Cell PRESS

Forum

The need for environmental horizon scanning

William J. Sutherland[1] and Harry J. Woodroof[2]

[1] Conservation Science Group, Department of Zoology, University of Cambridge, Downing Street, Cambridge, CB2 3EJ, UK
[2] Foresight Horizon Scanning Centre, Government Office for Science, Department for Innovation, Universities and Skills, Kingsgate House, 66–74 Victoria Street, London, SW1E 6SW, UK

Policymakers and practitioners in most fields, including conservation and the environment, often make decisions based on insufficient evidence. One reason for this is that issues appear unexpectedly, when with hindsight, many of them were foreseeable. A solution to the problem of being insufficiently prepared is routine horizon scanning, which we describe as the systematic search for potential threats and opportunities that are currently poorly recognized. Researchers can then decide which issues might be most worthwhile to study. Practitioners can also use horizon scanning to ensure timely policy development and research procurement. Here, we suggest that horizon scanning is an underused tool that should become a standard element of environmental and conservation practice. We make recommendations for its incorporation into research, policy and practice. We argue that, as an ecological and conservation community, we are failing to provide timely advice owing to a weakness in identifying forthcoming issues. We outline possible horizon-scanning methods, and also make recommendations as to how horizon scanning could have a more central role in environmental and conservation practice.

Introduction to horizon scanning

Albert Einstein's aphorism 'I never think of the future. It comes soon enough' might seem sensible advice within a world absorbed by speculating about the outcomes of elections, competitions and sporting fixtures. However, there is good reason to think rigorously about the future. All decisions are made to influence the future, so it behoves all decision makers, be they in government, organisations or industry, to ensure that their decisions are informed by robust evidence about the range of possible, plausible, futures that might occur. Being surprised by foreseeable events can be costly, as can failing to identify and exploit opportunities. A solution to avoiding such surprise is, we argue, horizon scanning.

Current science assessments

There is a long tradition of researchers and developers considering what might happen in the future. In some areas, such as research and development in the military arena, there are sophisticated procedures for scanning for potentially useful ideas. However, in most other areas, including ecology and conservation, this has usually been done in an unsystematic manner, and processes are not in place for regularly informing practitioners and researchers about possible developments.

What is the problem?

Currently, a failure to identify and respond appropriately to potential forthcoming issues can result in policymakers making unwise decisions. For example, President Bush's 2006 State of the Union Address declared a commitment to promoting biofuels; the European Union then followed with a similar commitment. However, much of the necessary research on the impact of such fuels was only carried out after the strategic policy decisions had been made. This subsequent research revealed the ecological, social and climate change impacts of the expansion of biofuels [1,2]. In retrospect, it is clear that the scientific and environmental policy communities had paid insufficient attention to the biofuel issue, with the result that decisions were made largely without their input.

However, does a lack of preparedness, as illustrated by the issue of biofuels, really cause problems often? The European Environment Agency searched for issues with an excessive delay between problem recognition and appropriate action that resulted in unnecessary harm [3]. The 14 issues considered in which the delay caused unnecessary health or environmental harm included radiation, benzene, asbestos, halocarbons, bovine spongiform encephalopathy (BSE), sulphur dioxide and tributyltin. Two key lessons identified from across these case studies were that reducing the likelihood of such problems in the future requires the need to 'research and monitor for early warnings' and 'search out and address blind spots and gaps in scientific knowledge' [3].

The examples stated above show the need to be better prepared. In the UK, horizon scanning is now taken seriously by Government as a result of a series of perceived failures in science and policy. For example, the Government had not recognized the possibility that the public might have serious concerns about GM crops until they emerged in the media. For the outbreak of Foot/Hoof and Mouth Disease in 2001, which resulted in the culling of 10 million sheep and cattle and an estimated cost of £8 billion, the Government was initially insufficiently prepared and reacted poorly. However, a recent review of the use of science in policymaking identified the problem to be that science is not involved sufficiently early in the policy process [4]. Our experience is that the UK is probably further ahead in its use of horizon scanning than are most other countries, primarily as a result of the problems described above.

Corresponding author: Sutherland, W.J. (w.sutherland@zoo.cam.ac.uk).

