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PRIORITY CONTRIBUTION

Future novel threats and opportunities facing UK biodiversity identified by horizon scanning

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Summary

1. Horizon scanning is an essential tool for environmental scientists if they are to contribute to the evidence base for Government, its agencies and other decision makers to devise and implement environmental policies. The implication of not foreseeing issues that are foreseeable is illustrated by the contentious responses to genetically modified herbicide-tolerant crops in the UK, and by challenges surrounding biofuels, foot and mouth disease, avian influenza and climate change.

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2. A total of 35 representatives from organizations involved in environmental policy, academia, scientific journalism and horizon scanning were asked to use wide consultation to identify the future novel or step changes in threats to, and opportunities for, biodiversity that might arise in the UK up to 2050, but that had not been important in the recent past. At least 452 people were consulted.

3. Cases for 195 submitted issues were distributed to all participants for comments and additions. All issues were scored (probability, hazard, novelty and overall score) prior to a 2-day workshop. Shortlisting to 41 issues and then the final 25 issues, together with refinement of these issues, took place at the workshop during another two rounds of discussion and scoring.

4. We provide summaries of the 25 shortlisted issues and outline the research needs.

5. We suggest that horizon scanning incorporating wide consultation with providers and users of environmental science is used by environmental policy makers and researchers. This can be used to identify gaps in knowledge and policy, and to identify future key issues for biodiversity, including those arising from outside the domains of ecology and biodiversity.

6. *Synthesis and applications.* Horizon scanning can be used by environmental policy makers and researchers to identify gaps in knowledge and policy. Drawing on the experience, expertise and research of policy advisors, academics and journalists, this exercise helps set the agenda for policy, practice and research.

Key-words: conservation, conservation policy, decision making, environmental risk, nanotechnology

Introduction

The importance of horizon scanning is increasingly recognized by the UK government (King & Thomas 2007), and by commercial organizations, as having a major contribution to make to strategic planning, risk management and policy making. It can also inform research prioritization. For policy makers and practitioners to make informed decisions, they require an evidence base on potential effects, and an assessment of the options for remedial policy responses. This evidence base needs to cover all relevant policy aspects: political, social and economic, as well as environmental and scientific. There is therefore a need for research relevant to policy issues that anticipates the future requirements of decision makers. Policy makers need to articulate the issues that they might have to deal with in the future for which they lack relevant information.

Information and evidence to support important policy decisions concerning biodiversity conservation may not be available at the right time for several reasons. Some issues occur suddenly and unexpectedly, so delays before science catches up may be unavoidable. However, many biodiversity challenges are the result of technical developments or environmental change with known or suspected impacts on biodiversity, while others result from an acceleration of current patterns of change or new legislation. Examples of previous issues in the UK include the impact upon biodiversity of genetically modified herbicide-tolerant crops in the UK and the issuing of the EU Water Framework Directive.

Why is the evidence-base relevant to these problems so often late or lacking? Sometimes scientists look ahead and spot a problem, but do not pursue it because of competing short-term interests or because they do not convince other scientists and policy makers with control of research funding that it should be examined in more detail. Issues may not be communicated well enough or there may be insufficient collaboration with other specialists when an interdisciplinary approach is necessary. Policy makers also foresee problems, but they may not be taken up by scientists because of differences in language, ways of thinking and lack of frequent contact. Furthermore, policy makers may not have the levers to direct science funding accordingly. We argue that these problems can be addressed by finding more effective ways for natural scientists to work across disciplines (including social sciences) and for scientists and policy makers to communicate with one another across the boundaries between disciplines about future problems. In this paper we present the results of such an exercise in consensual horizon scanning.

An important objective of horizon scanning is to identify those issues that are only just beginning to emerge, and whose impact is, at present, highly uncertain. These 'weak or conflicting signals' are worth tracking across a wide range of disciplines because, although some will turn out to be irrelevant, a proportion will develop into the central issues of the future. They often emerge in disciplines or sectors other than environmental sciences, hence the importance of scanning the horizon widely. The aim of this paper is to identify some of the future issues that might challenge conservation of biodiversity in the UK before 2050. It does not aim to be predictive and some of these issues may turn out to be unimportant. Some may also be less important than well-known, existing issues. Our approach was to use the expertise of the main UK governmental and non-governmental organizations and a range of academics, journalists and horizon scanners to identify and prioritize a list of issues. Many issues have both associated threats and opportunities.

Methods

Our approach builds on a previous exercise with a similarly composed group that identified the 100 ecological questions UK policy makers most wanted answered (Sutherland *et al*. 2006). In that exercise, selection of the questions was made entirely by the policy makers, with the academics facilitating and injecting information; for example, advising that a proposed question could already be answered. In the present exercise the policy makers and academics played equal roles in deliberation and prioritization of issues. The current exercise also had a more formal process of scoring and prioritization. Although a range of organizations have carried out horizon scans this was novel both by being restricted to issues relating to biodiversity and in the combination of wide participation and rigorous processes for selecting issues.

