**A Horizon Scan of Global Conservation Issues for 2011**

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**This paper describes outcomes of a 2010 horizon-scanning exercise building upon the first excercise conducted in 2009. The aim of both horizon scans was to identify emerging issues that may have substantial impacts on the conservation of biological diversity, and to do so sufficiently early to conduct policy-relevant, practical research on those issues. Our group included professional horizon scanners and researchers affiliated with universities and non- and inter-governmental organizations, including specialists on topics such as invasive species, wildlife diseases and coral reefs. We identified 15 nascent issues. These include new greenhouse gases, genetic techniques to eradicate mosquitoes, milk consumption in Asia and societal pessimism.**

**Introduction**

Horizon scanning is the systematic search for incipient trends, opportunities, and constraints that may affect the probability of achieving management goals and objectives. Explicit objectives of horizon scanning are to anticipate issues, accumulate data and knowledge about them, and thus inform critical decisions.

The importance of foresight has long been recognised. In the 6th century BC Sun-tzu recognized both the necessity of anticipating future events on the basis of diverse sources, as well as the cost effectiveness of these insights, writing, “The means by which enlightened rulers and sagacious generals moved and conquered others, that their achievements surpassed the masses, was advance knowledge,” and “no rewards are more generous” [1]. Similar principles apply when the aims of foresight are to address environmental quality and human health rather than to conquer neighbouring armies. With respect to human health, for example, horizon scanning has been used to identify both new technologies [2, 3] and potentially obsolete technologies [4]. The method is regularly used in business to identify new market opportunities [5] and continues to be used in the military to identify potential conflict zones together with relevant science and technologies that will provide military advantage [6].

Horizon scanning has not been widely applied by the conservation community [7, 8]. Occasionally, it has been used to identify policy options related to conservation of biological diversity [9], to describe possible future scenarios of environmental and social change, and to consider how those changes might affect conservation objectives and our ability to achieve them [10]. Nevertheless, the use of horizon scanning has been recommended by science advisors and policy-makers as a mechanism by which future research and policy needs can be anticipated [11, 12].

Our aim was to identify technological advances, environmental changes, novel ecological interactions, and changes in society that could have substantial impacts on the conservation of biological diversity (henceforth biodiversity, defined here as the full range of life on Earth and the ecological and evolutionary processes that support it), whether beneficial or detrimental. In 2009, a group of professional horizon scanners and conservation scientists, including several authors of the present paper, developed a list of 15 issues that met these criteria [13]. The exercise was repeated in 2010. In neither process did the group make predictions of the specific impacts of the issue on biodiversity. We believe that each issue is sufficiently important to warrant new research, policy consideration and sometimes pre-emptive, cost-effective action that might decrease the probability of undesirable consequences and increase the probability of desired outcomes.

The list of issues developed in 2009 was well received. Of the issues identified in 2009, there have been further significant developments in at least three. The ability to synthesize artificial life has improved with the synthesis of a bacterial genome containing about 1.1 million base pairs [14]; the invasive lionfish (mainly *Pterois volitans*) reached the Lesser Antilles in July 2010 and so has now colonized all subregions of the Caribbean Sea; and high-latitude volcanism became global news with the eruption of [Eyjafjallajökull](http://en.wikipedia.org/wiki/Eyjafjallaj%C3%B6kull) in Iceland in March and April 2010, although this was not severe or long lasting enough to have serious ecological impact (The last, of course, is likely to be coincidental rather than an indication of remarkable prescience by the authors.)

Authors of the 2009 effort considered whether their horizon scan overlooked issues that in hindsight should have been included. For example, the list did not highlight oil spills in deep ocean waters as exemplified by the Deepwater Horizon oil-rig explosion in April 2010. However, oil spills, including those in occurring in ever deeper water, such as the lxtoc oil spill at 3,600m in 1979, have been occurring sporadically for several decades. Accordingly, oil spills would not have met the general criteria for horizon scanning issues.

The authors of this current assessment include professional horizon scanners and specialists in subdisciplines of conservation science. The specialists are affiliated with universities and other organisations that have broad missions, including conservation. Each author, independently or in consultation with colleagues, identified and summarized 1-4 emergent issues that they felt were relevant worldwide or that may affect species, ecosystems, or regions of global interest. The resulting set of 71 issues was circulated to all contributors, who independently scored each issue on a scale from 1 (for well-known or poorly-known but relatively unimportant issues) to 10 (for poorly known but potentially important issues). Contributors also were asked to indicate, with a yes or no, whether they were aware of each of the 71 issues. The 35 issues that received highest mean scores were retained. Participants were invited to reinstate issues if they thought those issues merited further discussion; two issues were reinstated. The 37 retained issues were assessed at a workshop in Cambridge, UK, in September 2010. For each issue, two participants were selected by WJS in advance to provide an independent, critical assessment. After discussion, each participant again ranked the relative importance of each issue, this time on a scale from 0 to 100. Scores were converted to ranks and the 15 issues with the highest mean rank are presented below.

