nature issued by the Nature Positive Coalition [8]. Nevertheless, the impact of the outcomes of global climate and biodiversity meetings focused on global environmental governance and concrete actions to mitigate environmental degradation remain unclear.

Identification of issues

For the second successive year, we held our annual horizon scan workshop online. Although this format can sometimes enable those with additional responsibilities (e.g., childcare) to participate, some participants had to engage with the group at times of day or night that are not typically conducive to professional activity. More than 18 months into the COVID-19 pandemic, we were acutely aware of how shared breaks, meals, and other in-person interactions lead to vital, spontaneous conversations. Nevertheless, the use of an online platform facilitated parallel oral and text discussions, thus enabling more information to be shared within the limited time available for discussion of each issue.

Our methods were similar to those of previous years (e.g., [9,10]) (Box 1), and continued to ensure that the consideration and selection of issues was repeatable, transparent, and inclusive. We used a modification of the Delphi technique [11] that we have consistently applied since the inaugural scan in 2009 [9].

The 2022 issues

Floating photovoltaics

Power generation using floating solar panels–('floating photovoltaics', FPVs) is increasingly being deployed across the world's waterways [12]. FPV technology could mitigate many undesirable effects of terrestrial photovoltaic installations, such as land-cover conversion, erosion, deforestation, changes to microclimates, and wildlife mortality [13]. It also could offset the demand for more environmentally damaging structures such as dams [14]. Modified waterbodies, flooded mines,

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canals, and hydroelectric power reservoirs are particularly attractive for FPVs given the existing energy transmission and transport infrastructure and that these systems have already been modified significantly by previous developments. FPVs can improve local water quality by reducing toxic algal blooms, they operate at higher efficiencies than their terrestrial equivalents owing to evaporative cooling [12], and have fewer ecological effects than alternative forms of energy production. However, the ecological impacts of shading and barriers, and their technological and economic feasibility, are poorly understood [12].

Long-distance wireless energy infrastructure

Transmission of power via microwaves or lasers over relatively short distances is not new, and wireless charging of mobile and cellular telephones is now commonplace. Recent advances in metamaterials and beam-forming may now also enable relatively long-distance wireless power transfer to become widespread in both ground and aerial environments. Trials are underway to commercialise the wireless transmission of electricity via, for example, a series of line-of-sight rectangular antennas and relay stations that use non-ionizing beams of radio waves [15,16], or lasers that supply power to remote bases and drones [17]. The technology could transmit up to hundreds of kilowatts over tens of kilometres. Most power loss, which is currently about 30%, occurs when generating the beam. Wireless energy has the potential to reduce the impact of power infrastructure (e.g., pylons and overhead wires) on ecosystems and individual animals (e.g., large-bodied birds and bats that may collide with infrastructure, sometimes leading to electrocution), and may facilitate the supply of power to remote areas. Conversely, wireless energy infrastructure could lead to further energy demand and enable commercial development in previously isolated areas.

Atmospheric effects of satellites, including megaconstellations

Commercial entities are rapidly placing an unprecedented number of communications satellites into low Earth orbit, and a greater than 50-fold increase is projected in the next decade. The Starlink megaconstellation alone has a license to place up to 42 000 satellites in orbit [18].

Because rocket launches deposit radicals into the atmosphere that damage stratospheric ozone, these megaconstellations have the potential to change the chemistry of the upper atmosphere.

Box 1. Horizon scanning methods

The scanning process (Figure I) began in March 2021 when we invited our panel of 26 scientists and practitioners to canvass their networks and colleagues and submit two to five issues that were novel, largely unknown, and likely to affect biological conservation over large areas in the next 5–10 years. This year we relied heavily on virtual meetings and communication. We used e-mail, social media platforms, virtual conferences, and networking events. With these communication methods, we canvassed at least 1200 people, counting all direct in-person or online discussions separately but treating social media posts or generic e-mails as a single contact.

