CellPress

Trends in
Ecology & Evolution

Review

A global biological conservation horizon scan of issues for 2023

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We present the results of our 14th horizon scan of issues we expect to influence biological conservation in the future. From an initial set of 102 topics, our global panel of 30 scientists and practitioners identified 15 issues we consider most urgent for societies worldwide to address. Issues are novel within biological conservation or represent a substantial positive or negative step change at global or regional scales. Issues such as submerged artificial light fisheries and accelerating upper ocean currents could have profound negative impacts on marine or coastal ecosystems. We also identified potentially positive technological advances, including energy production and storage, improved fertilisation methods, and expansion of biodegradable materials. If effectively managed, these technologies could realise future benefits for biological diversity.

Highlights

Our 14th annual horizon scan identified 15 emerging issues of concern for global biodiversity conservation.

A panel of 30 scientists and practitioners submitted a total of 102 topics that were ranked using a Delphi-style technique according to novelty and likelihood of impact on biodiversity conservation.

The top 36 issues were discussed in person and online in September 2022 during which issues were ranked according to the same criteria.

Our 15 issues cover impacts from DNA-enabled biobatteries to submerged artificial light fisheries.

Other emerging issues include increased demand for chitosan, accelerating upper ocean currents, and microbiome stewardship.

Horizon scanning for conservation

Horizon scanning is a well-established method for identifying threats and opportunities that allows sufficient lead time to develop solutions and act [1]. Often conducted as a transdisciplinary, collaborative exercise, horizon scanning is intended to enable scientists, policy makers, and practitioners to better understand and manage or mitigate emerging threats and respond to potential opportunities that new technologies, innovations, or initiatives present, such foresight should enable more strategic responses [2]. Every year since the inaugural horizon scan of global conservation issues in 2009 [3], we have identified 15 issues (e.g., microplastics, synthetic meat, use of mobile telephones for data collection) before their substantive impacts were widely observed or measured. Some issues may never fully emerge, which is inherent to horizon scanning, whereas the early identification of others may contribute to averting them.

This year's horizon scan was conducted in the midst of major global events that may impact biological diversity. Although by the end of 2022 most countries had relaxed measures to address the coronavirus (COVID-19) pandemic, including lockdowns, the full impacts of that pandemic on biological diversity are yet to be realised. Mitigating emerging threats to biodiversity requires global collaboration and financial investment, which may be challenging when some governments have reduced environmental restrictions to facilitate economic recovery. We recognise that these global events are likely to affect the detection of some of the issues we identified. For example, a move towards greater self-reliance for energy and food production may accelerate the timing of some of the issues we outline in the following section.

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https://doi.org/10.1016/j.tree.2022.10.005

Identification of issues

After 2 years of meeting remotely during the COVID-19 pandemic, 24 participants in the 2023 scan convened in person, and an additional six participated online via Zoom. As many collaborative teams discovered during the pandemic, discussions are generally more inclusive and productive when most participants convene in person rather than remotely. Our methods followed those in previous years (e.g., [3,4]) (see Figure I in Box 1). We enhanced the repeatability, transparency, and inclusivity of the process of issue selection by applying a modification of the Delphi technique [3,5].

Box 1. Horizon scanning methods

The process for this horizon scan (Figure I) commenced in March 2022 when we invited 30 scientists, practitioners, and policy makers to canvass their networks and colleagues in person and via email, social media platforms, virtual conferences, and networking events and then submit two to five issues that they considered novel, largely unknown, and likely to impact conservation of biological diversity during the next 5–10 years. With these communication methods, we contacted approximately 1300 people (20% of whom were from the Global South). We counted all direct contacts, whether in person or online, but considered social media posts or generic emails as a single contact unless multiple individuals responded.

