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FORUM

The identification of 100 ecological questions of high policy relevance in the UK

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Summary

1. Evidence-based policy requires researchers to provide the answers to ecological questions that are of interest to policy makers. To find out what those questions are in the UK, representatives from 28 organizations involved in policy, together with scientists from 10 academic institutions, were asked to generate a list of questions from their organizations.

2. During a 2-day workshop the initial list of 1003 questions generated from consulting at least 654 policy makers and academics was used as a basis for generating a short list of 100 questions of significant policy relevance. Short-listing was decided on the basis of the preferences of the representatives from the policy-led organizations.

3. The areas covered included most major issues of environmental concern in the UK, including agriculture, marine fisheries, climate change, ecosystem function and land management.

4. The most striking outcome was the preference for general questions rather than narrow ones. The reason is that policy is driven by broad issues rather than specific ones. In contrast, scientists are frequently best equipped to answer specific questions. This means that it may be necessary to extract the underpinning specific question before researchers can proceed.

5. *Synthesis and applications.* Greater communication between policy makers and scientists is required in order to ensure that applied ecologists are dealing with issues in a way that can feed into policy. It is particularly important that applied ecologists emphasize the generic value of their work wherever possible.

Key-words: agricultural reform, biodiversity, conservation, fisheries, land management, restoration ecology

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Introduction

Despite an increased emphasis upon evidence-based environmental policy (Defra 2003), it is widely accepted that there is too little information flow between scientists and policy makers (Sutherland *et al*. 2004). The popular perception amongst many ecological practitioners and researchers is that policies are often developed without sound evidence derived from research and that the results that are produced are not used to the extent that they could be to inform decision-making. Narrowing this gap would be very beneficial in generating policies that are based more objectively on sound science. Conversely, it is desirable that research should be more clearly directed at issues that influence policies.

We set out to compile a broadly agreed list of specific ecological questions that are a priority in relation to policy development in the UK. The most famous example of an influential set of questions that has helped establish research agendas is that of Hilbert (1902). Other lists include those of Steffen *et al*. (2004), who provided a list of questions in environmental sciences, while Paul Erdös set mathematical questions with cash prizes for those who solved them (Hoffman 1998).

A list of such questions for ecology should produce a greater synergy between policy, practice and research, and could inform researchers and research funders as to where their efforts might best be focused. The questions would undoubtedly include some that can be answered more easily than others, depending both on the difficulty and complexity of the question and the way in which it is framed. Many questions are essentially too vague. This criticism has been set against many research questions in the ecological domain (Peters 1991); they are effectively unanswerable.

The objective of the exercise reported in this paper was to identify 100 research questions to which policy makers wanted answers. To this end we organized a workshop for policy makers, their advisers, lobbyists and members of the research community. This paper reports the list of questions that emerged, placing them briefly within the context of current environmental issues that require a policy response in the UK. While the academics at the workshop were involved in suggesting questions and facilitating discussion, the questions were selected and composed entirely by those involved in policy. This dialogue also provided the

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opportunity to discuss the impediments to integrating research and policy.

Methods

Invitations to select a representative to participate in the process were issued to a wide range of governmental institutions and non-governmental organizations (NGO) that either create policy or are involved in influencing policy in the UK. The universities and institutes associated with UKPopNet (a NERC- and English Nature-funded collaboration of five universities and the Centre of Ecology and Hydrology in the UK) plus the Centre for Population Biology at Imperial College, London, UK and the Wildlife Conservation Research Unit at the University of Oxford, Oxford, UK, were also invited to select representatives. The list of author affiliations provides a full list of participating institutions. In addition, 12 organizations were invited but neither submitted questions nor participated in the meeting (these included two from Wales, one from Northern Ireland and two from Scotland). The final list of questions was arrived at by consensus. Representatives were asked to consult widely with colleagues and to submit the questions of greatest priority for their organization in advance of the meeting. At least 654 people were involved in the initial consultation process and a total of 1003 questions was submitted for consideration, although a significant proportion of these were closely related, reflecting a shared perception of the importance of some policy questions. To be included, questions were required to be ecological and to apply to the UK. The submitted questions were divided into major policy areas.

The unabridged list of 1003 questions divided into 61 topic areas (see Appendix S1 in the supplementary material) was circulated in advance to all representatives who met for a 2-day workshop in February 2005. The list of questions in each topic area was reduced by mutual agreement among policy specialists, with academics acting as facilitators and recorders. The academics also tried to ensure that each of the questions was framed in such a way that it could be answered. An initial selection was made in four 2-h sessions. Policy specialists were first asked to indicate the importance they attached to individual questions in those topic areas in which they had an interest. Each individual was asked to select both his or her top 10% and second (10–20%) priority questions. Overall priorities were estimated by scoring 2 points for each top priority indication and one point for each second priority and totalling the points for each question. The total scores for each question were then used as a basis for shortlisting and reworking questions for each topic area. At this stage similar well-supported questions were combined, and questions were reworded for clarity if necessary. This exercise was carried out with participants working in three parallel sessions. The process to this point shortened the list to 188 questions.