Participants were asked to confidentially and independently score the long-list of 80 issues (from 1–1000 low to high), according to two criteria: its potential positive or negative impact on biological conservation and its novelty. Some participants included notes and additional links to contribute to the discussion. Voters can become fatigued when they are required to assess lengthy documents or lists. To counteract the effect of fatigue on scoring, participants were randomly assigned to receive one of three long-lists of issues, each in a different order [11]. The scores submitted by the participants were converted to ranks (1–80), and issues with the highest 33 median ranks were retained for the second round of assessment. At this stage, participants could retain an issue that was not initially ranked in the top 33. This year we retained three issues, thereby yielding 36 issues for discussion in the workshop.

Each participant was assigned up to four of the 36 issues to research in depth ahead of the online meeting, which we convened in September 2021. Despite differences in time zones and the fragility of some internet connections, the discussion was rich and detailed. Accompanying the verbal discussion was an active information exchange (e.g., providing links to articles) via a chat function. After each issue was discussed, participants re-scored the topic (1–1000, low to high) according to the criteria used in round 1. At the end of the workshop, the scores were converted to ranks and collated. The top 15 issues were identified from median ranks. Our top 15 issues are presented in the main text in thematic groups rather than rank order.

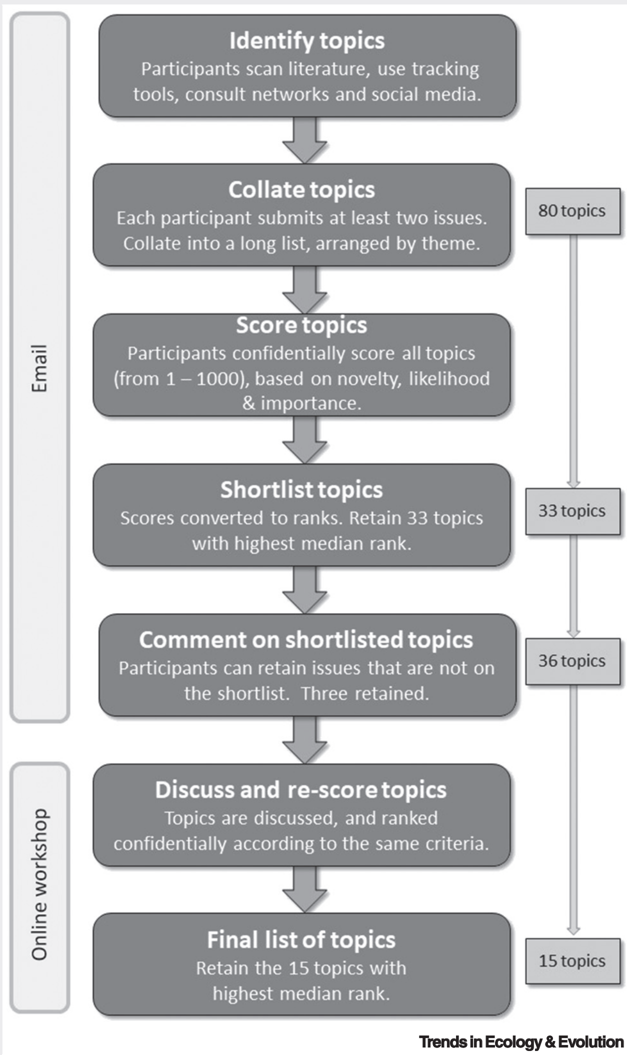

Figure I. Process for identifying and evaluating horizon scan issues.

Calculations based on Starlink satellites (mass ca 260 kg, mostly aluminium) suggest that high-altitude atmospheric aluminium deposition from re-entry will exceed natural forms and occur at a rate of 2.2 tonnes daily. The burning of aluminium that occurs during re-entry produces alumina, which is expected to further damage the ozone layer and, depending on atmospheric residence times, may increase Earth's albedo [19] and reduce warming. The development of satellite constellations may therefore weaken the protective role of ozone and influence climate change.