Participants scored each of the 102 initial submissions confidentially and independently from 1 to 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 links to information on a given issue. To counteract the effect of voters becoming fatigued when assessing long documents or lists, participants were randomly assigned to receive one of the three lists of issues, each in a different order [5]. Participants' scores were converted to ranks (1–102), and issues with the highest 33 median ranks were reviewed against the qualifying criteria. This year, prior to consolidating the list of topics for round 2, we revisited the issues that received high ranks, but were familiar to >50% of participants. We asked the contributors of these issues to identify the novelty that qualified the issue as a horizon topic. Issues for which the horizon element could not be easily identified or that are already affecting biological diversity were removed from consideration. We also removed one issue that was identified by a previous marine and coastal horizon scan [6]. We gave participants an opportunity to retain an issue that received a rank lower than 33. This year, no additional issues were retained and, because three issues tied for rank 34, we retained 36 issues for the workshop discussion.

Each participant was assigned to examine up to four of the 36 issues, none of which they had submitted, in greater depth ahead of the workshop. The workshop was convened in September 2022. We asked all in-person and remote participants to join online and contribute additional material, such as links to relevant publications, via Zoom's chat function. After each issue was discussed, participants again scored it from 1 to 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. Following the identification of the 15 issues with the highest median ranks, questions were raised about one of these issues, which was largely dependent on an unpublished analysis, and the issue was dropped. Because three issues received equal median ranks of 16, participants were asked to rank them again, and the highest-ranked issue was included in the top 15. Issues are presented in the following list in thematic groups rather than in rank order.

- Increased demand for chitosan
- Development and expansion of selective lithium extraction technologies
- DNA-enabled biobatteries
- Advances in converting human urine into fertilisers
- Reducing use of inorganic fertilisers via custom-designed microbes and plants
- Accelerating upper ocean currents
- Submerged artificial-light fisheries
- Diminished long-term resilience of coastal wetlands to sea-level rise
- Microbiome stewardship for conservation
- Potential effects of severe Perkinsea infection on amphibians
- Reporting and increasing prioritisation of biodiversity impacts by private actors
- Accelerated use of machine learning to create novel therapeutics and toxins
- Increasing efficiency of thermophotovoltaics
- Potential side effects of ocean garbage patches
- Countering the expansion of invasive tree monocultures by genome editing

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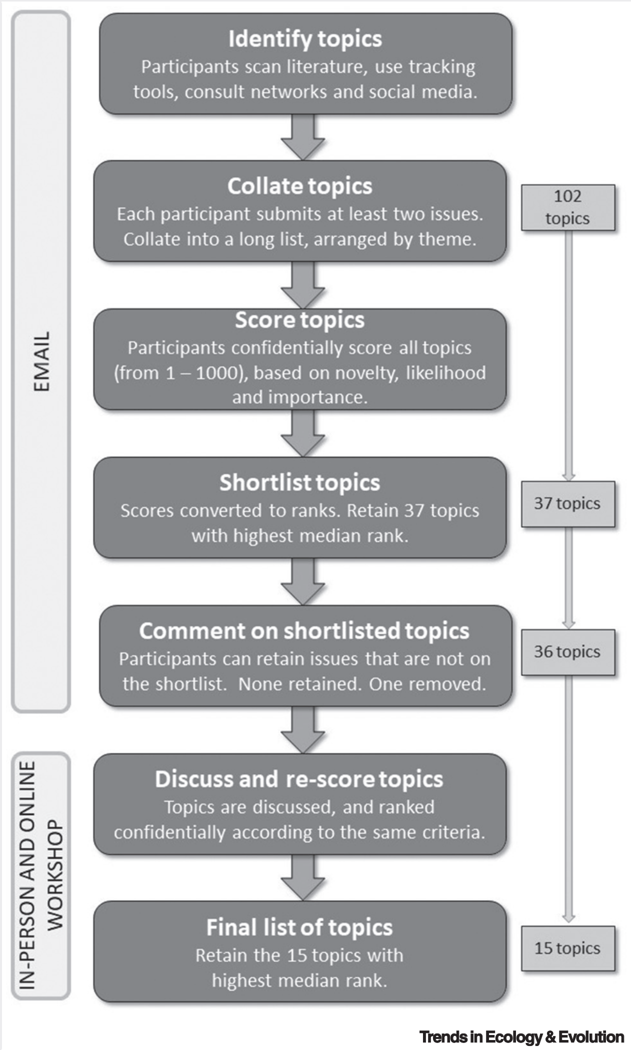

Figure I. Process for identifying and evaluating issues for Horizon Scan 2023.

