Update

Forum

A horizon scan of global conservation issues for 2010

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Horizon scanning identifies emerging issues in a given field sufficiently early to conduct research to inform policy and practice. Our group of horizon scanners, including academics and researchers, convened to identify fifteen nascent issues that could affect the conservation of biological diversity. These include the impacts of and potential human responses to climate change, novel biological and digital technologies, novel pollutants and invasive species. We expect to repeat this process and collation annually.

Introduction

For science to be relevant and useful, it must be offered at the appropriate times in decision-making processes. Excellent science completed after critical decisions have been made is of limited use. Horizon scanning – the systematic search for incipient trends, opportunities and risks that may affect the probability of achieving management goals and objectives – can, if conducted early enough, increase the capacity to adapt. Credible information about these nascent issues can be used to prioritise research and to inform policy development and strategic planning.

Horizon scanning is performed increasingly by corporations and governments, particularly across Europe. It has been undertaken for more than a decade in medicine and allied fields to anticipate and facilitate responses to rapid technological change. Sutherland and Woodroof [1] suggested that horizon scanning could identify both potential new threats to biological diversity (in terms of structure, composition and function) and new opportunities for its conservation. The aim of horizon scanning is not to predict the future, but to identify emerging issues in sufficient time to initiate research and develop policy and practical responses.

The need for horizon scanning of environmental issues is illustrated by the recent failure to foresee both the widespread adoption of the range of biofuels currently in use, and the environmental consequences of biofuels production. Many, including some conservationists, initially emphasised the environmental benefits of biofuels. It is only relatively recently that the costs have become widely recognised [2,3]. This example also demonstrates that new threats or opportunities may be caused by a series of events. Thus, in hindsight, horizon scanning might have identified three phenomena during the process of biofuels research and implementation: development of the technology decades ago, the initial production of commercial biofuel crops and the recent advocacy of biofuels.

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Sutherland *et al.* [4] used horizon scanning to identify a series of broad issues affecting the status and trends of biological diversity in the United Kingdom. The review presented here differs in geographic scope, presenting issues from across the globe. We envisage repeating this exercise annually to bring forthcoming issues to the attention of researchers and policymakers.

The authors of this assessment include people whose job includes horizon scanning, as well as academics, representatives of organisations with broad conservation interests, and specialists in subdisciplines of conservation science. Each author, independently or in consultation with colleagues, identified and provided a summary of 1–4 emergent issues that they felt were globally important or may have a local effect on species, ecosystems or regions of global interest. The resulting set of 61 issues was circulated to all authors, who scored each issue based on whether they were aware of it (score: yes or no) and whether it was poorly known but potentially important [score: 1 (well known or poorly known but relatively unimportant) to 10 (poorly known and potentially important)]. These scores were used to generate a shortlist of 35 issues. Participants were invited to reprieve issues that they thought merited further discussion; six issues were reprieved. We discussed the 41 shortlisted issues at a meeting in Cambridge, UK, in September 2009. Two participants were selected in advance to provide an independent, critical assessment of each issue. After discussion, each participant scored each issue on the same 10-point score and the 15 issues with the highest mean scores were identified. Following email discussion one issue was dropped and the next highest-ranked in the list included, resulting in the set presented here.

We provide here a synopsis of each issue. We deliberately did not rank or prioritise the final set of 15 issues. Many of the issues may have both positive and negative environmental effects. We have not attempted to examine the consequences in detail. This is mainly because the consequences of each are likely to be diverse and would require an independent exercise to assess.

The issues

Microplastic pollution

During the past 40 years, world production of plastic resins increased some 25-fold, while the proportion of material recovered was less than 5%. This has led to rapid accumulation of plastics in the environment [5,6]. Between 1970 and 2003, plastics became the fastest growing segment of the municipal waste stream, increasing nine-fold. They also now comprise 60–80% of general litter, particularly in coastal areas [7]. As plastic waste abrades and disintegrates, it forms tiny fragments that are widely dispersed in sediments and soils [8]. The impact of such microplastics on wildlife remains poorly understood. There is, however, considerable potential for toxicity. Toxic effects, notably hormonal disruption from plasticisers, may derive from the original plastics but also from hydrophobic marine pollutants adsorbed onto the plastics from the surrounding waters [9,10]. Such pollutants are most likely to be ingested by deposit-feeding and filter-feeding organisms [11], and transfer of microplastics through the food chain has been demonstrated [7].