Twenty-three governmental organizations, charities or businesses selected representatives to send to the meeting. They were joined by 12 academics. A science and technology journalist provided insights into future technological developments and a member of the UK Government Horizon Scanning Centre was invited to provide other perspectives. The author list provides details of participating organizations. Each participant consulted within and beyond their organization to generate issues; at least 452 individuals were consulted. Previous horizon scanning exercises that related to biodiversity were searched for possible issues, including: The UK Government Office for Science's Foresight programme and Horizon Scanning Centre's Delta and Sigma Scans (www.foresight.gov.uk), the Futures of the Wild Project (WCS Futures Group 2007), the Environment Agencies internal Horizon Scanning interactive database, Defra's Natural Resources Protection Trends Study (http://www.defra.gov.uk), paperwork for the then forthcoming Environmental Research Funders' Forum report (Environmental Research Funders' Forum 2007), the UK Biodiversity Research Advisory Group identification of research needs (Ferris 2007) and a report from the Centre for Environment, Fisheries and Aquaculture Sciences on future scenarios for marine ecosystems (Pinnegar *et al*. 2006).

To be included in the exercise, issues had to have the potential to impact upon biodiversity by 2050 in a manner important to policy makers and relevant to the UK (including waters of the Exclusive Economic Zone, but excluding the Overseas Territories), although the impacts could be a consequence of changes occurring outside this area. The aim was to determine issues that were novel and not a simple continuation of a current issue. In practice, almost all of the suggested issues currently occur to some extent somewhere and a major challenge was to evaluate the extent to which there is likely to be a step change in the potential impact in the UK.

A document listing and briefly describing the issues was repeatedly circulated amongst participants for additions and comments. At this stage, all comments were maintained in the 39 792 word document within the list of 195 issues. These issues were initially organized into 12 sections, such as people–biodiversity engagement or energy supply and demand, with coordinators responsible for collating the various suggestions and comments from the participants.

Prior to the meeting, participants scored those issues for which they felt they had sufficient expertise (many people scored all) on four 1–9 point scales: likelihood of occurrence, impact, novelty, and whether the issue should be included as one of the final 25 most important issues. Participants did this independently of other participants, but the scoring was often in collaboration with other experts in the same organization. The mean scores were distributed to all participants prior to a 2-day workshop in September 2007. The first day consisted of four groups of three parallel workshops covering the 12 subject areas and chaired by respective coordinators. Each issue was discussed, a decision was made as to whether it should be shortlisted, and shortlisted issues were then ranked in importance. Most issues were modified during this process and some were created by combining others giving a final shortlist of 41 issues. During the second day, each issue was described by the coordinator, discussed by the whole workshop and then given a single score (1–9 scale) by all participants. Issues were ranked by mean score and the final list of 25 issues was agreed in a final session.

Three parallel groups assessed whether the likelihood of occurrence and likely impact was 'low', 'medium' or 'high' based upon the initial scoring by all participants and subsequent discussion. Threats, opportunities and research priorities were agreed and tabulated. Summaries were prepared for the 25 shortlisted topics.

Accounts of issues

The threats, opportunities and research needs associated with each issue are listed in Table 1. Summary accounts follow.

NANOTECHNOLOGIES

These are a revolutionary set of technologies involving particles near, or substantially below, 100 nm scales. Due to their size and surface characteristics, nanoparticles have remarkable activity, behaviour and, possibly, biological properties, which provides a challenge to predicting their impact (Maynard *et al*. 2006). Future economic (*c.* \$1 tn p.a. globally within a decade) and social benefits are expected in medicine, electronics and the environment. Actual and candidate substances include: carbon nanotubes; particles based on metals like titanium, cadmium and cerium; and polymers of modified amino- or nucleic acids. Nanoparticles may exhibit toxicological mechanisms in the mammalian lung different from those of classically manufactured equivalents (Dreher 2004). Early evidence suggests nanoparticles irritate gills in fish (Smith *et al*. 2007), affect redox states and bind pollutants in ways that alter their bioavailability, bioaccumulation and movement. Benefits to biodiversity might arise from reductions in pollution and reduced bioavailability of chemicals following binding to nanoparticles. Challenges ahead include nanostructures, or their debris, that mimic functions found in cells (e.g. electron transport). Here, effects at surfaces or pores central to functioning in biological and environmental systems may be most important. If use becomes widespread or the structures are incorporated into 'near-living' systems, new approaches to risk will be needed.

INVASIVE POTENTIAL AND POSSIBLE ECOSYSTEM IMPACTS OF ARTIFICIAL LIFE AND BIOMIMETIC ROBOTS

Artificial life is being created in two ways. First, organisms may be engineered using synthetic oligonucleotides (Smith *et al*. 2003), with the Venter Institute recently applying for worldwide patents for a synthetic microbe, *Mycoplasma laboratorium*. Secondly, simple living systems are being created from non-living organic and inorganic materials through

Table 1. A summary of the issues, opportunities, threats, research needs, assessed likelihood and anticipated impact (opportunity, threat) on biodiversity. The issues in the table are not in rank order. Question marks signify particular uncertainty. A gap means no issues were identified