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The 2023 issues

Increased demand for chitosan

The biodegradable biopolymer chitin is present in crustacean carapaces, fungal cell walls, and insect exoskeletons and is second only to cellulose in global abundance [7]. Chitin can be chemically treated to remove associated proteins, minerals, and acetyl groups, converting it into the soluble polymer chitosan. The favourable properties of chitosan, including antimicrobial and antioxidant capacities, have led to its use in water treatment, wastewater remediation, cosmetics, pharmaceuticals, food packaging to reduce waste, and agriculture [7]. These properties can be enhanced by addition of metals, such as silver and zinc, and such enhancements can be combined with use of other nanomaterials to facilitate development of new batteries and innovations such as packaging that changes colour when food spoils [8]. These technological advances, in combination with legislative bans on single-use plastics, are projected to drive a rapid increase in global demand for chitosan. The impacts of this demand on biological diversity will depend on the sources of exploited chitin. Currently, chitin is derived primarily from shellfish waste, but increased demand could increase incentives for expansion of coastal aquaculture, with concomitant risks to coastal wetlands and nearshore ecosystems. New mass production methods might include derivation of chitin from pupal cases of insects raised on organic waste [9].

Development and expansion of selective lithium extraction technologies

Lithium is an important component of many batteries used in consumer, commercial, and military electronics, including electric vehicles, vaping devices, and grid-scale energy storage systems. Its production will rapidly expand to meet growing demands and could stress new source locations, resulting in the development of mines on public and tribal lands following expedited and less rigorous environmental and social review and regulation processes [10]. Expanding conventional lithium production to meet demand would likely require extraction from lower-grade salt brines and ores, increasing environmental impacts such as water use, surface and groundwater contamination, accumulation of toxic mine tailings, and the loss and fragmentation of natural, often xeric land cover that regenerates slowly [11]. Selective lithium extraction technologies, such as lithium-ion sieves or electrochemical-based extraction approaches, could increase the speed and quantity of lithium removed from traditional sources and from unconventional ores, clays, and brines. Such removal, in turn, would reduce pressure on salt flats and associated ecosystems while decreasing demands for energy (e.g., for material roasting) and chemicals (e.g., for acid leaching) in the extraction process [12]. These innovations could expand to other unconventional sources, such as industrial waste streams, seawater, oilfields, and geothermal brines [12], decreasing the need, extent, and associated biological and social impacts of conventional lithium assets [10].

DNA-enabled biobatteries

To date, the efficiency and capacity of biobatteries – energy-storing devices powered by organic compounds, such as glucose or lactate – have been limited. However, recent engineering improvements may considerably increase deployment and versatility of this technology. DNA-enabled biobattery technology uses a set of enzymes coupled to DNA to degrade organic compounds, releasing electrons and generating electricity [13]. Such batteries could theoretically supply power densities in orders of magnitude greater than widely used lithium-ion batteries [14]. Furthermore, DNA-enabled biobatteries can be dehydrated for safe storage and transport and can be reconstituted with seawater or freshwater to be applied in diverse and remote contexts. Civil application of this technology and reduced reliance on metal-chemistry batteries may have substantially positive environmental effects. The technology uses primarily biological materials to generate power, alleviating the need for mining metals; decreases the use and disposal of toxic materials; and biodegrades[i]. However, other environmental and life-cycle effects of this nascent technology are not well understood.