Nanosilver in wastewater

Of the more than 800 nanotechnology products available to the average consumer at least 20% use nanosilver – nanoparticles of silver or silver oxide or silver ions – as an active ingredient [11]. Nanoscale silver is primarily used as an antimicrobial with widespread potential uses in the manufacture of refrigerators, chopsticks, air conditioners, air purifiers, dummies (baby pacifiers), food preparation equipment, teddy bears, vacuum cleaners and a wide range of medical devices [12], as well as for reducing the odour of clothes and treating plant pathogens [13]. Nanosilver can enter the aquatic environment through many routes, e.g. washing of wounds treated with nanosilver plasters, washing machines equipped with nanosilver to purify clothing and laundering of treated fabrics [14], and could accumulate in sediments. The impacts on natural bacterial communities are largely unknown but nanosilver can kill nitrifying species [15,16]. Risk to aquatic vertebrates is suggested by an increased incidence of deformities and mortality of exposed zebrafish embryos [17]. It is unclear whether nanosilver particles could reach concentrations at which they could be a serious problem. Solutions to reduce nanosilver in wastewater, including carbon nanotube brushes [18] and adding ligands [19], are being examined.

Synthetic meat

As a response to environmental pressures, ethical concerns and human health issues, a variety of research efforts worldwide are now using technologies developed for bioengineering medical tissue to grow synthetic meat in the laboratory [20]. Muscle stem cells can be taken from live animals, multiplied in a growth medium and stretched to make muscle fibres [21]. Meat cells grown in a dish obviously do not move like their real animal counterparts, so scientists use a stimuli-sensitive scaffold of collagen or alginate to add texture to the meat. Periodic stretching of this scaffold, in response to changes in temperature or pH, exercises the cells. Despite the various technological challenges, a Dutch sausage maker has developed a process that transforms pig stem cells into muscle fibres in two weeks [22]. The greatest hurdle is still price: estimates of cost per kg vary between $10,000 [21] and $100,000 [23]. There is a promised reward of US $1 million for the first tasty *in vitro* chicken meat successfully sold to the public by the end of June 2012. Should synthetic meat become commonplace and protein production move from agricultural areas and oceans to factories, it could reduce livestock-produced greenhouse gases, demand for agricultural land and pressure on fish stocks. It might also have an adverse influence on those vegetation types dependent upon livestock grazing. The consequences would depend upon a range of factors, such as whether a majority of people would eat synthetic meat.

Artificial life

In recent years, the capacity to produce artificial life has increased dramatically, largely due to the work at the J. Craig Venter Institute. Under laboratory conditions, it is now possible to build and subsequently clone bacterial chromosomes within yeast cells. The new bacterial genome is then transferred to a bacterial cell in which it functions and reproduces [23–25]. Craig Venter's vision is a 'new version of the Cambrian explosion based on digital design' with new forms of life capable of producing vaccines and chemicals, including fuel derived from carbon dioxide. Freeman Dyson points out that thousands of people breed flowers or reptiles, and observes, 'Now imagine what will happen when the tools of genetic engineering become accessible to those people. .. Designing genomes will be a personal thing' [26]. The main risks, especially if the technology becomes widely accessible, are potential interactions with genes and species in natural communities and the potential for malicious use.

Stratospheric aerosols

Enthusiasm for geoengineering solutions to climate change is growing. Among the many technologies proposed, the release of particles (e.g. sulphate aerosols) into the stratosphere to scatter sunlight back into space has begun to receive serious attention [27], especially as the injection of aerosols into the stratosphere may become both affordable and effective. While such actions theoretically could reduce temperatures globally [28], they would do nothing to reduce atmospheric carbon dioxide concentrations or ocean acidification, and would require an artificial and potentially unstable tradeoff to be maintained between increased greenhouse gas concentrations and reduced solar radiation over centuries. Some aerosols also have the potential to acidify precipitation and increase ozone depletion, while all have potentially substantial impacts on regional climates through modification of precipitation patterns [29,30]. Thus, whilst stratospheric aerosols might mitigate global warming, they also might have negative effects on different components of biological diversity.