Potential effects of ammonia production for fuel

Ammonia is used in the production of a range of chemical compounds. It has also been proposed as a fuel, particularly for shipping [20], because it has nearly double the energy density of hydrogen, and the infrastructure for shipping and distribution exists [21]. Current production uses the Haber–Bosch process to generate hydrogen to react with nitrogen at the necessary temperature and pressure. This process accounts for ~1% of the annual production of greenhouse gases. Although the hydrogen required to produce ammonia can be produced by electrolysis using renewable energy, which does not produce greenhouse gases, there is a risk that ammonia could be promoted as a zero-carbon fuel despite the emissions generated by the conventional method of production. Given storage and transport challenges for use of hydrogen as a fuel, conversion into ammonia has also been suggested [22], but a means to convert ammonia back to hydrogen has yet to be demonstrated. Ammonia can be used directly in internal combustion engines or fuel cells, but incomplete combustion could increase emissions of oxides of nitrogen and ammonia, exacerbating air pollution and the ecological impacts of deposition of reactive nitrogen [23].

Biomonitoring with airborne eDNA

Environmental DNA (eDNA) is genetic material shed by organisms into their environment that can subsequently be used for species detection. eDNA has been used extensively in aquatic systems for monitoring species and communities. This method has recently been extended to the detection of airborne eDNA. One study [24] used this technique to monitor landscape changes in the distribution of invasive plants (including an insect-pollinated species for which the eDNA was thought to be from tissues rather than pollen), and another two studies showed the potential of airborne eDNA to detect the composition of insect [25] and vertebrate communities [26]. Although the applications, limitations, and biases need to be explored further, this approach may open opportunities including biodiversity surveys, monitoring of threatened, endangered, or invasive species, and enforcement against illegal wildlife trade.

Environmental consequences of new refrigerants

Hydrofluoroolefins (HFOs) are being marketed as zero-carbon replacements for hydrofluorocarbons that serve as refrigerants. Nevertheless, evidence is emerging that HFO decomposition pollutes air and water, and that some HFOs have a considerable greenhouse effect [27]. Decomposition of HFOs in the atmosphere forms trifluoroacetic acid, leading to trifluoroacetate in water and on the ground. Trifluoroacetate deposition rates in 2018/2019 and 2019/2020 in Germany were three- to fourfold higher than in 1995/1996, and trifluoroacetate persists for up to 30 years in the environment [28]. In addition, trifluoroacetate is difficult to remove from drinking water and is moderately toxic to many organisms. HFO refrigerants are formally categorised as having zero ozone-depletion potential and low global warming potential, and may therefore seem more environmentally benign than chlorofluorocarbons, hydrochlorofluorocarbons, or hydrofluorocarbons [29]. However, a dominant HFO in current use (HFO-1234ze) partially decomposes into HFC-23 (CHF_3) in the atmosphere. Accordingly, emissions of HFC-23 have been increasing, and were at their highest known levels in 2018 [27]. HFC-23 is one of the most potent greenhouse gases, and the most potent HFC [30]. Ozone-depleting pollution is persistent, but few regulatory frameworks address refrigerants.

Substituting volcanic rock for clinker in cement

Global production of cement is a substantial contributor to global emissions of CO_2 (estimated at ~8% in 2015 [31]). The demand for cement by worldwide construction projects is likely to increase. Most cement contains clinker, a binding material derived from limestone at high heat in the process that generates about half of all CO_2 emissions from cement production. Removal of limestone karst for use as clinker or for other reasons has been associated with losses of species and populations, including local endemics. Proposed substitutes for clinker that would generate fewer emissions include some types of volcanic ash or rock with low calcium and high alkali content, as well as fly ash [32]. Such volcanic material may also make cement highly resilient to cracking [33]. In our 2012 horizon scan we noted that increasing demand for cement could deplete limestone and negatively affect karst ecosystems [34]. Limestone substitutes would reduce these impacts. However, the potential ecological effects of mining, processing, and transporting volcanic ash for use in cement, including the emissions associated with its production, have not been explored in detail.