The issues below are not presented in priority order. We do not intend to describe in detail the relevance of each issue to environmental management and quality, or conservation of biodiversity, but emphasize that in several cases it may be desirable to evaluate more fully the probability of undesirable or beneficial outcomes.

**The issues**

**Environmental consequences of rising milk consumption in Asia**

In many Asian countries demand for dairy products has grown substantially in response to marketing by food companies and wider cultural change [***Pingali 2007)*** 15]. Newborn humans are able to metabolize lactose, but the production of lactase, the enzyme that digests lactose, falls dramatically post-weaning, especially in populations that do not traditionally consume dairy products; lactose-intolerance is widespread in these populations. Humans can develop tolerance to milk proteins, however, by habitually drinking milk or consuming dairy products during childhood. Consumption of dairy products among China’s 1.3 billion residents may increase rapidly if lactose intolerance does not remain a culturally maintained norm. The consequences of changes in land use to accommodate more dairy cattle and support infrastructure for an expanded industry could be manifold: greater emissions of methane and nitrous oxide, greenhouse gases associated with cattle [16, 17], further clearance of tropical forests to grow food for cattle, loss or changes in composition and structure of natural vegetation, and intensification of inputs and reduced water quality [16].

***Pingali, P. (2007) Westernization of Asian diets and the transformation of food systems: implications for research and policy. Food Policy 3 281-298.***

**New greenhouse gases**

Long-term monitoring at Cape Grim Research Station (Tasmania, Australia) has documented a rapid increase since 1978 in concentrations of two relatively unfamiliar greenhouse gases. While their radiative forcing effect is presently far less than the combined effects of the gases regulated by the Kyoto Protocol, they may have the potential to increase global temperatures. Nitrogen trifluoride (NF3) has an estimated global warming potential 17,000 times that of carbon dioxide over 100 years, and remains in the atmosphere for c. 550 years [18]. Its concentration increased at a rate of 11% per year to 0.454 parts per trillion in 2008. Sulfuryl fluoride (SO2F2), has a warming potential 4,780 times greater than carbon dioxide as a greenhouse gas over 100 years, and remains in the atmosphere for about 36–40 years [19]. Its concentration increased at a rate of 5% per year to 1.53 parts per trillion in 2008. Both NF3 and SO2F2 are substitutes for other gases regulated under the Kyoto or Montreal Protocols. NF3 is a substitute in the electronics industry for perfluorcarbons (PFCs) and is a byproduct of manufacturing plasma screen televisions and other goods, whereas sulfuryl fluoride is a crop fumigant that has replaced methyl bromide to preserve fresh produce.

**Increases in productivity of polar oceans driven by loss of sea ice**

Dramatic changes in ice cover are taking place, including the collapse of the Larsen B ice shelf in Antarctica, and rapid decreases in the extent of both multi-year and summer sea ice in the Arctic. Sea ice reflects solar radiation, whereas ocean water absorbs large quantities of heat. Reducing ice cover alters physical and biological conditions in marine systems and generally increases primary production at least initially, while simultaneously reducing activity in the area of light refraction at the perimeter of the sea ice. There is uncertainty about the net effect of losing ice cover over large areas of ocean [20]. Exposure of 24,000 km2 of open water around the Antarctic Peninsula from the loss of ice shelves and coastal glaciers has caused a large increase in pelagic and benthic biomass in the last 50 years [21]. Newly established communities on the seabed and in the water column have a standing biomass of c. 900,000 tonnes of carbon, and are storing an estimated 3,500,000 tonnes of carbon per year (equivalent to 60-170 km2 of tropical rainforest), of which about a fifth is deposited to the sea bed. Much greater increases in biomass may have occurred in the Arctic, where losses of ice cover have been far greater than in Antarctica (a decrease of 3,600,000 km2 in September sea ice extent between 1980 and 2007 [22]. Such changes in biomass and carbon assimilation will affect marine food chains.

**Biological impacts of perfluorinated compounds**

Many perfluorinated compounds are used in manufacturing and other industries. These persist in the environment because the carbon–fluorine bond is strong and not degraded by most natural processes. The two compounds that have received the most attention from toxicologists and regulators in recent years are perfluorooctanoic acid (PFOA, used to make fluoropolymers, such as Teflon) and perfluorooctanesulfonic acid (PFOS, used in the semiconductor industry and to produce stain-resistant coatings and fire-fighting foams). These compounds are lipophobic and hydrophobic and bind to proteins in the blood rather than accumulating in lipid [23]. They have been detected in tissues of fishes, birds and marine mammals around the world and were recently recognized to function as endocrine disruptors [24]. Accumulation of PFOA appears to be associated with a 200% increase in probability of thyroid disease in humans [25]. Knowledge of the effects of these compounds on other biota, particularly their sublethal effects in combination with other pollutants, is rudimentary.