Promotion of biochar

Growing plants remove carbon from the atmosphere; decomposing plants release it. When organic matter is burnt in the absence of oxygen (pyrolysis), biochar is produced. This process lessens decomposition, thus sequestering carbon [31,32]. Consequently, there is growing interest in whether biochar can mitigate some of the undesirable effects of climate change [27,33]. Biochar is very similar to charcoal, except that it is produced specifically to be incorporated into the soil. During its production a mixture of gases are formed, which may be collected for bioenergy. Once added to the soil, biochar may also help boost agricultural yields [34] and remediate degraded soils. Biochar is expected to persist for millennia [32], but its permanence may vary as a function of production conditions [35]. In addition, burning biomass for energy displaces carbon-intensive forms of energy production, thus may reduce atmospheric carbon dioxide concentrations more effectively than burning biomass to make biochar. To contribute meaningfully to global carbon sequestration, biochar would need widespread deployment [27,31], possibly leading to the direct or indirect conversion of land cover associated with high species richness or agricultural production. Proponents, including nearly 20 countries and several influential individuals, have argued for inclusion of biochar production within the Clean Development Mechanism of the United Nations Framework Convention on Climate Change. Were this to occur, the rapidity of biochar deployment might outstrip the ability to undertake precautionary research, and might have similar impacts on biological diversity as first-generation biofuels.

Mobile-sensing technology

Mobile sensing, the use of mobile (or cellular) telephones to observe the environment, has potential to become more practical and widespread [36]. Currently available and affordable mobile technology permits accurate positioning with GPS, compass, tilt, yaw and altitude sensors, and recording of videos, photos, light and sound. Additional sensors, such as temperature, moisture and humidity, can easily be attached and real-time information on weather accessed. Advances in fuel cell technology to power these devices will permit long-term mobile sensing. This new generation of phones is permanently connected to the internet via mobile networks, WiFi or Bluetooth, and can thus provide real-time data with covariates (such as location and time). The dramatic uptake of applications ('apps') for specific tasks has opened up a range of potential opportunities to aid scientific and other aspects of conservation by involving a wide audience who would be unable to buy specialised equipment. The numerous technologies include camera traps to sense wildlife; ground-truthing of remotely sensed data; software recognition of the calls of birds, bats, amphibians and insects; image recognition of species; submission of photos for expert identification and keys to identify species. These apps could be linked so that the identification software only considers species present in a given location and season, and the record is automatically downloaded onto a centralised database.

Deoxygenation of the oceans

The dissolved oxygen concentration of tropical ocean waters at depths of 300–700 m has declined over the past 50 years. The intermediate-depth, low-oxygen layers (Oxygen Minimum Zone) of the central and eastern tropical Atlantic and the equatorial Pacific Oceans have expanded and become more anoxic since 1960 [37]. This zone has expanded and contracted in the past, with some periods having extensive areas of hypoxic conditions characterised by low levels of biodiversity; although some species are specialists in the edge of this zone [38]. Models predict a further decline in the concentration of oxygen dissolved in the oceans as the climate continues to warm. Schaffer *et al.* [39] predict a considerable increase in the long-term depletion of oxygen and the expansion of minimum zones, even under a relatively benign emissions scenario [40]. Deoxygenation of the oceans is likely to have substantial effects on ocean ecosystem structure and productivity. Hypoxic conditions (usually defined as < 2–3 mg of oxygen per litre of water) have been shown to affect growth and food intake in juvenile and adult fish, crustaceans, echinoderms and bivalve molluscs, whilst most fish die at concentrations of 1–2 mg/L O_2 [41].

Changes in denitrifying bacteria

Nitrogen loading has increased in the sea over recent decades in response to anthropogenic inputs associated with growing human populations, conversion of land to urban areas, more extensive sewage systems and wider use of synthetic fertilisers. Most of this anthropogenic nitrogen is then converted to inert molecular nitrogen N_2 by microbially-mediated denitrification in the sediment of estuaries and the coastal shelf; the nitrogen then returns to the atmosphere. However, cores from Narragansett Bay, Rhode Island, USA, show that these sediments have recently switched from being a net sink to a net source of nitrogen [42,43]. The exact cause of such a disruption to the nitrogen cycle is unknown, but the evidence suggests that primary production within the estuary has declined, perhaps due to a change in climate. The resulting reduction in organic matter in the sediment may have prompted a switch from denitrification to nitrogen fixation. The excess nitrogen, however, is not accumulating in the bay or stimulating algal blooms, and indeed the local waters appear to have become more oligotrophic. This suggests that some estuaries may no longer retain and remove nitrogen. If so, anthropogenic nitrogen is reaching the open ocean, where consequences may include ocean acidification or an accumulation of nitrous oxide [44]. This process may be occurring in other estuaries, such as those in the northern Bering Sea [43,45].