Table 1. A taxonomy of horizon-scanning methods used in identifying and prioritising future possible issues[a]

Scanning stage	Method	Approach	Strengths	Weaknesses	Examples
Scoping	Interviews	One-to-one questioning (usually of senior experts or stakeholders) to identify issues and explore important driving forces and areas of uncertainty; can be highly structured, with no debate (e.g. '7 questions'), or open and involve discourse	Well understood, so generally accepted, technique; good at getting key individuals' perspectives on the future	No interaction among individuals with an interest or expertise	Environmental Research Funders Forum Horizon Scanning Study [19]
	Issue tree	Breaks down key question into a mutually exclusive and completely exhaustive set of sub-questions	Identifies the information needed to provide a complete answer to the key question	Less suitable for general or imprecisely scoped issues	Foresight project on Brain Science, Addiction and Drugs (http://www.foresight.gov.uk/OurWork/CompletedProjects/Brain%20Science/index.asp)
Gathering information	Literature searches and state-of-science reviews	Search for published threats and opportunities	Makes use of only published evidence (which might have been peer-reviewed)	Can be backward-looking unless a deliberate effort is made to produce outlooks of the future (as in Sigma Scan)	Literature search: Sigma Scan commissioned by UK Government Office for Science's Foresight's Horizon Scanning Centre. (http://www.sigmascan.org) State-of-science reviews: any Foresight project (http://www.foresight.gov.uk)
	Expert workshops	Bring together team of experts to suggest possible issues based on their own experience and knowledge of the literature	Use of experts provides credibility; interactive nature of workshops draws out deep (or partially formed) ideas, and refines issues	Findings will depend on who is involved; can also depend on process used to elicit their knowledge	Horizon scan of conservation issues in UK [11]. Assessment of 100 ecological questions of highest priority to global conservation [16] Delta (Science and Technology) Scan commissioned by UK Government Office for Science's Foresight Horizon Scanning Centre (now incorporated in their Sigma Scan) (http://www.sigmascan.org)
	Open fora	Contributions by anyone into, for example, an on-line forum (such as Wikipedia)	Makes use of 'wisdom of crowds', and, potentially, broadest possible range of contributors	Lacks a rigorous system for ensuring quality of entries	Future Wikia (http://future.wikia.com/wiki/Main_Page) http://signtific.org/
Spotting signals	Delphi questionnaire	Consultation of experts through questionnaire (usually two-stage)	Good at providing overview of what is happening in an area of science	Not interactive	The Millennium Project's Global Energy Scenarios (http://www.acunu.org/millennium/energy-delphi.html)
Watching trends	Trend analysis	Study historic performance to identify future trends	Aids identification and understanding of drivers	Past performance is not necessarily a guide to the future	A State of the Nation's Ecosystems 2008 [20] (http://www.heinzcenter.org/ecosystems/)
Making sense	Scenarios	Consider a range of possible future states and then explore the possible consequences of each	Helps organisations prepare for change, and test robustness of current strategies	Require substantial resources (time and expertise) to produce	Wildlife Conservation Societies' Futures of the Wild [21]
	Systems maps	Show the relationships between all factors influencing the central issue, and whether their effect is positive or negative	Provides an understanding of the range of issues influencing the central issue	Requires pre-existing knowledge	Foresight project on Tackling Obesities: Future Choices (http://www.foresight.gov.uk/OurWork/ActiveProjectsObesity/Obesity.asp)
Agree the response	Backcasting	Describe a vision of the preferred future, then identify the key steps needed to reach it	Can be done as a stand-alone exercise	Requires careful structuring to identify all relevant factors	Visioning and backcasting for UK Transport policy (http://www.ucl.ac.uk/~ucft696/vibat2.html)

[a]Some non-environmental examples are given to illustrate how the method could be applied. Foresight's 'toolkit' of futures techniques (http://www.foresight.gov.uk/toolkit) gives further methods and a range of case studies.

What is horizon scanning?

Horizon scanning requires a systematic approach to distinguish it from mere opining and similar less credible activities. It is necessary to ground mental excursions into future possibilities within a thorough understanding of the present (and, hence, also the past), while seeking out early signs of key developments. Climate change and terrorism inspired by religious views are examples of such early signals that have moved over 10–15 years from the margins of mainstream thinking to become issues that are central to many agendas. Energy security and food security have shown signs, in recent months, of following the same trajectory; whereas water security and loss of ecosystem services provided by biodiversity could become central to the thinking of society and government in the near future.

The use of systematic methods and processes for considering the future (Table 1) to inform strategy and policy is believed to have been confined within the UK Government to a few departments (e.g. Ministry of Defence) until the early part of this decade. Since then, most departments, and many Government Agencies, have established horizon scanning or futures groups, often as part of their strategy units or policy planning units. A specific technology futures programme was begun in 1994, when the Foresight Programme was launched (http://www.foresight.gov.uk/). By 1999, the Foresight Programme had widened its scope to include interactions between technology and wider market issues and social issues. Its area of interest broadened further within its programme of large projects that began in 2002, and the trend has been strengthened even more by the work of the Foresight Horizon Scanning Centre. This was launched in 2004 and conducts strategic futures work across the whole spectrum of public policy. Strategic futures activities of other governments have also tended to widen their scope as their potential value is recognized. For example, the Risk Assessment and Horizon Scanning Programme of Singapore (http://rahs.org.sg/) initially focused on national security, but is now extending its remit to other policy areas.