**Expansion in mining for lithium used in rechargeable batteries**

Production and use of electric cars is promoted by many governments. Some countries, such as Spain, have set targets for the number of vehicles produced or sold, and the industry is subsidized in the United States, United Kingdom, China and Japan. These policies, combined with increases in the use of mobile technologies and storage systems for renewable energy, have led to a rapid rise in demand for rechargeable batteries. Most electric cars currently use lithium-ion batteries. The world’s unexploited reserves of concentrated lithium are mainly in shallow saline lakes in the high–elevation Andean deserts of Argentina, Chile and Bolivia. Species that inhabit the lakes (including microbes) are little studied, though they are important sites for three flamingo species, including the globally threatened Andean Flamingo (*Phoenicoparrus andinus*) [26].The Salar de Uyuni salt flat in Bolivia, which contains almost half of the world’s known lithium reserves, is currently exploited on a small scale by a Bolivian state corporation. Much more intensive extraction is planned [27]. The potential environmental and social impacts of a large increase in extraction of lithium, including installation of mining and transport infrastructure, are poorly understood. Financial analysts anticipate intense competition for lithium between the mobile electronics and automotive industries by 2015 [28]. Competition will raise the price of lithium, which may stimulate exploitation of new lithium resources that currently yield little to no profit. It may also drive the development of new battery technologies.

**Genetic techniques to eradicate mosquitoes**

The mosquito *Aedes aegyptii* transmits dengue, yellow fever and chikungunya viruses to humans, especially in tropical urban and suburban areas [29, 30, 31]. A range of modifications of the species’ genome that may lead to its eradication are being developed, including a strain that has healthy, fertile males but wingless females [32]. If release of this strain reduces transmission of disease, development of transgenic strains may be attempted for other mosquito species, and for other flying insects that are thought to have negative impacts on human health. The potential impacts of such releases on conservation are unclear. Little is known about the ecological role of particular mosquito species as food for insectivorous species, or in regulating populations of other species by transmitting disease or reducing fitness of individuals [33, 34].

Need to add ***Wickson (2010) Nature 466 1041***

**Nitric acid rain**

Following their identification as sources of acid rain, sulphur dioxide emissions from coal-burning power plants were reduced in Europe and the United States in the 1970s and 1990s, respectively, and in China in recent years [35]. Regulation of sulphur dioxide emissions from international shipping also is underway [36]. Similarly to oxides of sulphur, oxides of nitrogen emitted by human activity dissolve in precipitation to form nitric acid, which is toxic to animals, and can leach nutrients, mobilize aluminium in the soil, and cause eutrophication. Even sporadic acid deposition events may reduce the viability of fish populations, such as those of Atlantic salmon (*Salmo salar*), by affecting the juveniles [37]. Control of emissions of oxides of nitrogen from vehicles and agricultural fertilizers is limited. By the end of 2010, 11 European countries are expected to exceed the emissions limits for oxides of nitrogen set by the European Union - some by more than 40% [38] (European Environment Agency 2010). There is evidence of widespread reduction in species richness in grasslands across Europe, possibly linked to the acidifying effect of nitrogen deposition [39]. Acid rain linked to industrial emissions of oxides of nitrogen has recently been reported in the Niger Delta region of Nigeria [40], although the environmental impacts of the rain have not been quantified.

**Substantial changes in soil ecology**

Large-scale functional shifts appear to be taking place in the world’s soils. Global soil respiration rates have been increasing by 0.1% yr-1 since 1989, apparently in response to increases in global air temperature [41]. An estimated 98 billion tonnes of carbon are now emitted from the world’s soils each year, an amount 20-30% higher than previous estimates. However, it remains unclear if this represents a net loss of carbon to the atmosphere [42] (Smith and Fang 2010). If the emissions are from plant roots, then they may be balanced by CO2 absorption during photosynthesis. However, if they result from increased microbial action, there probably will be a net release of carbon to the atmosphere, possibly exacerbating climate change. Evidence of long-term changes in soil carbon in the temperate soils of the UK is inconsistent: a steady drop in soil carbon content between 1978 and 2003 [43] does not appear to have continued to 2007 [44].

**Denial of biodiversity loss**

Dyson [45] argued that growing denial of drivers of long term threats to human quality of life and health, such as climate change and HIV, are predictable social and political phenomena. The social responses to HIV/AIDS, such as increasingly limited use over time of condoms among many sectors, indicate the potential scale of denial of scientific evidence and that many people change their behaviour only when they are likely to experience serious, immediate impacts. The character of social responses to climate change is similar, with the proportion of people denying the scientific evidence now growing, at least in the USA [46]. On the basis of measurable behavioural responses to threats, social psychologists suggest that denial might be expected to increase both in extent and intensity as scientific evidence of a threat from phenomena such as climate change or biodiversity loss accumulates [47]. In such a landscape of manufactured uncertainties (Beck and Kropp, 2007), risk perceptions and individual behaviours are subtlely amended. Dickinson [47] argued that when a new dogma threatens an individual’s self-esteem, actions to prevent the occurrence of the new problem might be expected to be small, while those that exacerbate will become increasingly common. The denial of climate change, which is a threat potentially experienced directly by individuals, indicates that more remote and tenuous problems, such as the prevention of biodiversity loss, are even more likely to engender a strong denial response. The link between reductions in biodiversity and individual consumption behaviours of manufactured goods and food is complex. Nevertheless, such behaviour combined with aspirations worldwide frame the intentions and actions regarding conservation outcomes [48].