High-latitude volcanism

Since the growth of large ice sheets and glaciers began over 30 million years ago in the polar regions, large areas of volcanic activity have been covered by ice of varying thickness. At the global level, the major outcome of ice sheet genesis was a dramatic reduction of volcanic gas and dust production, which is now being reversed, owing to climate change. The removal of this ice is having local to regional effects in the Arctic and may affect extensive areas in the future [46]. In Iceland and elsewhere, small-scale volcanic activity that has been covered by glaciers is being progressively revealed, resulting in marked local effects on land cover and ecological relationships. At a larger scale, the West Antarctic Ice Sheet, potentially the least stable part of the Antarctic Ice Sheet, is underlain by a large continental rift system with associated volcanism. The West Antarctic Ice sheet is currently decreasing in size. Mass loss is particularly evident in the Thwaites, Smith and Pine Island glaciers, where melting is occurring at progressively faster rates [47,48]. There is strong evidence that a volcanic eruption 2,200 years ago broke through the ice above it [49]. The geology of west Antarctica makes further large-scale volcanic activity likely, although the approximate timing of future eruptions is unpredictable. Thinning ice will make breakthrough eruptions more likely. Any substantial volcanic activity also increases melt at the base of glaciers and ice sheets, leading to an increase in freshwater runoff and sea level.

Invasive Indo-Pacific lionfish Small numbers of predatory Indo-Pacific lionfish (mainly *Pterois volitans*) were first recorded in waters along the eastern coast of the United States in 1992 [50]. The source of introduction is uncertain. The rate of lionfish range expansion was initially slow, but increased markedly after the colonisation of Bahamian coral reefs in 2004 [50,51]. Lionfish are now established throughout most of the northern Caribbean and have been recorded as far north as Rhode Island and south to Colombia [52]. Where they are established, lionfish are found at densities far exceeding those reported for their native range (e.g. > 390 lionfish ha^{-1} in the Bahamas compared to about 80 ha^{-1} in the Red Sea [53]). Lionfish grow to a maximum length of about 45 cm, and prey on a wide variety of fish and invertebrates [54]. On experimental reefs in the Bahamas, young lionfish reduced the recruitment of native coral reef fish by nearly 80% [55]; the effects of lionfish on natural reefs are still unmeasured. Lionfish are protected by venomous spines, and while small lionfish can be eaten by large groupers [56], such predators are rare throughout the Caribbean. Lionfish are, however, now being fished and offered on the menu of some Bahamian restaurants [57].

Trans-Arctic dispersal and colonisation

In the mid-Pliocene, the waters of the Arctic cooled and became a major dispersal barrier between the Pacific and Atlantic Oceans for marine species, allowing the development of distinct biogeographic realms [58]. As ocean temperatures increase, polar ice melts and wind patterns shift, boreal-temperate species once again may be able to survive in the Arctic Ocean and move between the Atlantic and Pacific [59,60]. This process was recently illustrated by the appearance of a Pacific diatom in the North Atlantic [59]. Decreasing spatial and temporal sea-ice coverage will allow primary productivity to increase substantially in the Arctic, supporting increased survival of relatively large-bodied species from adjacent oceans. Thus, a natural process of colonisation and migration between oceans is to be expected [60]. At the same time, a rapid increase in shipping is likely to commence through both the Northwest and Northeast Passages during summer months [61]. This will facilitate the transport of species between the Pacific and Atlantic Oceans. It is unclear what the full array of effects will be on ecosystems, on commercial and recreational fishing or on individual species via new competitive interactions.

Assisted colonisation

Assisted colonisation – moving species to sites where they do not currently occur or have not been known to occur in recent history [62] – is being trialled as a response to range contractions and potential extirpations caused by climate change. In the UK, two native species of butterfly were recently translocated approximately 65 km northward into areas identified by modelling as climatically suitable for occupancy by the butterflies [63]. The endangered conifer (*Torreya taxifolia*), whose range in Florida may become climatically unsuitable in the future, has also been introduced to sites some 600 km away. Given that 15–37% of terrestrial species may be threatened with extinction by 2050 due to climate change [64], assisted colonisation is likely to be increasingly considered as a conservation strategy. However, non-native species are recognised as a major conservation problem and assisted colonists could be viewed as invasive. Assisted colonisation has therefore been described by some authors as ‘tantamount to ecological roulette’ [65]. Others have suggested that such risks can be minimised by rigorous assessment protocols [66], or by restricting translocation efforts to genotypic variants within existing ranges [62].The vigorous debate over assisted colonisation [67,68] is likely to intensify as individuals and organisations begin to translocate organisms beyond their recent range.