Issue	Opportunity	Threat	Research needs	Likelihood	Opportunity	Threat
Nanotechnologies	Binding of other substances reduces their impact on biodiversity. Opportunities for bioremediation	Toxicity, physical impacts and increased bioavailability	Characterize particles, identify sources and transport pathways, determine and quantify effects and their mechanisms, assess biodiversity impacts. Bioremediation techniques. Understand drivers for development, use and regulation	High	?	?
Invasive potential and possible ecosystem impacts of artificial life and biomimetic robots	Provision of ecosystem services; pollution control	Unknown, but may be analogous to invasive species	Assess remediation potential, dispersal and impacts. Efficacy of termination procedures. Understand drivers for development, use and regulation	Low	?	?
Unintended consequences of pathogens developed by modern biotechnology methods		Genetically modified pathogens (e.g. virally vectored immunocontraceptives) impact UK biodiversity	Determine host specificity including ability to evolve. Assess likelihood of spread outside intended range	Low		?
Direct impact of novel pathogens	Potential increases in community diversity	Widespread reduction in the abundance of key/critical species	Routine horizon scanning of emergent disease threats to biodiversity, their impacts and possible interventions	High	Low	High
Impacts of control efforts for novel pathogens		Vector habitat removal and chemical/biological control impacts	Analysis of trade-off between conservation need and effectiveness of disease control. Development of acceptable control regimes	High		Medium
Facilitation of non-native invasive species through climate change and 'invasional meltdown'	Possible increases in ecosystem function and diversity	Domination of communities by invasive species. Native species extinctions	Identify conditions for invasional meltdown. Identification of potential invaders and control strategies	Medium	Low	High
Large-scale restoration for iconic wildlife and habitats	Restoration of sustainable food-webs	Low cost-effectiveness, and diversion of conservation resources from critically threatened species/habitats	Identification of the scale at which iconic species and habitats are viable, the consequences for other species, and the socio-economic costs and benefits	Medium	High	Low
Action to facilitate species range change in the face of climate change	Facilitates dispersal and conservation objectives	Consequences of management actions may be unpredictable and damaging	Effectiveness of translocations. Understanding range shifts. Trade-offs between translocations and increasing connectivity	High	High	High?

Table 1 *Continued*

Issue	Opportunity	Threat	Research needs	Likelihood	Opportunity	Threat
Frequency of extreme weather events	Certain species might benefit, e.g. from fewer cold winters; early successional species might benefit from drought and storms	Extreme events reduce biodiversity, cause local extinctions	Review frequency and impacts of extreme events and predict probabilities. Mesocosm experiments on extremes. Assess sensitivity to combinations of extremes. Process based monitoring and investigation of extremes	High	Medium	High
Geo-engineering the planet to mitigate the effects of climate change	Mitigation of climate change impacts on biodiversity	Unknown or unforeseen consequences for biodiversity	Risk assessment of geo-engineering schemes	High	High	High
Implications for biodiversity of the adoption of an ecosystem approach	More sustainable and widely supported conservation programmes developed	Biodiversity protection no longer the top priority for land management	Develop and test framework for the ecosystem approach, which quantifies the economic, social, soil and biodiversity elements	Medium	High	Medium
Increased fire risk	Benefits to fire tolerant species and early successional communities. Better fire management regimes create new habitat opportunities	Changed fire regimes negatively impact on species and communities, especially in non-fire-adapted habitats	Development and assessment of fire management regimes for biodiversity. Developing new technologies for predicting and detecting fires	High	Low	High
Increasing demand for biofuel and biomass	Reduced cultivation techniques used for biomass crops. Some crops may be of greater conservation interest than conventional crops or land uses	Loss of semi-natural habitat, increased intensification, pesticide use and water use in agricultural land	Quantify the biodiversity associated with each crop, and the impact of location and scale of development. Understand demand, uptake and regulation	High	Low	High
Step change in demand for food and hence pressure on land for agriculture		Loss of semi-natural habitats and increased intensification of farmland	Risk assessment for novel cropping system. Understanding farmer responses to increased food prices and production incentives, and development of new regulatory approaches	Medium	High	High
Ocean acidification	Potential increase in non-calcifying organisms	Reduced calcification rates of marine organisms. Decrease in calcifying (shelled) marine organisms	Estimate population and biological community consequences of reduced calcification. Possible interventions	High	?	?
Reduction of coldwater continental shelf marine habitats	Expanding potential range of warm-tolerant species and habitats	Shrinking potential range of cold-tolerant or cold-requiring species and habitats	Develop climate envelope-type models to predict the movement and extinction probability of species, including research on the scale and extent of marine habitats and habitat specificity of species. Implications for management of marine ecosystems, fisheries and protected areas	High	Medium	High