45. Dyson T. (2005) On development, demography and climate change: The end of the world as we know it? *Population and Environment*, 27, 117-149.

46. Pew Research Centre (2009) Fewer Americans see solid evidence of global warming. New Release, 22 October 2009. <http://people-press.org/report/556/global-warming>. Accessed 06/10/2009.

47. Dickinson J.L. (2009) The People Paradox: Self-Esteem Striving, Immortality Ideologies, and Human Response to Climate Change. *Ecology and Society*, 14, 17.

48. Rands, M.R.W., Adams, W.M., Bennun, L., Butchart, S.H.M., Clements, A., Coomes, D., Entwistle, A., Hodge, I., Kapos, V., Scharlemann, J.P.W., Sutherland, W.J. and Vira B. Biodiversity conservation: challenges beyond 2010. *Science*, 329, 1298-303

Beck U and Kropp C. 2007. Environmental risks and public perceptions. In Pretty J, Ball A S, Benton T, Guivant J, Lee D, Orr D, Pfeffer M and Ward H (eds). 2007. *Sage Handbook on Environment and Society*. Sage, London, 601-611

**Protected area failure**

Many protected areas were established to conserve specific systems (e.g. rare land-cover types) or species, but some of these areas are failing to meet the stated aims for their establishment [49, 50, 51, 52]. To date, the protected status of most protected areas has been retained even if long-term conservation of their primary targets is in question. However, in the first systematic review of protected area downgrading (a decrease in legal restrictions), downsizing (a decrease in area) and degazetting (loss of legal protection for the entire protected area) (PADDD), Mascia and Pailler [53] identified at least 89 instances of PADDD in 27 countries since 1900. With growing pressures from the intensification of agriculture, expansion of agriculture in areas such as Latin America, human population growth, pollution, resource extraction, and climate change [54, 55, 56] the number of failing protected areas, or ones perceived to be failing, both on land and in the sea, is likely to increase dramatically.

**Re-emergence of rinderpest**

Two major viral diseases, small pox in humans and rinderpest in cattle, have been eradicated by mass vaccination programs. It appears that global eradication of the *Morbillivirus* rinderpest was achieved very recently [57, FAO (2010)]. Comprehensive vaccination programmes have now been halted for both diseases. However, pathogens that cause both diseases have closely related wild relatives that could mutate and spread rapidly through a naïve population of humans or livestock that has no population-level immunity to infection. This process is illustrated by the 20-fold increase in the incidence of human monkey pox in the Democratic Republic of Congo from the 1980s to 2006-7, 30 years after small pox vaccination ceased [58]. Closely related pathogens of the rinderpest virus include canine distemper (carried by dogs), peste des petits ruminants (carried by sheep and goats), and measles in humans. There is therefore a possibility of a re-emergence of rinderpest. The last major rinderpest pandemic in the 1890s is said to have killed 90% of Kenya’s wild buffalo, and other ungulate species in sub-Saharan Africa were severely affected, including wildebeest and giraffe [59]. A link between rinderpest in cattle and ecosystem processes and features such as fire and tree cover was documented following eradication of rinderpest from the Serengeti [60]. A new, widespread outbreak of the disease could affect species’ habitats and ecosystems throughout Africa, Latin America, the Indian subcontinent and much of Europe. Negative impacts on people and agriculture might be severe given the very large increase in human populations since the last outbreak.

**Add this?**

FAO (2010) The Global Rinderpest Eradication Programme Progress report on rinderpest eradication efforts as of October 2010.

<http://www.fao.org/ag/againfo/resources/documents/AH/GREP_flyer.pdf>.

**Climate governance**

The only global agreement with specific targets to control greenhouse gas emissions, the Kyoto Protocol, expires at the end of 2012. Failure of negotiating parties to reach agreement on a successor means that it is now almost inevitable that any new agreement will take effect some time after the Kyoto Protocol expires. It is possible that a global agreement is not feasible [61]. Nevertheless, local efforts to reduce emissions are likely to continue in many countries. Under a global agreement, there might be opportunities to optimize or target emission reduction mechanisms, particularly those designed to reduce deforestation or enhance carbon storage in natural systems, which might also benefit native species [62]. Without an overarching global agreement, it is unclear which mechanisms will be available to ensure that the probability of persistence of native species increases rather than decreases in response to climate change mitigation. It is known that projected environmental outcomes can differ according to whether power within a governance framework operates at the local versus national or international level and whether the state or the market steers society [63]. Climate change mitigation that may involve global carbon markets without global coordination has not previously been attempted.