Advances in converting human urine into fertilisers

Recent disruption of supply chains for agricultural commodities has turned attention to demand for fertilisers from local sources. Meeting this demand may exacerbate global greenhouse gas emissions from synthetic fertilisers [15]. Human societies have used urine and faeces as fertiliser for millennia, and recent progress in waste management and processing may herald a step change in the role of urine as a nutrient source for crops. Widespread use of human waste for fertiliser is currently limited to application of sewage sludge (biosolids), a combination of waste products that often includes contaminants (e.g., endocrine disruptors and pharmaceuticals) [16]. However, urine diversion systems may offer environmental and public health benefits by separating human waste from other waste products. One modelled system that replaced synthetic fertilisers with nutrients from human urine substantially reduced emissions of greenhouse gases, energy consumption, volume of freshwater used, and nutrient loads from wastewater [17]. New designs may help popularise urine diversion toilets by changing their odour profile and making them easier to use. Novel approaches to processing urine include drying into solid blocks that can be applied directly to crops [16,18]. The social acceptability and ecological feasibility of such applications remains uncertain. Extensive application could reduce the volume of nutrients released into freshwater and coastal systems from sewage, and further reduce nitrogen oxide emissions. Alternatively, increased use may lead to cheaper and more readily available fertilisers that increase eutrophication and increase greenhouse gas emissions.

Reducing use of inorganic fertilisers via custom-designed microbes and plants

The production and use of inorganic fertilisers in agriculture results in extensive environmental contamination. In recent decades, in addition to deployment of legumes in agriculture, it has become more common to inoculate cereals with nitrogen-fixing rhizobacteria that promote plant growth [19]. However, inoculation outcomes are often weak and condition dependent. Recent genetic advances could expand the use of bacterial inoculants. Genetically engineered signalling networks among plants and rhizobacteria allow targeted regulation of bacterial gene expression and fertilisation of agricultural plants. For example, engineered production by barley plants of the signal molecule rhizopine facilitated control of rhizobacterial gene expression [20], and a hybrid rhizopine uptake system increased rhizopine perception by targeted nitrogen-fixing rhizobacteria [21]. In parallel, microbial inoculants have been improved with synthetic biology to reinforce nitrogen fixation in the maize rhizosphere [22]. If these prove transferable beyond experimental settings, these custom-designed microbes and plant–microbe symbioses could reduce use of inorganic fertilisers, decrease demand for fossil fuels to produce nitrogen fertiliser, and reduce nitrogen oxide emissions and eutrophication.

Accelerating upper ocean currents

Ocean currents transport substantial quantities of water, heat, and nutrients and are key components of global weather and climate. In response to sea surface warming and other aspects of climate change, upper ocean currents are becoming shallower and faster, which increases stratification and potentially decelerates deeper-ocean circulation [23]. The energy of upper ocean currents has increased by at least 15% per decade since 1990 [24]. These changes could reduce the global capacity of the surface ocean to absorb heat, warming surface waters and reducing biological productivity by preventing ocean upwelling, thereby trapping nutrients in deeper water [25]. Such increasingly variable ocean conditions may affect species distributions at global and ocean-basin extents. The shoaling of the mixed layer in these currents could also reduce the predictability of ocean conditions, complicating projections of marine dynamics that are relevant to fisheries and conservation efforts.

Submerged artificial light fisheries

The use of lights at, or close to, the sea surface to attract and aggregate fishes and invertebrates, notably squid, at night has a long history in pelagic purse seine, squid, and other capture fisheries. However, lights are now deployed at greater depths, from 50 to 1000 m. These lights have commercial applications, such as deep-water bottom trawls for Mediterranean shrimp [26] and other trawl and trap fisheries (e.g., [27]). Such lighting can substantially increase catches but may also increase bycatch of undersized or immature individuals [26]. By contrast, potential benefits include a reduction of bycatch in some contexts [28] and replacement of trawls with traps [27]. The ecological effects of persistent artificial light in deeper waters, as compared with surface waters, are largely unknown, but likely are negative given that deep-water species have adapted to dark conditions. In the absence of clear policy frameworks, the potential environmental impacts from use of artificial lights in fisheries may remain unaddressed by market forces.