Challenges to the regulation of new systemic insecticides

The neonicotinoid class of systemic insecticides threatens insect populations through exposure of non-target groups such as bees (e.g., [35,36]). These effects have led to restrictions on the use of neonicotinoids in some regions, including those encompassed by the EU, where four common neonicotinoids (imidacloprid, thiamethoxam, clothianidin, and thiacloprid) are banned from outdoor agricultural use. New types of systemic insecticide are coming to market to replace neonicotinoids. These insecticides have the same mode of action as neonicotinoids (agonists of nicotinic acetylcholine receptors to target the insect nervous system), but different chemical structures. The new compounds include flupyradifurone and sulfoxaflor (the first butanolide and sulfoximine-based insecticides, respectively) which have been registered for agricultural use [37]. Emerging evidence indicates that field-realistic exposure to these new chemical classes also has substantial sublethal effects on bees and predatory arthropods [38], and therefore will have effects on non-target species that are similar to those of neonicotinoids.

Biological invasions by invertebrates that become clonal in captivity

The ecological effects of non-native invasive species have long been a global focus. The marbled crayfish *Procambarus virginalis* probably evolved clonal parthenogenetic reproduction while in the captive aquarium trade [39]. Parthenogenicity has major consequences: a single individual can establish a new population and therefore spread more rapidly; without the need for males, populations can grow more quickly. *P. virginalis*, that acts as a disease vector for native crayfish, was first reported in the wild in 2003 in Karlsruhe, Germany, and was only formally described as a species in 2017. Since then it has spread rapidly across Europe, Africa, and Asia, with populations expanding from two countries in 2012 to 12 countries, including Madagascar and Japan, by 2020 [40,41]. With growth in human cultivation of invertebrates for food and other services, the potential for evolution and escape into the wild and subsequent rapid spread of other clonal species is increasing.

Government intervention as a means to change human diets

Plant and animal cultivation for human food accounts for ~28% of anthropogenic greenhouse gas emissions and is a leading driver of losses of native species worldwide [42]. A major shift to plant- or fungus-based foods might mitigate climate change and reduce agricultural expansion into natural areas, but may require government action or facilitation [43]. Nations are beginning to act. For example, to combat its national increase in meat consumption (349% since 1960) and to contribute to achieving its carbon targets, in 2016 the central government of China set a goal of halving meat consumption by 2030. This goal has promoted major innovations in synthetic meats at prices comparable to real meat, initiating mainstream use of highly processed synthetic meat alternatives [44]. Media campaigns have been launched to increase demand for non-animal products, causing younger generations to see meat-free options as healthy and fashionable. There has also been considerable government investment and creation of incentives for businesses to promote animal-free alternatives, including replacement of meat in some schools. As a result of these initiatives, the Chinese domestic plant-based meat industry was valued at 6.1 billion yuan (910 million United States Dollars) in 2018, reflecting a 14.2% increase since 2017, and has a projected annual growth of 20–25%.

Growth in rural social capital leads to national transitions towards conservation and sustainability

Social institutions shape biodiversity and conservation outcomes. The collective governance of natural capital by local groups benefits species, ecosystems, and productivity, and is an essential part of sustainable development [45], but can be eroded by the multinational political economy. A global assessment [46] of the past 20 years of government, non-governmental, and third sector projects provided evidence that the number of new social groups has increased from 0.5 million (2000) to 8.5 million (2020), positively influencing the management of 300 Mha. This growth in rural social capital has enhanced the sustainable management of forests and agricultural systems, the use of water, and the development of distributed renewable energy sources such as solar photovoltaics [47]. The magnitude of this increase, the trend of increasing support from policymakers, and the greater focus on sustainability are expected to lead to significant conservation impacts over the next few decades.