Table 1 *Continued*

Issue	Opportunity	Threat	Research needs	Likelihood	Opportunity	Threat
Significant increase in coastal and offshore power generation	Creation of safe havens for some marine species by physical exclusion of fishery activity	Loss of key estuarine and coastal habitats with risk to migratory birds, fish, sea mammals. Negative effects on benthic habitats and species	Assess impacts of schemes. Comparative cost-benefit analysis of renewable energy schemes and identification of optimal locations and scale. Life-cycle analysis to include biodiversity impacts	High	Low	High
Extreme high-water coastal events	Ecological succession following event. Restriction in development along coastlines and adoption of managed coastal retreat	Loss of coastal and intertidal habitats and low-lying freshwater bodies, effects of salinification	Understanding ability of coastal vegetation and intertidal systems to respond. Scenario and restoration planning. Design of resistant coastlines	Medium	High	High
Sea level rise resulting in loss of coastal and intertidal habitats	Potential for the creation of new inshore benthic habitats	Loss of coastal and intertidal habitats	Quantify dynamic melting of ice sheets. Identify wider freshwater, agriculture, and coastal biodiversity adaptation options (managed retreat) and consequences for future terrestrial and marine spatial planning	Low	Medium	High
Dramatic changes in freshwater flows	Increased connectivity and extent of wetlands in higher flow areas	Altered ecological communities in rivers, wetlands, estuaries and coastal waters; loss of connectivity in lower flow areas	Monitoring and assessment of ecological impacts of extreme flows. Develop models of cumulative impacts. Determine impacts of increasing hydrological connectivity and decreasing ecological connectivity. Cost-effective management interventions	High	Medium	High
Nature conservation policy and practice may not keep pace with environmental change		Conservation objectives may be inappropriate or unattainable	Tested forecasting of biodiversity responses to environmental change, and understanding of institutional and cultural constraints to change. Methods for risk assessment in setting conservation priorities	High		High
Internet and new e-technologies connect people with information on the environment	Improved knowledge, understanding and engagement with biodiversity issues	e-technologies become a substitute for experiencing real biodiversity	Development and deployment of novel technology designed to encourage engagement, data collection and dissemination	Medium	Low	High
Decline in engagement with nature		Reduced environmental knowledge and concern	Understand how people engage with nature, and undertake longitudinal studies of changes in attitude and behaviour	High		High
Adoption of monetary value as the key criterion in conservation decision-making	Integration of biodiversity into mainstream decision-making	Shifts in values and perceptions of biodiversity. Potentially low biodiversity values downgrade perceived value of conservation	A research tool that integrates biodiversity values appropriately into decision making	High	High	Medium
Public antagonism towards wildlife due to perceived human health threat		Hostility reduces tolerance and support for wildlife conservation	Understanding what forms public attitudes and how these may be influenced	High		High

self-assembly, with metabolic processes driven by an external supply of free energy. Such artificial organisms have living characteristics (autonomous metabolism, self-replication, evolvability). In future, there are real possibilities of release into the environment, accidentally or maliciously, of synthetic life-forms that become 'invasive'. These may have unpredictable effects, such as organisms created for biofuel production and therefore ostensibly benign, or more predictable, where pathogens are constructed. Further, biomimetics are being used to develop robotics capable of animal-like behaviour (e.g. Meyer *et al*. 2005). Most of these developments are for military purposes, toys or pets, but may become novel invasive species.

UNINTENDED CONSEQUENCES OF PATHOGENS DEVELOPED BY MODERN BIOTECHNOLOGY METHODS

Genetic engineering of pathogens could have future impacts on UK biodiversity. For example, experimental viruses have been produced that have contraceptive effects on the host (Hardy *et al*. 2006). The virally vectored immunocontraceptives produced to date have been designed to target red foxes *Vulpes vulpes*, in Australia where these species are non-native pests (and have major conservation impacts on native biota), while other programmes target mice (Arthur *et al*. 2007). If licensed and released elsewhere, it is probable that deliberate or accidental release would eventually occur in the UK, even though the target species may be native. Depending on the host specificity of the virus, and of the antigen promoting immunocontraception, such a pathogen might also impact upon related species especially if absent from the countries where the pathogens were developed and so not considered in local risk assessments. As genetic engineering becomes easier, control and regulation is likely to become much more difficult.

DIRECT IMPACT OF NOVEL PATHOGENS

The UK is very likely to have to deal with novel pathogens. These may suddenly emerge, as in the *de-novo* emergence of Devil Facial Tumour Disease, which is locally eliminating the Tasmanian devil *Sarcophilus laniarius* (Hawkins *et al*. 2006). Alternatively, novel pathogens may arrive from overseas. A series of fungal pathogens have devastated North American forests (Holdenrieder *et al*. 2004). *Phytophthera ramorum* has recently appeared in the UK and could have similar impacts on native woodlands. Not only can such pathogens threaten the host species, but they may also profoundly influence community dynamics where the susceptible species have strong interactions with others.

IMPACTS OF CONTROL EFFORTS FOR NOVEL PATHOGENS

New pathogens of people and livestock are likely to become established in the UK in future years, particularly as climate change facilitates the persistence of arthropod vectors that could not survive formerly. Attempts to control such emerging pathogens may include both increased use of insecticides (with impacts on biodiversity) and also habitat modification. For example, while the re-establishment of malaria in the UK is considered unlikely, widespread drainage of wetlands has been linked to the eradication of this disease (Kuhn *et al*. 2003). If malaria – or a pathogen dependent on a similar vector – were to (re)invade the UK, drainage of ponds and larger wetlands could well be recommended, as has been reported as a response to avian influenza in Russia and Asia, and the creation of large new wetlands might be impeded on public health grounds.