Diminished long-term resilience of coastal wetlands to sea level rise

Coastal wetlands provide habitat for millions of migratory birds and spawning fish and support ecosystem functions on which human societies rely. Widespread losses of such wetlands have been recorded, notably from conversion to urban areas, agriculture or aquaculture. Although sea level rise might be expected to threaten such ecosystems, cautious optimism has been maintained through observations that vertical accretion and landward migration of coastal wetlands may mitigate extensive losses (e.g., [29]). In addition to the fact that economic development in coastal areas can prevent inland movement of coastal wetlands, there is growing evidence that the rate of vertical accretion of wetlands may be slower than previously thought and slower than the rate of increase in sea levels. Short-term studies had suggested that wetland growth and allochthonous sedimentation could support rates of accretion equivalent to current and projected rates of sea level rise. But new studies, including long-term studies of Holocene change, suggest that such rates cannot be maintained over longer periods. Although accretion may continue, more spatially extensive and nonlinear processes of subsidence could lead to an elevation deficit in many areas [30,31]. This latter work points to a likely acceleration in coastal wetland losses in the coming decades due to climate change.

Microbiome stewardship for conservation

Advances in high-throughput sequencing have allowed identification of global trends in microbial homogenisation that may disrupt symbioses and reduce the viability of many species and ecosystems [32]. Moreover, captivity can alter the microbiomes of individuals and affect the success of species reintroductions [33]. Since it has been reported that the microbiome can be manipulated to improve human health and support agriculture, interest in the potential benefits of active microbial manipulation for conservation and restoration is now growing. For instance, manipulation of soil microbiota can repair degraded soils [34]. Research on manipulation of the marine microbiome in the vicinity of corals to enhance resistance to coral bleaching is advancing rapidly [35]. Peixoto *et al.* [32] encouraged rapid development of probiotic applications to the environment but argued that such development is hampered by risk assessment and regulation, and proposed a new, evidence-based framework for microbiome stewardship. Although it remains uncertain where and when microbiome stewardship facilitates conservation or has unintended consequences, it is likely that microbiome stewardship will increase in the future.

Potential effects of severe Perkinsea infection on amphibians

Severe Perkinsea infection, the third most common infectious disease in amphibians in North America, leads to mass mortality of tadpoles. The disease is caused by a clade of NAG01 Perkinsea protists with unknown distribution and uncertain effects on different amphibian taxa. Screening of tadpoles in Panama, and an investigation of captive-bred tadpoles in the UK, detected similar protists [36]. Perkinsea was also detected in *Pristimantis* frogs in Ecuador [37], and new analyses suggest that the pathogen will continue to result in considerable mortality of amphibians as climate change and the amphibian trade enable its geographic expansion [38]. The known range of Perkinsea has extended to Central and South America. The climate in several regions with high species richness of amphibians, yet in which Perkinsea has not yet been detected, suggests potential for further transmission and impacts. The diversity of taxa in which Perkinsea protists have been detected is also increasing. Moreover, the route by which Perkinsea was transmitted to at least one captive population in Europe is unclear, suggesting that the protists may be undetected elsewhere in captivity. A persistent lack of biosafety protocols for transporting live amphibians means that Perkinsea and other pathogens have considerable opportunity to spread to naive communities where, similar to chytrid fungus, they could drive mass mortality or extinctions in naive populations.

Reporting and increasing prioritisation of biodiversity impacts by private actors

New biodiversity reporting requirements for finance and business sectors are being introduced and are an emerging theme in global markets and natural capital accounting. Biodiversity tracking is also being integrated into legislation. For example, in France, a national climate and energy law adopted in 2019 accounts for the preservation of species and ecosystems[ii]. This law requires financial institutions to disclose effects of their investments not only on climate change but on biodiversity. The law recognises that corporate information is relevant to assessing a company's value and its impact on climate and the environment. Furthermore, the law requires financial institutions to disclose their targets and strategy for reducing effects of their investments on biological diversity. Following the outcomes of the 2021 European Climate Law and a proposed European Nature Restoration Law[iii], other countries may pass similar legislation. In response to such signals, the global Taskforce on Nature-related Financial Disclosures (TNFD), established in 2021, aims to deliver a risk management and disclosure framework for organisations to report and act on nature-related risks [39]. These frameworks and legislation, combined with market-led initiatives and increasing use of supply-chain traceability, are likely to advance efforts to achieve biological conservation and restoration outcomes.