Possible impact of REDD on non-forested ecosystems

The focus of the proposed United Nations mechanism for Reducing Emissions from Deforestation and Forest Degradation (REDD) is on minimising carbon emissions caused by destruction of living forest biomass [69]. Enhanced forest protection may increase pressure to convert or modify other ecosystems, especially savannahs and wetlands, for food or biofuel [70]. Some of these ecosystems may also have high carbon sequestration potential or contain very large volumes of non-living soil carbon. Globally, peatlands cover only 3% of the land surface but store twice the amount of carbon as all the world's forests [71], whilst mangrove forests and saltmarshes are examples of relatively low-biomass ecosystems with high levels of productivity and carbon sequestration [72,73]. REDD thus has the potential to negatively affect species and ecological processes in non-forested ecosystems and to reduce carbon sequestration.

Large-scale international land acquisitions

One effect of the recent global food and financial crises is accelerating acquisition of large areas of arable land in developing countries by foreign governments and private companies. The purchasers aim to ensure food supply in their home country and investment returns [74–76]. Parcels of several hundred thousands of hectares are being bought or leased in Africa, Central and Southeast Asia, and Eastern Europe by food-importing countries with domestic land and water constraints but abundant capital, such as the Gulf States, or by countries with large populations and food security concerns, such as China, South Korea and India. These land acquisitions have the potential to inject investment, technology and market access into agriculture and rural areas in developing countries. However, conversion of forests and grasslands to intensive agricultural production and monocropping may threaten biological diversity, carbon stocks and water resources. Enforcement of environmental laws might be simpler when there are few large-scale land owners rather than many small-scale farmers. However, such large-scale land acquisitions also raise concerns about the potential impacts on local people, who risk losing access to and control over resources on which they depend [77].

Conclusions

Our horizon scanning process identified 15 issues, associated with diverse taxa, phenomena and locations, which may affect our ability to achieve conservation objectives in the near to medium-term future. Conservation professionals traditionally focus on issues of well-recognised importance. We suggest that greater attention be given to more speculative issues and to those, such as nanotechnology, which are established in other disciplines but have not yet been linked strongly to conservation. The merit of this is that conservation issues may be better accommodated in policy and management if they are identified early.

Climate change is a dominant concern in conservation science and policy, and many of the issues highlighted by our horizon scanning relate to direct impacts or potential human responses to climate change. Policy responses, such as Reducing Emissions from Deforestation and Degradation (REDD) and geoengineering, will have considerable influence on natural systems in a manner that cannot be predicted by current Global Circulation Models. Similarly, predicting the impacts of synthetic materials such as microplastics and nanosilver is a serious scientific challenge for our community.

Several of the issues we identified relate to technological innovations. Some of these, such as nanosilver, have already provided substantial benefits to consumers and industry and thus their use may be difficult to reverse, even if the technology proves to have undesirable effects on aquatic and terrestrial ecosystems. For technologies at early stages of development (e.g. creation of artificial life and synthetic meats), it may be possible to conduct early assessments of their effects on biological diversity that can inform development of regulatory frameworks. Technological innovations also bring opportunities, such as those presented by the advent of mobile (cellular) phone monitoring. The diffuse network of monitoring points that mobile phone users can represent far exceeds our current coverage capabilities.

Believing that advance notice is desirable, we sought to identify a range of potentially important issues that are poorly recognised. In discussing the list of issues with various scientists and policymakers, we believe we have achieved this objective. This does not mean that the issues are necessarily the most globally relevant or that a different team would have identified exactly the same issues.

Our additional aim is to encourage further consideration of these issues. Some may indeed not hinder conservation outcomes in the future. Others may bring considerable benefits to biological diversity and human society. Strategic targeting of research efforts may lead to a more timely appreciation of the conservation threats and opportunities presented by the issues highlighted here.

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