**Transformation of oceans and domestication of marine species**

The way humans view and use the sea may be changing dramatically, from a wild space that provides resources to an intensively managed space that is ‘farmed’ [64, 65]. Use of the oceans to generate energy, produce food, and mitigate climate change is advancing rapidly. Increasingly common forms of marine industry include deep-sea fish farming, marine renewable energy generation, floating server plants and extraction of rare metals from sea water. Aquaculture is expected to supply 50% of the quantity of aquatic sources of human food by 2015 [66]. Already the abundance of large predators has been much reduced in virtually all oceans, with more dramatic declines in intensively used areas such as the North Atlantic [67, 68]. Shallow sea beds are extensively trawled [69]. The rate of infrastructure construction, especially for production of renewable energy, is accelerating. While none of these individual issues is highly novel, these rapid simultaneous developments across multiple sectors are likely to have a dramatic impact on the oceans and the species they support.

##### Vegetation change facilitated by earthworms in North American forests

European earthworms, especially *Lumbricus rubellus,* have colonized previously earthworm-free temperate and boreal forests in eastern North America [70]. Earthworms affect composition and structure of the soil ecosystems. As detritivores, they affect primary producers by changing soil characteristics, plant-herbivore interactions, and flow of nutrients, water and carbon. The depth of litter in forests colonized by earthworms rapidly is reduced, with mixing of litter and humus into deeper horizons of the soil and reduced availability of nitrogen and phosphorus in upper soil horizons. Earthworms alter the soil food web and cause declines in abundance of forest herbs, woodland salamanders, and other native species. Earthworms can also facilitate invasion of forests by non-native plants, such as the European buckthorn *Rhamnus catharthicus* [71]. Earthworm invasion leaves a tree-ring signature in sugar maple *Acer saccharum*, leading to the discovery that trees in invaded areas are more sensitive to drought [72]. Transformation of large areas of North American forests is underway and the long-term consequences remain unclear.

**Hydraulic fracturing**

The threat to environmental quality posed by open-cast mining of oil sands has been widely highlighted, but comparatively little attention has been given to the threats arising from hydraulic fracturing to extract natural gas from organic-rich shale basins.. It is estimated that 1,744 trillion cubic feet (50km3) of natural gas could be recovered from U.S. shale basins [74]. Depending on site conditions, hydraulic fracturing at a single horizontal well may require 8-38 thousand tonnes [or cubic metres?] of water-based fracturing fluids being pumped at high pressure into the bedrock creating fractures that allow the subsequent flow of gas out to the wellhead [75]. While these reserves are usually far below any aquifers and wells can be effectively sealed to prevent leakage, there have cases of both surface water and aquifer pollution and of gas leakage, and the very large numbers of wells required increases the likelihood of occasional accidental failure. Fracturing fluids contain a number of toxic chemicals, including naphthalene, butanol, fluorocarbons and formaldehyde, which are considered carcinogenic and linked to numerous human illnesses [76]. Hydraulic fracturing is exempt from the Safe Drinking Water Act and therefore unregulated by the U.S. Environmental Protection Agency. Gas companies are not required to disclose the composition of fluids, which may result in less effective treatment by wastewater plants [76]. The very high water requirements are typically extracted on-site from groundwater or nearby streams, raising concern about the impact on aquatic ecology and public water resources. The growth of this industry across the US and elsewhere is considerable. For example in Pennsylvania some 710 wells were drilled into the rich Marcellus shale in 2009, with projections for 1700 new wells in 2010, 2200 in 2011 and thereafter a more steady rise to 3500 being drilled in 2020. The spatial reach of each well is limited so a high density of wells, access roads and pipelines is needed for comprehensive gas extraction, creating a very large spatial footprint which is already affecting large areas of natural landscapes. Over 30% of the 8900km2 of State Forest Land in Pennsylvania have already been made available for natural gas extraction, with growing pressure for more land to be released.

**Conclusions**

As with the 2009 horizon scanning exercise [13], the 15 topics cover a wide range of issues that relate to the major drivers of environmental quality and biodiversity loss: land cover and land use change, pollution, invasive species and climate change. Issues associated with pollution are prominent, but there are also issues associated with new technologies and societal change. The effects of some issues likely will be at the local or regional level, whereas others will undoubtedly have global impacts.

Which issues are identified in a horizon-scanning exercise depends to some extent on the composition, interests and expertise of the group involved. The 15 issues presented here were judged to be the most novel and potentially the most significant: but what of the other 20 also considered in detail, or the remaining 36 that were put forward but not shortlisted? All these were considered of concern by one or more well-informed conservation practitioners or researchers. In the full list of 71 issues, the highest-ranking topic areas were new technology (c. 23%), climate change (c. 18%), and societal change (c. 14%). This changed during the process of discussion, the highest-ranked topic areas in the final 15 becoming pollutants/extractive industry (c. 27%) and societal change (c. 20%), followed by climate change, change in use of land or sea, and invasive species/disease (two issues, c. 13%, each).