Applications of horizon scanning include strategy making, policy making, risk management, threat identification and research prioritisation. Although it is increasingly finding applications in government [5], industry and business [6], we suggest that horizon scanning is insufficiently used, including within the environmental field.

How is horizon scanning done?

The challenges of horizon scanning include obtaining relevant and credible evidence, and using it to prioritise the response. The objective is not to predict the future but to assist current decision-makers to produce strategies and plans that are sufficiently flexible and adaptable to remain robust in a range of possible plausible futures that have been identified within the exercise. Horizon scanning can be divided into six stages: (i) scoping the issue; (ii) gathering information; (iii) spotting signals; (iv) watching trends; (v) making sense of the future; and (vi) agreeing the response. Several main techniques for identifying, describing and responding to these futures are listed in Table 1. A horizon-scanning activity should start by agreeing the key question that the project will answer, and getting a clear understanding among participants about how the information that it generates will be used. This is a vital step, without which firm planning or process design cannot safely proceed; it might also require several iterations to obtain the necessary clarity. Formal interviews (Table 1) are often helpful at this stage in identifying important issues. If the horizon scanning is intended to contribute to the formulation of strategy, then the next step might be an expert workshop (Table 1) to identify the major drivers of change. Identifying social, scientific, technological, political, economic and environmental drivers is usually sufficient, although the scope of the particular topic might justify including additional specific categories, such as ethical drivers or legal drivers. In general, the prior knowledge of the participants should be supplemented by material synthesized from literature searches (Table 1) and previous relevant futures studies to help ensure that all key drivers are identified. A pair of drivers can form the axes used to define a set of four scenarios (Table 1). These should describe relevant, plausible, different futures within which new strategies can be developed (and existing ones tested for resilience). Information about the numerous drivers that were not selected as axes should be used in the scenario descriptions. Finally, back-casting (Table 1) can identify the steps needed to reach any of the futures described by the scenarios.

A fundamental principle of horizon scanning is to avoid the limitations inherent in conducting just a narrow 'forward look' within a single domain or area of interest. There are many examples of developments in one field having far-reaching impacts on a seemingly unrelated area. For example, the nature of land warfare during the early twentieth century was strongly influenced by a development that arose from nineteenth-century urbanisation associated with the Industrial Revolution: tinned food. This meant that armies no longer needed to forage and so could remain in once place, thus creating the conditions in which the defensive technologies of the machine gun and barbed wire (itself a development from another domain – agriculture) could, for nearly four years, dominate the battlefields of World War I. As a current example of how impacts can arise from unexpected directions, the overwhelming problem now challenging conservation organisations is the turmoil in the financial markets affecting income for conservation projects and core activities.

Why is horizon scanning useful to the ecology and evolution communities?

Horizon scanning includes looking for threats and opportunities; many issues have components of both. For example, nanotechnology, the development of atomic or molecular-scale materials, is widely predicted to become a huge industry [7]. As well as social and economic benefits, there are potential environmental benefits, for example, self-cleaning clothes could reduce water pollution, whereas nanofibres could be used to ameliorate pollution incidents. However, the same properties of nanoscale particles, often resulting from their large surface area relative to their mass, which make them so commercially exciting, could also create problems. For example, silver is usually

extremely inert but, as a nanoparticle, it limits bacterial growth and so can have a wide range of commercial uses but its environmental impacts are unknown. Nanotubules (carbon cylinders with walls one-atom thick but millimetres in length) have proved to be remarkably strong, are efficient heat conductors, and could be used to miniaturize electronics. However, they have also been shown to have impacts on mammalian lungs [8] and fish gills [9] and could cause mesothelioma [10]. Identifying that these are issues that warrant consideration can encourage further research and policy development.

What sort of issues should we be considering now? We recently ran an exercise [11] bringing together policymakers and academics to identify environmental issues that might increase in importance and thereby warrant further consideration. The issues identified included the following. First, following the capacity to create synthetic microbes referred to as *Mycoplasma laboratorium*, (US Patent Application: 20070122826), it is likely to become increasingly straightforward to develop artificial life forms for specific purposes. However, the possible impacts of such species as novel invasives need to be considered. Second, biomimetic robots capable of animal-like behaviour have been developed [12]. Although these developments concentrate on military applications, toys or pets, they could become novel invasive species. Third, virally vectored immunocontraception, as designed to target red foxes *(Vulpes vulpes)* and mice in Australia [13], might also impact upon related species. An issue is whether local risk assessments will consider the impacts on species in other countries to which they might spread. Fourth, the predicted and observed retraction of the Arctic ice edge might facilitate invasion of marine species from the Pacific Ocean to the Atlantic Ocean through increased Arctic shipping and wind-driven transport of plankton.