FACILITATION OF NON-NATIVE, INVASIVE SPECIES THROUGH CLIMATE CHANGE AND 'INVASIONAL MELTDOWN'

Climate change may facilitate the spread of damaging non-native species (Simberloff 2006); for example, allowing establishment of species that are currently held in check by winter temperatures. Establishment of non-native algae in UK freshwaters may reduce biodiversity, for example through allelopathy (Figueredo *et al*. 2007). Retraction of the Arctic ice edge will facilitate invasion of marine species from the Pacific Ocean to the Atlantic through increased Arctic shipping (Wilson *et al*. 2004) and wind-driven transport of plankton (Reid *et al*. 2007). Further, 'invasional meltdown' may occur as each invader facilitates subsequent invasions (Simberloff 2006). This could accelerate biodiversity change in future and 'invasive communities' might emerge. Alternatively, species new to the UK could occasionally have benefits, such as replacing lost species and their ecological functions.

LARGE-SCALE RESTORATION FOR ICONIC WILDLIFE AND HABITATS

In the last 20 years some of the most prominent conservation programmes have involved species restoration (e.g. corncrake *Crex crex* and bittern *Botaurus stellaris*) or reintroductions (e.g. white-tailed eagle *Haliaeetus albicilla* and red kite *Milvus milvus*). Looking ahead, the next phase of such programmes could be allied to large-scale habitat/ecosystem restoration where there will be more emphasis on ecosystem functions and processes (Sutherland 2002a). Vera's (2000) suggestion that some of western Europe's landscapes were kept open by herbivores, and that many species are dependent upon grazed landscapes, has underpinned much of the philosophy in this area (Sutherland 2002b). Within Europe, restoration possibilities are illustrated by experience from the Oostvaardersplassen, a 5600 hectare reserve in the Netherlands created in 1974–78 in a newly created polder (Sutherland 2002b) In the UK, comparable large-scale restoration schemes are likely to occur in low-lying basins susceptible to flooding (East Anglian fenlands) and in the uplands (possibly in the Lake District and the Scottish Highlands), where there could be more emphasis on iconic species such as the lynx *Felis lynx* as motivation for ecosystem restoration.

ACTION TO FACILITATE SPECIES RANGE CHANGE IN THE FACE OF CLIMATE CHANGE

Projected climate change is likely to change the area within the UK that is climatically suitable for many species (Walmsley *et al.* 2007). The rate at which species' distributions respond is likely to vary enormously. Some species may be unable to keep pace with climate change because of their limited dispersal ability combined with too few or remote habitat patches available for colonization. If existing sites become less suitable they could become scarcer even though suitable habitat is available elsewhere. Conversely, mobile and generalist species may move rapidly (Warren *et al*. 2001). Improving habitat connectivity and permeability or appropriate translocations could facilitate welcome increases in some taxa, as already seen by the natural colonization and spread of species such as the silver-spotted skipper butterfly *Hesperia comma* (Thomas *et al*. 2001). Current conservation guidelines do not facilitate movement of species outside their known historical ranges. However, under climate change this may not be appropriate (McLachlan *et al*. 2007). Measures will be taken to facilitate species dispersal by improving the ecological networks through habitat protection, restoration and creation (Hopkins *et al*. 2007).

FREQUENCY OF EXTREME WEATHER EVENTS

With climate change, there is expected to be an increase in extreme events, both as a result of changes to the mean climatic conditions and as a result of increases in variance (Solomon *et al*. 2007). Currently, there is a very poor understanding of how individual extreme weather events and their frequency of occurrence impact on species and communities. A decline in the number of frosts, for example, can be expected to lead to the range expansion of frost-sensitive species, and an increase in storms could lead to changes in forest structure, but the full implications of these and other extreme events for species distributions and community structure are poorly understood (Watkinson *et al*. 2007). Combinations of extreme events involving temperature, rainfall and wind are liable to have major, but unknown impacts on many aspects of biodiversity.

GEO-ENGINEERING THE PLANET TO MITIGATE THE EFFECTS OF CLIMATE CHANGE

Geo-engineering, the large-scale manipulation of the Earth's environment, is increasingly attracting attention as a way of mitigating against climate change (Cicerone 2006). Proposals include injecting sulphur dioxide into the stratosphere to reflect sunlight; putting trillions of lenses in orbit to deflect the sun's energy; the construction of a giant orbiting mirror; augmenting oceanic primary production using iron fertilization; laying reflective plastic over the oceans or deserts; spraying water on ice sheets to stabilize the freshwater to saltwater ratio; pumping of sea-water droplets into the atmosphere to increase cloud cover and hence albedo, and the creation of 'synthetic trees' to absorb CO_2. However, changing the Earth's environment will almost certainly impact the Earth's biodiversity and in some cases will uncouple temperature and carbon dioxide rise (Wigley 2006). Possible consequences include enhancing acid rain through increasing stratospheric sulphur dioxide, while increasing oceanic primary production could affect dissolved oxygen levels. Research into the possible environmental impacts of geo-engineering will aid assessment of the overall merit of these mitigation technologies.