Accelerated use of machine learning to create novel therapeutics and toxins

Machine learning is a set of methods within artificial intelligence that automate supervised or unsupervised tasks by iteratively adjusting model parameters to better fit data. Drugs are generally developed to improve the health of individual organisms or groups of organisms, often by killing viruses, bacteria, or other taxa deemed pests or pathogens. In the pharmaceutical sector, machine learning is being applied to designing and screening drugs with respect to potential bioactivity or toxicity, matching drugs to conditions or individuals and designing and monitoring results of clinical trials [40]. The application of drug-related machine learning methods for conservation is in its infancy, and it may facilitate swift counteraction of emerging threats to species that society wishes to conserve. For instance, a recent machine learning model was used to predict whether any proposed new herbicide, fungicide, or insecticide would be toxic to honeybees on the basis of the proposed compounds' molecular structure [41]. However, it also may become necessary to increase surveillance of malicious introduction of novel toxins that thwart sustainability and conservation objectives at the level of genes, species, or ecosystems.

Increasing efficiency of thermophotovoltaics

Thermophotovoltaics, or thermal batteries, store energy as heat at high temperatures. The energy can later be released on demand as electricity. This technology has potential to both decarbonise the electricity grid and reduce use of lithium-ion batteries [42], which ultimately reduces the ecological effects of human activities. Although energy storage costs of thermophotovoltaics are orders of magnitude lower than those of current energy storage methods, they have not yet been commercialised due to their poor efficiency in converting stored energy to electricity [43]. However, recent advances have increased the efficiency of thermophotovoltaic cells to more than 40%, which is comparable to average turbine-based heat engines [44]. These thermophotovoltaic cells could compete economically with currently available energy storage solutions. The modular design of thermophotovoltaic systems facilitates their creation at different capacities or extents, removing the need for large, centralised energy production systems, such as hydropower, and associated distribution networks, alleviating the environmental impacts of these alternative forms of power production. Additionally, thermophotovoltaics can be used to store and provide both heat and electricity. Further improvements and adoption of this technology will expedite the use of renewable energy storage facilities, potentially reducing human use of land and water.

Potential side effects of ocean garbage patches

The Sargasso Sea is widely known as an oceanic gyre with an abundance of floating marine life known as obligate neuston. Although inaccessibility has limited the study of their ecology, other oceanic gyres are known to accumulate anthropogenic marine debris, including large quantities of plastic. These garbage patches are hypothesised to be a threat to marine life and a source of toxicants [45]. Samples from the interior of the North Pacific garbage patch contained significantly higher densities of floating life than samples from its periphery, and the relation between neuston abundance and plastic abundance was positive and significant [46]. Both neuston and plastic appear to be concentrated by surface winds and current patterns. Negative environmental effects notwithstanding, these concentrations of anthropogenic debris may enable development of ecosystems supporting complex marine food webs novel to the Anthropocene. Some neuston species may benefit from plastics that provide oviposition sites and habitat structure [47]. The influence of these novel systems on mobile and migratory megafauna, including turtles, whales, tuna, and billfish, may be complex and difficult to gauge. Ecosystems within each garbage patch may be distinct, presenting a challenge for designing remediation strategies that minimise accumulation of plastics in the ocean while retaining potential ecological benefits of aggregated plastics.