Horizon scanning can also identify opportunities that can have environmental benefits. Examples include robotics that identify weeds, which can then reduce the need for broad-scale pesticide applications; or nanotubules that can be used to clear pollution incidents (although see above) [14].

Many potentially beneficial issues will involve possible risks that need assessment. An example is the large-scale manipulation of the environment of the Earth ('geo-engineering') [15]. The range of proposals include adding iron to oceans to augment primary production; 'synthetic trees' used on a large scale to absorb CO_2; injecting sulphur dioxide into the stratosphere to reflect sunlight; reflecting sunlight by placing reflective plastic over the deserts or oceans; spraying water onto ice sheets to stabilize the ratio of freshwater to saltwater; pumping of sea-water droplets into the atmosphere to enhance cloud cover and, hence, albedo; and defecting the energy of the sun through creating a huge orbiting mirror or placing trillions of deflecting lenses in orbit [11]. The current controversy over biofuels, tidal power and wind power shows the need to ensure that environmental consequences are evaluated. Achieving this will make creation of sensible policy decisions about the possible extent and location based upon the costs and benefits easier.

As well as conducting timely horizon scanning, a major challenge is to make the results widely accessible by presenting the information in a format that is useable by policymakers and researchers. Academics seem genuinely interested in knowing what is of interest to policy makers. To our astonishment, our article identifying the ecological research questions of highest priority for policymakers [16] was the third most downloaded paper from the 850 journals from Blackwells Publishers in that year.

Where do we go from here?

How can the academic community use horizon scanning? It is striking that current ecological and conservation conferences rarely consider upcoming issues (e.g. nanotechnology) although they have fully embraced climate change. We suggest that, as a community, we need to invest more effort in identifying and considering future issues. Our recommendations include: (i) regular horizon scanning slots in conferences outlining future possible issues; (ii) opinion pieces in journals outlining potential developments; (iii) routine collation and dissemination of the results of horizon scanning in a means accessible to researchers, policymakers and practitioners (we are starting a process of annual global horizon scans); and (iv) increased encouragement, through funding and reward systems, of research into issues on the horizon.

How can governments, organisations and companies use the output of horizon scanning? Each issue goes through a range of stages before it potentially becomes a problem. For example, a new technology might start as a concept, then become patented, then be commercially produced and, finally, become widely adopted. A major challenge is to balance being appropriately prepared at each stage against the costs of preparing for issues that never become important. Seven key questions must be addressed once a relevant issue has been identified.

(i) How might the issue impact upon the interests of the organization?
(ii) If the issue does develop, then how long would the organization need to respond to, for example, carry out research, develop policies or carry out interventions?
(iii) How much advance warning of developments is likely?
(iv) What planning and preparation is appropriate considering the uncertainty, the speed at which it might develop, and the time required to act?
(v) What specific developments (such as extension or commercialisation of a technology or the arrival of a disease in a nearby country) could change the potential impacts or urgency?
(vi) Is the current knowledge commensurate with the identified impact and urgency, and how should gaps be filled?
(vii) If the strategy is to wait until developments occur, then what processes are in place to ensure the organization is informed?

What are its limitations?

The major risks of horizon scanning are that it might take time to carry out, divert effort from current genuine concerns to false alarms, and create complacency with the belief that

the future is being thoroughly considered. Although efforts can be made to make the process as comprehensive and rigorous as possible, there must be a subjective element; some issues will inevitably be identified late whereas other potential issues will turn out not to be of concern.

Early identification of issue and research priorities is essential, but just one part of the solution. For example, scientists have long stated that continuing existing fisheries policies would lead to the collapse of global fish stocks, yet the policies persisted and the fisheries collapsed [17,18]. For horizon scanning to be useful requires that it is followed by appropriate action.

Conclusion

Effective horizon scanning consists of using foresight to identify developments that might be important, having insight to understand the implications, and acting to ensure that the foresight and insight are available to, and used by, decision-makers. It is an essential (but underappreciated) tool for being better prepared to respond to a world of increasingly rapid change.

Acknowledgements

We thank the referees for useful comments and the Arcadia Fund for support to W.J.S.