IMPLICATIONS FOR BIODIVERSITY OF THE ADOPTION OF AN ECOSYSTEM APPROACH

Land and water habitats form ecosystems, which provide a range of ecological, social and economic services (Millennium Ecosystem Assessment 2005). Traditional farming, forestry, game shooting, and more recently conservation interests, will probably be modified by other priorities, such as renewable energy production, carbon conservation, water catchment management (for flood control and provision of clean water) and tourism (Sutherland 2004; Thompson *et al*. 2005). The ecosystem approach offers a framework for management, which integrates the broad range of functions, costs and benefits. The role of biodiversity conservation in the delivery of ecosystems services will be more explicitly recognized if it can be appropriately valued, offering new opportunities for the direction of public support in the form of subsidies and incentives. There will probably be shifts from funding streams focused on agricultural support (under the EU Common Agricultural Policy) to schemes centred on carbon and water conservation, renewable energy support, diffuse pollution control and human health benefits. Such developments will require a shift in focus of conservation management practices, such as burning, bracken control and livestock grazing, towards novel goals centred on carbon, soil and water resource protection, as well as on health and wealth generation. Some aspects of biodiversity conservation are likely to benefit, but others may be adversely affected by the changes in land use required by this approach.

INCREASED FIRE RISKS

One of the most serious potential consequences of climate change is increased fire risk, especially in woodland, heathland and peatland areas where fuel loads are relatively high. Increased frequency of fire may result in substantial changes in community composition and structure, as well as in the spread of invasive plants (Ausden 2007). Recently, capabilities have been developed to predict fire risk on a daily basis (e.g. http://www.firebeaters.org.uk/). Novel means of predicting and managing fires are needed (e.g. Davies *et al*. 2006), together with a framework for assessing the long-term impacts of fire and fire management on wild species. If the risk of severe fire outbreaks increases, there can be losses of soil organic matter and carbon (Woube 1998). Changes in the phenology of flowering, insect emergence and animal life cycles (notably bird breeding seasons) will require adjustments to permitted prescribed burning regimes and timings (some of which are governed by legislation enacted decades ago, e.g. Hill Farming Act 1946).

INCREASING DEMAND FOR BIOFUEL AND BIOMASS

By 2020 UK Government targets are for one-fifth of total energy supply to come from renewable sources. This will include bioethanol from wheat and sugar beet, biodiesel from oil seed rape and novel crops such as monocultures of high-sugar grass species or biomass crops such as *Miscanthus* and willow (Tuck *et al*. 2006). Direct negative effects on biodiversity may include the introduction of non-native, potentially invasive, species (e.g. Raghu *et al*. 2006), greater intensification of remaining cropland for food, loss of semi-natural habitats, increased use of herbicides and pesticides on biomass crop monocultures and increased demands for irrigation. However, these crops may be subject to wider environmental considerations and could be managed in ways that promote biodiversity (e.g. biomass crops may provide more stable habitat networks in the agricultural landscape). The overall impact will depend on the intrinsic value of the crop relative to alternative land-uses and their location, scale and spatial distribution.

STEP CHANGE IN DEMAND FOR FOOD AND HENCE PRESSURE ON LAND FOR AGRICULTURE

The intensification of agriculture has been one of the major conservation challenges of recent decades and is not a novel threat to biodiversity. However, political unrest and instability, climate change, increasing human population, increased wealth (especially in India and China), and novel crops (e.g. providing pharmaceuticals, plastics, or fuel) could result in growing food security issues and a step change in the demands for UK agricultural production (Defra 2006). Pressures, responses and impacts will be complex, but may result in intensification of production on agricultural land, the introduction of new crops and the cultivation of seminatural habitat. The existing regulatory systems to protect biodiversity in the agricultural environment may be threatened and incentives for agri-environment measures may be inadequate in the face of sudden increases in demand and change in public attitudes regarding food security.

OCEAN ACIDIFICATION

Ocean pH is predicted to decrease by 0·3–0·5 pH units by 2100, changes that are 100 times faster than those seen over the last 100 000 years (Haughan, Turley & Poertner 2006). The reduction in carbonate ions is likely to make skeletal construction and maintenance more costly for organisms with calcareous exo-skeletons (molluscs, corals and plankton, such as coccolithophores) with potential impacts on fish where calcifying organisms are major components of the diet. While the predicted pH change is almost certain, the ecological and biodiversity effects are largely unknown and difficult to evaluate at the appropriate spatial scale (Anonymous 2005; Haughan, Turley & Poertner 2006).

REDUCTION OF COLDWATER CONTINENTAL SHELF MARINE HABITATS

Mean temperatures in European shelf seas are rising faster than on the adjacent land masses and faster than global average temperatures while extreme events are becoming more frequent (Mackenzie & Schiedek 2007). Warming seas have increased habitat availability for southern species and northern species have moved northwards (Perry *et al*. 2005) with consequences for birds and mammals feeding at higher trophic levels (Harris *et al*. 2007). It is not clear whether cold-water communities are shifting northward or whether there is a squeeze or reduction in habitat area given that the reduced area of shallow continental shelf restricts the capacity of species to move north.

SIGNIFICANT INCREASE IN COASTAL AND OFFSHORE POWER GENERATION

The drive for more energy generated from alternative sources may arise from uncertainty of energy supplies from outside the UK and/or increased consumer demand for 'clean' renewable energy. Some impacts on biodiversity of estuarine tidal power generation, wave-power and offshore windfarms are already known, but the evidence-base is poor (Hossel *et al*. 2006; Stewart *et al*. 2007) and large-scale investment in coastal and off-shore power generation has the potential to impact on marine and coastal biodiversity much more widely (Gill 2005). The individual and cumulative impacts of renewable energy developments on biodiversity need to be understood, including negative impacts on specific habitats and species, and associated changes in sedimentation or current patterns (e.g. from tidal energy schemes). Biodiversity impact assessments of the entire enterprise, including construction, maintenance, grid connection and decommissioning are needed. Indirect impacts, such as fishery exclusion zones associated with wind farms and wave and tidal power generators, may provide positive opportunities for biodiversity.