Group discussion and assessment is probably as good a way as any to refine the set of issues of concern. This does argue, however, for a fairly frequent and regular horizon-scanning process that also incorporates a review of previously proposed issues (at least those ones considered novel) to consider whether their significance may have changed. There might also be genuinely important issues missing because no-one raised them at all. A degree of turnover in the group’s composition (and pro-active filling of any obvious gaps in expertise) is thus also desirable.

Having identified a range of potential issues, what responses are appropriate? Very often the most sensible approach is to wait to see how the issue develops: this is appropriate if the issue is likely to develop slowly and gives time for the necessary research and policy development. Another option is to improve the science needed to predict the likelihood of different impacts and the likely consequences. Diacu [77] argues for this approach to improve the science for predicting events or phenomena such as pandemics, rapid climate change and tsunamis. Finally if the issue is likely to develop rapidly then immediate consideration of the policy options may be appropriate. Identifying a list of issues is in itself, of course, unlikely to bring about any direct policy responses. At best it may set going, initially through the re-focused attention of researchers and conservation NGOs, a complex chain of interactions that may in the end result in policy developments.

It is this shift in focus and attention, to track, research and understand better the issues identified, that we advocate here. Not all these issues may ultimately may have undesirable global effects; some may turn out to be entirely unimportant. However, they are issues that organisations should review, and decide whether to ignore, watch or develop research or policy responses.

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 **References**

1. Sun-tzu (1994) *Art of War*. Translated by Sawyer, R.D. Westview. Boulder Colorado

2. O 'Malley, S.P. and Jordan, E. (2009) Horizon scanning of new and emerging medical technology in Australia: its relevance to Medical Services Advisory Committee health technology assessments and public funding. *Int. J. Technol. Assess. Health Care*, 25, 374-82

3. Stafinski, T. *et al.* (2010) The role of surgeons in identifying emerging technologies for health technology assessment. *Can. J. Surg*. 53, 86-92

4. Ibargoyen-Roteta, N. *et al.* (2009) Scanning the horizon of obsolete technologies: possible sources for their identification. *Int. J Technol. Assess. Health Care*, 25, 249-54

5. Brown, D. (2007) Horizon scanning and the business environment — the implications for risk management. *BT Technology Journal,* 25 214-218

6. Quiggin, T. (2007) *Seeing the invisible. National Security Intelligence in an uncertain age.* World Scientific. Singapore

**7. Sutherland, W.J. *et al*. (2008) Future novel threats and opportunities facing UK biodiversity identified by horizon scanning.** J. Appl. Ecol. **45, 821-833**

8. Sutherland, W.J. and Woodroof, H.J. (2009) The need for environmental horizon scanning. *Trends Ecol. Evol*. 24,523-527

9. Sutherland, W.J. *et al.* (2010) The identification of priority opportunities for UK nature conservation policy. *J. App. Ecol.,* 47, 955-965

10. WCS Futures Group (2007) Futures of the Wild, Wildlife Conservation Society

11. Government Office for Science (2010)

12. National Intelligence Council. 2008. Global Trends 2025: A transformed world. http://www.dni.gov/nic/PDF\_2025/2025\_Global\_Trends\_Final\_Report.pdf

13. Sutherland, W.J. *et al.* (2010). A Horizon Scan of Global Conservation Issues for 2010. *Trends Ecol. Evol.,*25, 1-7

14. Gibson DJ et al (2010) Science 329, 52-56

15. Robert, P. (2008) *The end of food*. Bloomsbury

16. Cribb, J. (2010) *The Coming Famine. The Global Food Crisis and What We Can Do to Avoid It*. CSIRO Publishing and University of California Press

17. Popp A. *et al.* (2010) Food consumption, diet shifts and associated non-CO2 greenhouse gases from agricultural production. *Global Environ. Chang.,* 20, 451-462

18. Weiss R.F. *et al.* (2008) Nitrogen trifluoride in the global atmosphere. *Geophys. Res. Lett.,* 35, L20821

19. Muhle J. *et al.* (2009) Sulfuryl fluoride in the global atmosphere. *J. Geophys. Res-Atmos.***,** 114, D05306

20. Cai W.J. *et al.* (2010) Decrease in the CO2 Uptake Capacity in an Ice-Free Arctic Ocean Basin. *Science*, 329, 556-559

21. Peck L.S. *et al.* (2010) Negative feedback in the cold: ice retreat produces new carbon sinks in Antarctica. *Glob. Change Biol.*, 16, 2614-2623

22. Perovich, D.K. and Richter-Menge, J.A. (2009). Loss of sea ice in the Arctic. *Annu. Rev. Mar. Sci.*. 1, 417-441

23. Hundley, S. *et al.* (2006) Absorption, distribution and excretion of ammonium perfluoroctanoate (APFO) after oral administration to various species. *Drug Chem. Toxicol*., 29, 137-145