Countering the expansion of invasive tree monocultures by genome editing

Many current and proposed reforestation programmes have been designed to help meet climate mitigation, carbon capture, and renewable energy targets. However, monocultures of rapidly growing trees are less likely to positively contribute to biodiversity targets, in part because non-native tree species can become invasive. Commercially planted conifers, particularly *Pinus* spp., can become ecologically damaging invasives when their seeds disperse from planted forests [48]. Pine invasions have had adverse ecological and economic impacts in South Africa, New Zealand, and parts of Europe and South America. Clustered regularly interspaced short palindromic repeats (CRISPR) technology recently was used to edit the genomes of cultivated pine species [49]. The effects of such genome editing in *Pinus* spp. could be rapid and dramatic, preventing plantation trees from spreading into other ecosystems. The concept could be applied to other taxa, such as *Eucalyptus*, in the future. However, costs of implementation and regulation of gene editing may be prohibitive and may divert resources from more effective ecological interventions [50]. Furthermore, sterility induced through genome editing could have negative and unintended effects on other native species.

Concluding remarks

The 15 topics presented this year generally fell into four categories: resource exploitation (e.g., increased demand for chitosan, changes in lithium mining methods, and submerged artificial light fisheries), disruption of species and their habitats (e.g., threatened microbiome rewilding, emerging diseases, and sea level rise threatening coastal marshes), advances in technology (e.g., artificial intelligence-driven therapeutics and the increasing efficiency of thermal batteries), and policy and legal frameworks (e.g., measures for reporting biodiversity impacts from private actors).

Most issues in this scan, if realised, may positively impact biological diversity and conservation. This was particularly evident in the technological issues. Advances in energy production and storage, expansion of biodegradable materials, and improvements in agricultural fertilisation methods could reduce the impact of human activities on biodiversity. This highlights the growing capacity and motivation for companies and governments to move towards sustainable alternatives in energy, food production, and manufacturing. However, many issues may also have negative impacts, emphasising the value of assessing the environmental trade-offs of nascent technologies before they are applied commercially. Other developments may not deliver on their initial promise. For instance, engineering bacteria to adjust nitrogen fixation rates in response to signals from plants could be hampered in field conditions by mutations that draw energy from the plants while minimising the amount of nitrogen they fix.

Given societal efforts to address climate change through mitigation and adaptation, it did not surprise us that seven of this year's top-ranked issues relate to climate change. Three are associated with energy storage (selective lithium extraction technologies, DNA-enabled biobatteries, and increasing efficiency of thermophotovoltaics); two may impact land use or alter emissions of greenhouse gases from land use change (converting human urine into fertilisers, countering the expansion of invasive trees); and two highlighted new or accelerated impacts of climate change (accelerating upper ocean currents, sea level rise on coastal wetlands). Given increasing impacts of climate change, future horizon scans are likely to continue to assess potential unpredictable impacts of novel mitigation and adaptation responses [51].

In 2019, we presented a 10-year retrospective of issues raised in the first horizon scan [52]. Since then, in our annual presentation of issues, we have examined issues raised a decade ago (Box 2).

Although our implementation of horizon scanning identified some issues that subsequently were realised (Box 2) [52], it is not, for example, intended to highlight known threats that may increase in magnitude. For example, the highly pathogenic avian influenza (HPAI H5N1) that emerged during summer 2022 and spread across Europe [60] and into Canada [61] has had unprecedented severe impacts. Similarly, the current geopolitical instability in Eastern Europe has had dramatic, immediate global impacts on fossil fuel prices, supply chains, and international political collaboration. Neither issue was included here because they were considered current, even if escalating, rather than imminent.

Box 2. Reflections on the 2013 horizon scan

The 2013 horizon scan [53] identified several issues that affected biological diversity or conservation in the subsequent decade, including

- 3D printing developed rapidly and is now widely utilised for a range of objects (e.g., [54]);
- Transplantation of coral fragments became an established method for coral reef restoration[v];
- The use of environmental DNA (eDNA) became integral to detecting species presence in aquatic systems (e.g., [55]);
- Drones are increasingly used to spread seed in forest restoration projects (although evidence for success is limited [56]); and
- The number of hydropower installations in the Andean Amazon increased substantially, affecting regional biodiversity (e.g., [57]).

Some horizon issues may take longer to materialise although they are still on an upward trajectory. In 2013, we featured the development of thorium-fuelled nuclear power. China completed construction of a thorium-based nuclear reactor in 2021 [58]. Commissioning was approved in August 2022[vi]. This form of power generation is likely to be more widely used in the next 50–100 years as global availability of uranium declines [58].