EXTREME HIGH-WATER COASTAL EVENTS

Extreme new high-water levels may be generated by increasingly frequent high energy storms and tsunamis hitting shorelines with increased sea levels and steeper shores, resulting in increased run-up heights. Approximately five North Atlantic tsunamis take place per century (Andrade *et al*. 2006), and the risk may be increased by marine construction and drilling (Solheim *et al*. 2005). Extreme events are likely to swamp coastal defences, generate ingress of salt water into brackish and freshwater systems (e.g. Norfolk Broads), deposit marine sediments inland, and re-deposit sediments in the intertidal and subtidal zones. Much of the UK's coastal biodiversity is vulnerable because it has been reduced to a narrow strip squeezed between sea-wall defended agriculture or urbanization and the sea. Potential damage may be compensated by policies allowing natural processes to re-assert themselves along coastlines and by recreation of intertidal habitats.

SEA LEVEL RISE RESULTING IN LOSS OF COASTAL AND INTERTIDAL HABITATS

Over the course of the current century, sea level is projected to rise by up to 0·6 m (IPCC 2007), although this is based largely on thermal expansion of the seas and does not take into account emerging evidence for rapid dynamic disintegration of ice sheets (Hansen 2007). Hansen (2007) argues that sea level change of the order of metres on a century timescale is conceivable. Coastal habitats (especially grazing marsh, saltmarsh, maritime cliffs and saline lagoons) are most at risk from sea level rise as they are squeezed between sea and intensive agricultural land. Under extreme sea level rise there may be benefits of creating more subtidal habitat, though this may be offset by the loss of present littoral habitat.

DRAMATIC CHANGES IN FRESHWATER FLOWS

Climatic and societal change could have dramatic consequences for water resources and the ecology of freshwater environments (Wilby *et al*. 2006). While there is considerable uncertainty over future freshwater flows, it is highly likely that we will see reduced summer and increased winter river flows, as well as an increase in the frequency and magnitude of flooding at any season. These changes will impact directly on the freshwater environment and also indirectly through changes in flood risk management and water abstraction. There are potential opportunities for biodiversity conservation that relate to flood mitigation measures through catchment storage and management (Watkinson *et al*. 2007), but also concerns over substantially reduced flows in some areas including major changes to sediment transport and concomitant physical modification of aquatic habitats; drying and isolation of wetland habitats; and changes in the supply of contaminant, nutrients and organic matter to estuaries. These will impact water quality and also produce significant alterations to ecological communities in rivers, wetlands, lakes, estuaries and coastal waters that are difficult to predict.

NATURE CONSERVATION POLICY AND PRACTICE MAY NOT KEEP PACE WITH ENVIRONMENTAL CHANGE

Changes in species' distributions and community composition are already taking place, associated with climate and land-use changes, at even more rapid rates than those with which we are familiar (e.g. Warren *et al*. 2001). The current legislative frameworks, such as the EC Habitats Directive (92/43/EEC), Birds Directive (79/409/EEC) and Sites of Special Scientific Interest, successfully underpin the protection of habitats and species. Further scientific work is needed to identify ongoing and potential changes in species, habitats and ecosystem processes, and to inform development and tests of new approaches to conservation in dynamic environments. It may be necessary to modify some legislation, or the way in which it is applied, if legal protection of sites is to be maintained once the species and habitats for which they were designated decline or disappear. This will be necessary to prevent the loss of habitats and processes vital for the persistence, movement and colonization of species in response to climate change.

INTERNET AND NEW E-TECHNOLOGIES CONNECT PEOPLE WITH INFORMATION ON THE ENVIRONMENT

The internet is rapidly changing the way people interact with information. Not only has it allowed access to unprecedented levels of data but it also allows people to capture, store and pass on their individual experiences of the world. The combination of freely available data, human ingenuity and new technologies allows information about biodiversity and the environment to be tracked and recorded in new ways. This allows people to access details of environmental quality in their local area and make decisions on such information, thus increasing the likelihood of taking environmental action. New technologies may further allow people to monitor environmental indicators such as pollution sensors embedded in mobile phone handsets or personal DNA analysers to record local biodiversity. Creating, displaying and viewing of environmental data in this way may encourage people not only to interact more with their surroundings but also collectively to influence the future of biodiversity in their environments (Pretty 2003).