24. Lau C. *et al.* (2007) Perfluoroalkyl acids: A review of monitoring and toxicological findings. *Toxicol. Sci*., 99, 366-394

25. Melzer D. *et al.* (2010) Association between Serum Perfluorooctanoic Acid (PFOA) and thyroid disease in the us national health and nutrition examination survey. *Environ. Health Persp.*, 118, 686-692

26. BirdLife International (2010) Species factsheet: *Phoenicoparrus andinus*. 1/7/2010 (http://www.birdlife.org)

27. Eizel L. (2010) Bolivia advances lithium project. *Mining Weekly* online news. 6/10/2010 ([www.miningweekly.com/article/bolivia-advances-lithium-project-2010-07-03](http://www.miningweekly.com/article/bolivia-advances-lithium-project-2010-07-03))

28. Tahil, W. (2008) The Trouble with Lithium 2: Under the Microscope. Les Legars, France: Meridian International Research. 20/09/2010 (<http://www.meridian-int-res.com/Projects/Lithium_Microscope.pdf>.)

29. Tandon, N. and Ray, S. (2000) Host Feeding Pattern of *Aedes aegypti* and *Aedes albopictus* in Kolkata, India. *WHO Dengue Bulletin,* 24

30. Ponlawat, A. and Harrington, L.C. (2005) Blood feeding patterns of *Aedes aegypti* and *Aedes albopictus* in Thailand. *J. Med. Entomol.* 42, 844-9

31. Morrison, A.C. *et al.* (2008) Defining challenges and proposing solutions for control of the virus vector *Aedes aegypti*. *PLoS Med* 5(3): e68. doi:10.1371/journal.pmed.0050068

32. Fu, G. *et al.* (2010). Female-specific flightless phenotype for mosquito control. *Proc. Natl. Acad. Sci.* 107: 4550. doi:10.1073/pnas.1000251107

33. Fang, J. (2010) A world without mosquitoes. *Nature,* 466, 432

34. Phalan, B. (2010) Mosquitoes: retain an ex situ population for ecological insurance. *Nature,* 466, 1041

35. Lu, Z. *et al.* (2010) Sulfur dioxide emissions in China and sulfur trends in East Asia since 2000. *Atmospheric Chemistry and Physics*, 10, 6311-6331

36. Fuglestvedt J. *et al.* (2009) Shipping Emissions: from cooling to warming of climate-and reducing impacts on health. *Environ. Sci. & Technol*., 43, 9057-9062

37. McCormick S.D. *et al.* (2009) Impacts of episodic acidification on in-stream survival and physiological impairment of Atlantic salmon (*Salmo salar*) smolts. *Can. J. Fish. Aqua. Sci.*, 66, 394-403

38. European Environment Agency (2010). Comparison of projections as reported by the EU-27 Member States in December 2009 with the emission ceilings of the National Emission Ceilings Directive (2001/81/EC) 04/10/10 (<http://www.eea.europa.eu/highlights/europe-to-exceed-air-pollutant/nec-directive-2009-preliminary-data>.)

39. Stevens C.J. *et al.* (2010) Nitrogen deposition threatens species richness of grasslands across Europe. *Environ. Pollut.*, 158, 2940-2945

40. Nduka J.K.C. & Orisakwe O.E. (2010) Precipitation chemistry and occurrence of acid rain over the oil-producing Niger Delta region of Nigeria. *Scientific World Journal*, 10, 528-34

41. Bond-Lamberty, B. and Thomson, A. (2010) Temperature-associated increases in the global soil respiration record. *Nature*, 464, 579-582.

42. Bellamy, P.H. *et al.* (2005) Carbon losses from all soils across England and Wales 1978-2003. *Nature*, 437, 245-248

43. Smith, P. and Fang, C. (2010) Carbon cycle: a warm response by soils. *Nature*, 464, 499-500

44. Emmett B.A. *et al.* (2010). Soils report from 2007. Countryside Survey Technical Report No. 9/07. Centre for Ecology and Hydrology. 08/10/10 (<http://www.countrysidesurvey.org.uk/pdf/reports2007/CS_UK_2007_TR9-revised.pdf>.)

45. Dyson T. (2005) On development, demography and climate change: The end of the world as we know it? *Popul. Environ*., 27, 117-149.

46. Pew Research Centre (2009) Fewer Americans see solid evidence of global warming. New Release, 22 October 2009. 06/10/2009 (<http://people-press.org/report/556/global-warming>).