References

1 Fitzherbert, E.B. *et al.* (2008) How will oil palm expansion affect biodiversity? *Trends Ecol. Evol.* 23, 538–545
2 Koh, L.P. and Wilcove, D.S. (2008) Is oil palm agriculture really destroying tropical biodiversity? *Conserv. Lett.* 1, 60–64
3 European Environment Agency (2001) *Late Lessons from Early Warnings: The Precautionary Principle 1896-2000*, Environmental Issue Report No 22, Office for Official Publications of the European Communities
4 Holmes, J. and Clark, E. (2008) Enhancing the use of science in environmental policy-making and regulation. *Environ. Sci. Policy* 11, 702–711
5 King, D.A. and Thomas, S.M. (2007) Taking science out of the box-foresight recast. *Science* 316, 1701–1702
6 Saffo, P. (2007) Six rules for effective forecasting. *Harv. Bus. Rev.* 85, 122–131
7 Maynard, A.D. *et al.* (2006) Safe handling of nanotechnology. *Nature* 444, 267–269
8 Dreher, K.L. (2004) Health and environmental impact of nanotechnology: toxicological assessment of manufactured nanoparticles. *Toxicol. Sci.* 77, 3–5
9 Smith, C.J. *et al.* (2007) Toxicity of single walled carbon nanotubes to rainbow trout (*Oncorhynchus mykiss*): respiratory toxicity, organ pathologies, and other physiological effects. *Aquat. Toxicol.* 82, 94–109
10 Poland, C.A. *et al.* (2008) Carbon nanotubes introduced into the abdominal cavity of mice show asbestos-like pathogenicity in a pilot study. *Nat. Nanotechnol.* 3, 423–428
11 Sutherland, W.J. *et al.* (2008) Future novel threats and opportunities facing UK biodiversity identified by horizon scanning. *J. Appl. Ecol.* 45, 821–833
12 Meyer, J.A. *et al.* (2005) The Psikharpax project: towards building an artificial rat. *Robot. Auton. Syst.* 50, 211–223
13 Arthur, A.D. *et al.* (2007) Cross-strain protection reduces effectiveness of virally vectored fertility control: results from individual-based multistrain models. *J. Appl. Ecol.* 44, 1252–1262
14 Owen, R. and Depledge, M. (2005) Nanotechnology and the environment: risks and rewards. *Mar. Pollut. Bull.* 50, 609–612
15 Cicerone, R.J. (2006) Geoengineering: encouraging research and overseeing implementation. *Clim. Change* 77, 221–226
16 Sutherland, W.J. *et al.* (2006) The identification of one hundred ecological questions of high policy relevance in the UK. *J. Appl. Ecol.* 43, 617–627
17 Lawton, J.L. (2007) Ecology, politics and policy. *J. Appl. Ecol.* 44, 465–474
18 Gezelius, S.S. and Raakjaer, J., eds (2008) *Making Fisheries Management Work: Implementation of Policies for Sustainable Fishing*, Springer-Verlag
19 Environmental Research Funders Forum (2007) *An Environmental Research Funders Forum Report – Horizon Scanning Study*, Environment Research Funders' Forum
20 The Heinz Center (2008) *The State of the Nation's Ecosystems 2008: Measuring the Land, Waters, and Living Resources of The United States*, Island Press
21 WCS Futures Group (2007) *Futures of the Wild,* Wildlife Conservation Society

0169-5347/$ – see front matter
doi:10.1016/j.tree.2009.04.008 Available online 5 August 2009

Letters

Eutrophication science: moving into the future

Bayden D. Russell and Sean D. Connell

Southern Seas Ecology Laboratories, School of Earth & Environmental Sciences, University of Adelaide, South Australia 5005, Australia

We were impressed by the timely review of the effects of eutrophication in coastal marine systems by Smith and Schindler [1]. We agree that although there has been substantial work towards identifying the causes of regime shifts in coastal systems, our understanding of the drivers is still far from satisfactory. Nonetheless, we feel that a critical point was not addressed in their review; the effects of eutrophication are likely to be substantially altered under future climate conditions. There is a pressing need to understand how local eutrophication and global climate stressors will interact.

Although the effects of combined climate stressors are increasingly well studied in marine systems (e.g. CO_2 and temperature; [2,3]), it has only recently been recognized that local and global stressors are likely to interact in unpredicted ways [4]. For example, the historical and continuing deforestation of algal canopies in favour of small, fast-growing turfs across the temperate coastlines of the world is a focus of considerable research [5]. Developing theory explains these shifts as a function of altered

Corresponding author: Russell, B.D. (bayden.russell@adelaide.edu.au).