DECLINE IN ENGAGEMENT WITH NATURE

There is growing evidence that there has been a recent decline in engagement with nature and green places, especially amongst children and young adults (Louv 2005; Pretty 2007). Should this trend continue the demographic age distributions will result in widespread disengagement with nature across the generations by 2050. Young children today spend approximately half the time outdoors compared to those of 20 years ago. This leads to a fall in knowledge of biodiversity and associated accumulated memories, which in turn leads to a decline in likelihood of caring about the environment and biodiversity. If biodiversity memories (of specific species, habitats or encounters) are not created in this way, then there is likely to be diminished political support for biodiversity and environmental protection in the future. At the same time, declines in outdoor physical activity (as part of people's normal lifestyles) further decrease the likelihood of continuing engagement with nature and natural places, as well contributing to the obesity crisis. Structural changes in settlements (more suburban, more out-of-town shopping) are likely to increase the sedentary nature of lifestyles. Nature is also known to contribute to mental and physical health, thus giving biodiversity an additional value, which is not widely appreciated (Pretty *et al*. 2005, 2007; Fuller *et al*. 2007).

ADOPTION OF MONETARY VALUE AS THE KEY CRITERION IN CONSERVATION DECISION-MAKING

There is increasing interest in placing financial values on biodiversity and the services biodiversity provides (e.g. Constanza *et al*. 1997). Based upon a review of the economic studies that have assessed the value of natural habitats, Balmford *et al*. (2002) estimated that an effective global programme for conserving remaining natural communities has at least a 100 : 1 benefit:cost ratio. Stern (2007) used a financial analysis to show that it was sensible to invest now to reduce greenhouse gasses in order to reduce the risk of subsequent future costs resulting from climate change, which significantly contributed to climate change being taken more seriously by world leaders. A similar review of the economic benefits of biodiversity has been suggested. Economic analyses could also be used at a range of scales to assess the overall consequences of conflicting land use proposals and can direct landscape-scale planning.

PUBLIC ANTAGONISM TOWARDS WILDLIFE DUE TO PERCEIVED HUMAN HEALTH THREAT

Some pathogens that infect wildlife can also cause human disease. The perceived risk of acquiring such an infection is known to reduce people's willingness to interact with wildlife, and to increase their support for measures such as culling wildlife or physically separating wildlife from people through fencing (Peterson, Mertig & Liu 2006). Were infections such as avian influenza or rabies to become established in UK wildlife, public attitudes to biodiversity might be profoundly altered. This could lead to reduced political and financial support for conservation efforts, higher rates of killing wildlife (whether legal or illegal), and habitat management to reduce wildlife densities. Importantly, such a change in public attitude need not reflect the true risk of becoming infected, especially from a disease originating outside the UK. Understanding the drivers of public attitude is therefore vital to develop communication strategies that would encourage proportionate media and public responses to any novel pathogen.

Discussion

This exercise identified 195 environmental issues and then selected the 25 of highest relevance to UK biodiversity. We sought to identify the 25 of highest relevance but not to rank these (we believe it would need another round of discussion and voting to do this properly). However, with the methodology we used nanotechnology scored highest because of the uncertainties involved in both the way the technology would come to be used and the environmental impacts.

We anticipate that this paper will be used in four ways. First, that policy makers will examine how the issues identified here might impact upon their interests and then decide whether any warrant action and on what time scale. Secondly, we expect that this exercise will help the ecological research community engage in the likely issues of the future. The authors hope researchers, funders and those working on policy and regulation will use the outcome from this exercise when considering the future direction of strategic research. Thirdly, the approach can be used as a model for similar exercises applied to other subjects and geographical areas; for example, although our exercise probably has wide applicability for other temperate areas, there will be a very different set of issues affecting polar or tropical regions. It would also be useful to repeat this UK exercise at regular intervals, perhaps every 3 years. Finally, this exercise may encourage further consideration and debate about the issues that are on the horizon and the ways in which scientists and decision makers can best communicate about them.

This exercise involved participants with a wide geographical and subject coverage including participants from the natural sciences, social sciences, horizon scanning and journalism. We also incorporated issues from other horizon scanning exercises. Our experience was that this broad range of approaches and knowledge was invaluable and those, such as science journalists, who can identify issues outside those usually considered by ecologists, are particularly useful. A challenge is to identify people who can give a broad view of developments in other fields.

The issues identified by a group such as this one will undoubtedly depend on the people involved. That is why we initially placed a considerable emphasis on acquiring input from a range of organizations; this provided the opportunity to consult more widely and gain specialist inputs. For the workshop, the imperative was to have input from those who would take a broader perspective, but collectively covered a wide range of disciplines or interdisciplines. Nevertheless, there were a number of debates at the workshop that might have ended up differently with different advocates.

Two generic topics were repeatedly identified in different contexts during the workshop. These were: (a) the need to improve *risk assessment* procedures so that the Earth system and ecological factors could be taken more completely into account in environmental management; and (b) the need for intelligent surveillance and *monitoring* systems based on knowledge of ecological and environmental processes. Both developments will need research to identify environmental limits and indicators of change that provide early warnings of adverse impacts as part of an ecosystem-based approach to managing and properly valuing resources such as biodiversity. For a range of the issues, the potential threats could also be minimized through effective risk-assessment followed by appropriate monitoring and controls (e.g. novel pathogens, nanotechnology). Development of these procedures could and should complement many research activities.

How should we as a community deal with issues on the horizon? Once potential issues have been identified there is a need to assess the research and policy requirements and then determine the timeframe for development. For some issues it may be pragmatic to wait to see how they develop, while others might develop at a speed and have such impact that action is required urgently. We hope horizon scanning will help to reduce the frequency with which policy dealing with foreseeable issues has to be done in the absence of the appropriate research.

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