47. Dickinson, J.L. (2009) The People Paradox: Self-Esteem Striving, Immortality Ideologies, and Human Response to Climate Change. *Ecol. Soc.*, 14, 17

48. Rands, M.R.W. *et al.* (2010) Biodiversity conservation: challenges beyond 2010. *Science*, 329, 1298-303

49. Graham, N.A.J. *et al.* (2008) Climate warming, marine protected areas and the ocean-scale integrity of coral reef ecosystems. *PLoS ONE* 3, 9

50. Mora, C. (2008) A clear human footprint in the coral reefs of the Caribbean. .*P Roy. Soc. Lond. B Bio.,* 275, 767-773

51. Craigie, I.D. *et al.* (2010) Large mammal population declines in Africa's protected areas. *Biol. Conserv.* 143, 2221-2228

52. Lawton, J.H. *et al.* (2010) Making Space for Nature: a review of England’s wildlife sites and ecological networks. Deport to Defra

53. Mascia, M.B. and S. Pailler. In press. Protected area downgrading, downsizing, and degazettement (PADDD) and its conservation implications. *Conservation Letters*

54. Godfray H.C.J. *et al.* (2010) The future of the global food system. *Philos. Trans. R. Soc. Lond. B Biol. Sci.*, 365, 2769-77

55. Garcia S.M. & Rosenberg A.A. (2010) Food security and marine capture fisheries: characteristics, trends, drivers and future perspectives. *Philos. Trans. R. Soc. Lond. B. Biol. Sci.*, 365, 2869-80

56. Smith P. *et al.* (2010) Competition for land. *Philos. Trans. R. Soc. Lond. B. Biol. Sci.*, 365, 2941-57

57. Normile, D. (2008) Rinderpest: Driven to extinction*.* *Science*, 319, 1606-1609

58. Rimoin A.W. *et al.* (2010) Major increase in human monkeypox incidence 30 years after smallpox vaccination campaigns cease in the Democratic Republic of Congo. *P. Natl. Acad. Sci.*, 107, 16262-16267

59. Plowright, W. (1982) The effects of rinderpest and rinderpest control on wildlife in Africa. In: Edwards M.A. and McDonnell U. (eds) *Animal diseases in relation to animal conservation*. Academic Press, London

60. Holdo R.M. *et al.* (2009) A Disease-Mediated Trophic Cascade in the Serengeti and its Implications for Ecosystem. *C. Plos Biol.*, 7, 12

61. Hulme, M. (2009) *Why we disagree about climate change*. Cambridge University Press

62. Venter, O. *et al.* (2009) Harnessing carbon payments to protect biodiversity. *Science,* 326,1368

63. Watkinson, A. R. *et al.* (2007) Environmental impacts of future flood risk. In: *Future flooding and coastal erosion risks* (eds C. R. Thorne, E. P. Evans and E. C. Penning-Rowsell), pp. 29-46.Thomas Telford, London

64. Marra J. (2005) When will we tame the oceans? *Nature*, 436, 175-176.

65. Simpson, S. (2009) Taming the Blue Frontier. *Conservation Magazine*, 10, 2. (<http://www.conservationmagazine.org/2009/04/taming-the-blue-frontier/>)

66. Bostock, J. *et al.* (2010) Aquaculture: global status and trends. *Philos. Trans. R. Soc. Lond. B Biol. Sci.*, 365, 2897-912

67. Myers, R.A. *et al.* (2007) Cascading effects of the loss of apex predatory sharks from a coastal ocean. *Science*, 1846-1850

68. Sibert, J. *et al.* (2007) Biomass, size, and trophic status of top predators in the Pacific Ocean Science, *Science*, 314, 1773-1776

69. Watson, R. *et al.* (2006) Fishing gear associated with global marine catches: II Trends in trawling and dredging. *Fish. Res.,* 79, 103-111

70. Frehlich, L. *et al.* (2006). Earthworm invasion into previously earthworm-free temperate and boreal forests. *Biological Invasions,* 8, 1235-1245

71. Heimpel G.E. *et al.* (2010) European buckthorn and Asian soybean aphid as components of an extensive invasional meltdown in North America. *Biological Invasions*, 12, 2913-2931

72. Larson, E.R. *et al.* (2009). Tree rings detect earthworm invasions and their effects in northern hardwood forests. *Biological Invasions*. DOI: 10.1007/s10530-009-9523-3

73. U.S. Department of Energy (2008) *U.S. Natural Gas Annual Report*, EIA-0131(08), US DOE, Washington D.C.

74. U.S. Department of Energy (2009) *Modern Shale Gas Development in the United States: A primer*, DE-FG26-04NT15455, U.S. DOE: Washington D.C.

75. ProChemTech Int. (2009) Marcellus Gas Well Hydrofracture Wastewater Disposal by Recycle Treatment. *Technical Applications Bulletin*. 12/10/10 (http://prochemtech.com/Literature/TAB/PDF\_TAB\_Marcellus\_Hydrofracture\_Disposal\_by\_Recycle\_1009.pdf)

76. Kargbo, D.M. *et al.* (2010) Natural Gas Plays in the Marcellus Shale: Challenges and Potential Opportunities. *Environ. Sci. & Technol*., 44, 5679-5684

77. Diacu, F. (2009). *Megadisasters*. Oxford University Press, Oxford