Transition towards extensive wetland protection and restoration by China

Loss of wetlands is especially stark across the East Asian–Australasian Flyway (EAAF) where rapid conversion of spatially extensive coastal and inland wetlands to other land uses has resulted in high rates of their loss [48]. The Flyway supports the world's greatest species richness and abundance of threatened migratory waterbirds, including species designated as Critically Endangered by the International Union for Conservation of Nature, such as spoon-billed sandpiper *Calidris pygmaea* [49]. The recent inclusion of Yellow Sea tidal wetlands in China and the Republic of Korea on the World Heritage List, and long-term financial commitments by China to extensive protection and restoration of coasts, major rivers, high elevation and floodplain lakes, and other wetlands, have greatly increased wetland protection across the region. Links between such increases and changes in national environmental governance can result in increases in waterbird populations [50]. China has the world's fourth-largest wetland area [51], and the global footprint of its international development ambitions, such as the Belt and Road Initiative, is likely to grow. Accordingly, the extent and pace of ecological conservation by China within and beyond its boundaries is likely to strongly influence global wetland conservation outcomes.

Expansion of mangroves because of sedimentation from upstream deforestation

Throughout the 1990s the deforestation rate of mangroves was among the highest of all forest ecosystems [52]. Driven in part by increases in protection of the world's remaining mangroves, the rate of loss declined dramatically in most regions, with a 73% reduction in loss rates from anthropogenic causes between 2000 and 2016 [53]. Some new growth reflects natural colonisation of accreting coastal sediments, facilitated by increased rates of upstream deforestation and associated erosion, and the expansion of mangroves into higher-latitude tidal marshes and landwards as the climate warms [54], although sediment supply from deforestation may be reduced by dam construction. Mangroves are likely to expand into terrestrial systems as sea levels rise, although coastal development may limit such expansion. Depending on the change in distribution of these effects, it is possible that there will soon be no net global mangrove loss. Nonetheless, mangrove losses and gains remain unevenly distributed, and rapid losses are still reported, for example, in Southeast Asia [52].

Exceptional heat waves as potential near-term drivers of intertidal transitions

Intertidal zones are among the most extreme systems on Earth: inhabitants are resistant to considerable daily fluctuations in temperature and salinity and to desiccation, physical disturbance, and predation. Historically, mass mortality from heat waves has been rare and localised (e.g., [55]). Record-setting high temperatures during low tides in the Pacific Northwest over 3 days in June 2021 led to mass mortality of mussels, clams, oysters, barnacles, sea stars, rockweed, and other taxa over 6000 km of coastline [56]. If the frequency, duration, and intensity of heat waves increase as projected [57], many intertidal systems may not be able to adapt to conditions outside their contemporary tolerance range. Concurrent rapid changes in intertidal areas, such as salinity from altered precipitation or ice melt in polar regions, and increases in nutrient loading and eutrophication, are exacerbating stresses on intertidal ecosystems [58]. Given the vital functions performed by intertidal invertebrate species and ecosystems (e.g., maintaining water quality, providing prey for wading birds, coastal stabilisation, and food provision), mass mortality events may have a profound impact on the ecosystem services they have historically provided.

Commercial mining of the deep sea may commence in 2023

We signalled the risk of deep-sea mining in an earlier scan [34], and we now anticipate a step-change. In June 2021, the nation of Nauru notified the International Seabed Authority (ISA) that it intends to sponsor an application by Nauru Ocean Resources Inc., a subsidiary of the Canadian corporation The Metals Company, to start deep-sea mining [59]. This notification triggers a rule compelling the ISA to either adopt mining regulations within 2 years or to review any later applications under the general provisions and norms of the United Nations Conventions of the Law of the Sea [60]. Nauru's notification would be the first invocation of the ISA rule for commercial deep-sea mining. The ISA has yet to agree a regulatory framework for deep-sea mining, and the legal instruments in place by mid-2023 therefore may not provide strong environmental protection. Because Nauru is not a member of the International Union for Conservation of Nature (IUCN), it may ignore the IUCN 2021 non-binding moratorium on deep-sea mining. Although most factors governing deep-sea ecosystem function are poorly understood, mining will create an extinction risk through destruction of the habitat of a diverse suite of poorly known and geographically restricted, nodule-obligate fauna [61].

Concluding remarks

Discussing and selecting issues, especially in estimating the probability that new issues will be realised, is a challenge in horizon-scanning exercises. Many of the issues we have discussed have emphasised new chemicals (such as new refrigerants and pesticides) and their impacts, marking a continuing misalignment between development, comprehensive assessment and regulation: new compounds are developed and permitted before the full suite of risks has been assessed. The new compounds will add to the legacy of chemicals that continue to have impacts decades after they were banned. For example, in 2021, no rivers in England were deemed to be in good chemical health because of this legacy, but new toxicants continue to emerge [62].