Two issues identified in 2013 [53] have developed significantly and therefore are featured in this year's scan. A decade ago, understanding of the associations among human and animal health and microbial diversity was emerging. That year, we highlighted the health benefits of exposure to a diversity of microbes, through soil, other animals, and the environment. Indeed, it was proposed that more frequent interaction with natural systems could lower the prevalence of allergies and autoimmune diseases [53]. Since then, research has greatly improved understanding of the role of microbes in human health and well-being (e.g., [59]). This year, we emphasise the potential benefits of enhancing the microbiome of captive animals to increase the success of reintroduction. We discuss active microbial manipulation for conservation and the potential for microbiome restoration through probiotic applications in the environment.

In 2013, we identified the potential for use of antimicrobial peptides as food wrapping to reduce food waste [53]. The issue of concern was the environmental transport and fate of such peptides and its environment effects. This year, we identify the increase in demand and potential overexploitation of one such polymer, chitin, when converted to chitosan. We discuss the potential impact on coastal wetlands of an increase in harvesting of chitin from unsustainable sources.

We believe that the issues we identify in this scan should be considered in the context of well-known global trends in climate change and biodiversity changes. The aim of our annual horizon scan is to provide novel information that society and decision-makers may wish to consider in legislation, planning and actions that contribute to environmental sustainability, and mitigating threats [62]. It is inevitable that we miss issues that have incrementally increased in impact and therefore do not qualify as novel or have not undergone a major step change in impact. For example, at current levels of greenhouse gas emissions, five of 16 known tipping points, including melting of the Greenland ice sheet, mass die-off of coral reefs, or fundamental loss of ecological resilience across the Amazonian rainforest, may be approaching [63,64]. The challenge for horizon scanning is to identify an explicit issue that may impact biodiversity conservation in the next 5–10 years.

Our list of issues is wide-ranging and geographically extensive, although we acknowledge that in future, such work might benefit from increasing geographic representation of authors from the Global South and expertise in certain sectors, such as technology and commercialisation and the military, pharmaceutical, sociology, and agricultural sectors.

Some of the issues we identified may be indicative of more comprehensive topics of current debate. For example, microbiome stewardship and financial disclosure are aspects of society–nature interactions and are inherently linked to debates about humanity's environmental influence. It has proven challenging to realistically envision how society transitions from exploiting nature for profit to viewing nature as a vital living system, the function of which depends on the interdependence of wild species and humans[iv] [65].

Acknowledgments

This exercise was coordinated by the Cambridge Conservation Initiative and was funded by the Natural Environment Research Council and the Royal Society for the Protection of Birds (RSPB). We are grateful to everyone who submitted ideas to the exercise and to the following who suggested topics that made the final list: Oona Buttafoco (biobatteries); Joe Fargione (advances in converting human urine into fertilisers); Mark Hancock (tree monocultures and genome editing); and Marcus Nyman (novel therapeutics). W.J.S. and A.T. are funded by Arcadia; J.E.H-R. is supported by the Whitten Programme in Marine Biology; X.L.R. is supported by the French Institute of Research for Agriculture, Alimentation and Environment (INRAE, ECODIV Department).

Declaration of interests

No interests are declared.

Resources

[i] www.gov.uk/government/news/dstl-scientists-develop-pioneering-bio-batteries

[ii] www.greenfinanceplatform.org/policies-and-regulations/frances-law-energy-and-climate-adds-coverage-biodiversity-ecosystems-and

[iii] www.euractiv.com/section/energy-environment/news/eu-plans-law-to-reverse-decades-of-biodiversity-loss/

[iv] https://acss.org.uk/the-social-nature-of-our-species/

[v] https://reefresilience.org/management-strategies/restoration/coral-populations/coral-gardening/field-based-nurseries/

[vi] www.world-nuclear-news.org/Articles/Chinese-molten-salt-reactor-cleared-for-start-up

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