There are trade-offs in the transition towards more sustainable forms of energy production, including the extraction of the materials required to produce renewable energy. The consumption of metals used in renewable energy generation and other decarbonisation technologies will likely increase dramatically by 2050, often necessitating mining in remote areas and causing cascading changes in land cover and the status of native species. In addition, the deep-sea mining footprint on the marine environment may expand rapidly if such mining begins in 2023, especially if other nations follow Nauru.

Another notable trend is the growing access to environmental impact litigation against companies and governments by private citizens. Increased access to knowledge, technology, and support has enabled bodies to be held accountable not only for climate change but also for a diverse set of issues ranging from pollution to the generation of microplastics to losses of species. This democratisation of action seems likely to play a growing role in sustainable development globally.

Two years ago we reviewed topics identified during the first horizon scan in 2009 [63]. We subsequently decided to reflect each year on the issues featured in the scan 10 years before. Our retrospective on the 2012 Horizon Scan is presented in Box 2.

Box 2. Reflections on the 2012 horizon scan

Some of the issues highlighted in 2012 [34] have materialised. For example, wildfires in the tundra have become more frequent and severe. The resulting emissions of greenhouse gases are likely compounding the speed of reduction in cover of sea ice as air temperatures increase throughout the Arctic. During 2021, over 4 Mha of tundra burned in Yakutia, corresponding to more than 505 Mt of CO_2-equivalent emissions. During September 2021, the minimum annual extent of Arctic sea-ice was 4.72 million square kilometres, the 12th lowest in the nearly 43 year satellite record. Wildfires and abrupt thawing of tundra could increase carbon emissions by up to 40% by the year 2100 unless fossil fuel emissions are drastically reduced. These examples illustrate the potential long-term effects of realisation of current horizons, particularly those issues that reflect an inability to learn from history (e.g., the lack of effective regulatory frameworks for the identification of potentially harmful chemicals).

Other issues identified in 2012 have undergone a significant step-change in impact. For example, in the 2012 horizon scan we discussed the potential effect of advances in technology that would make deep-sea mining operational. This year we identified the immediate impact from legislation that may allow deep-sea mining to begin in 2023.

One of the innovations identified in the 2012 scan [34] was the development of graphene. The development of products containing graphene has continued apace since 2012, but graphene has not become ubiquitous. Graphene technology is advancing, and it is likely that the material will be incorporated into products such as water filters, clothing, and electronics in the next 5–10 years. The 2012 horizon scan also raised the possibility that graphene would reduce the growth of plant seedlings and animal cells. A recent review of toxicity of graphene to plants [64] suggested that graphene delays seed germination and strongly affects morphology of the seedling, and careful work to reduce this toxicity will be necessary.

With new global goals for biodiversity and climate on the horizon, we believe that it is crucial to ensure that the mechanisms for reaching those global goals do not have unintended consequences. Horizon scanning can help to identify vital, often overlooked, issues.

Acknowledgments

This exercise was coordinated by the Cambridge Conservation Initiative with funding offered by the Natural Environment Research Council and the RSPB (this funding was not needed because the proceedings were held online). We are grateful to everyone who submitted ideas to the exercise and the following who suggested a topic that made the final list: Jason Dinsdale (wireless energy infrastructure), Ian Francis (floating photovoltaics), Robin Freeman (airborne eDNA), Lizzie Garratt (environmental consequences of new refrigerants), Lammert Hilarides (mangrove expansion), and Jiping Shi (green ammonia). We would also like to thank Mick Clout who contributed to the process but was unable to attend the workshop, and the referees for comments. The results, conclusions, and opinions expressed are those of the authors and do not necessarily reflect the views of any of their organisations. A.T. and W.J.S. are funded by Arcadia.

Declaration of interests

No interests are declared.

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