On the second day the list was divided into three and shortened to a final target number by three independent subgroups. Much of the second day was spent in revising questions to provide a more coherent expression of the policy issue, most often involving the broadening of the question to reflect a wider constituency of concern about the issue or to provide greater scientific tractability to the questions posed. The list was agreed by consensus and compromise. In consequence, some participating organizations may not endorse the inclusion of certain questions.

Results

There is no ideal way of categorizing the questions. A few of the questions related to understanding the value of biodiversity in terms of its impact on ecosystem services, while the majority related to understanding the drivers of biodiversity change and the effectiveness of the conservation response. Here we categorize the questions around 14 topics relating to these broad issues. The categories were agreed collectively during the 2 days.

ECOSYSTEM SERVICES

The last decade has seen a growing realization that humans gain enormous material benefits from natural habitats (Millennium Ecosystem Assessment 2005). The value of these is often only appreciated when they have been lost. Such benefits are difficult to value using conventional economic methods for a number of reasons. These include problems concerning ownership, substitutability and the reluctance of people to put costs on services that have typically been regarded as free. Major research issues involve quantifying ecosystem services and understanding which components of the ecosystem are essential for providing valuable services.

1. What are the benefits of protected habitats in terms of water resources, carbon sequestration and other goods and services, relative to non-protected land?

2. What is the role of biodiversity in maintaining specific ecosystem functions (e.g. biogeochemical cycles)?

3. What are the roles of soil biodiversity (and specifically little-known groups such as mites or nematodes) in ecosystem function, resilience and recovery?

4. How does soil biodiversity both influence and respond to above-ground biodiversity?

5. What is the role of marine biota and benthopelagic coupling in ocean–atmosphere carbon cycling and primary production?

6. How can we measure natural capital (renewable and non-renewable resources) and integrate such a measure into gross domestic product (GDP)?

FARMING

Increased production and intensification have brought with them far-reaching consequences for the natural

environment (Robinson & Sutherland 2002), and semi-natural habitats in the UK have been lost to agriculture at an unprecedented rate. All member states of the European Union (EU) have optional agri-environment schemes that attempt to ameliorate such effects. These can be very successful (Peach *et al*. 2001) but a review of all EU studies has shown that success so far is mixed (Kleijn & Sutherland 2003).

Over the next decade, agriculture in the EU is likely to change radically as a result of the Common Agricultural Policy (CAP) mid-term review (Sutherland 2004). The main policy change is to separate ('decouple') subsidies from production. Farmers are now to be given a 'single farm payment', which can be linked to cross-compliance (the payment being subject to other conditions, such as minimum environmental conditions). Thus subsidies will be paid each year irrespective of production, providing the land is kept in good agricultural and environmental condition (European Commission 2003). The consequences of this change in EU funding are uncertain and are likely to vary between different agricultural systems. They could result in both increases and decreases in intensification, depending on the system.

It is also important to recognize technological developments in agriculture. For instance, recent years have seen the development of genetically modified (GM) crops and the future will undoubtedly see more efficient means of production and more effective control of weeds, pests and diseases. There are also likely to be new crops such as biofuels and raw materials for the plastics and pharmaceuticals industries.

7. How will CAP reform affect biodiversity at the landscape scale?

8. What are the environmental consequences of farming patterns ranging between the extremes of widespread extensification vs. complete segregation of agricultural production and conservation areas?

9. How do farming systems such as conventional, integrated farm management and organic compare in terms of their effects on biodiversity and other environmental impacts?

10. How do current agricultural practices affect the conservation value and extent of non-agricultural habitats such as woodland edges, hedgerows and ponds, and how can detrimental impacts be mitigated?

11. What are the impacts of agricultural activities and practices (e.g. fertilizers, pesticides and physical disturbance) on soil biodiversity and soil functions?

12. What are the ecological consequences of changes in upland grazing regimes for biodiversity and soil ecology?

13. What are the impacts on soil and surface-active invertebrates of poaching (trampling of flooded soil by livestock) and soil compaction at different stocking levels?

14. What are the impacts on biodiversity of prophylactic treatment of farm livestock with antibiotics, anti-fungal and anti-helminthic compounds?

15. What lessons can be learnt from agri-environment schemes to optimize their biodiversity gain and ecological benefit?

16. How does the ecological impact of UK farming compare internationally?

FORESTRY

The forestry industry in the UK has shifted from concentrating upon industrial conifer production to providing public benefits such as amenity and biodiversity. The Statement of Forest Principles from the Convention on Biological Diversity (Anonymous 1992), resolutions from the 1993 Helsinki European Union conference on the Protection of Forests in Europe and the UK Forestry Standard all include an obligation to conserve and enhance the biodiversity value of forests (Forestry Commission 1998). New forests are being planted and, with current changes in CAP funding, there is the possibility of natural regeneration of the uplands. Increasing wild and feral deer, however, are considered a major problem, especially for ancient woodlands (Fuller & Gill 2001).

17. What are the environmental benefits of large-scale woodland planting schemes such as community forests and the new national forests?

18. Where should new woodlands be located?

19. What overall number, age structure and spatial distribution of trees are necessary for the long-term survival of species dependent on ancient/veteran trees?

20. What are the relative benefits for biodiversity of the re-introduction of management to ancient semi-natural woodlands vs. the continuation of an absence of active management?

21. Why have many woodland birds declined?

22. Which approach to the removal of plantations on ancient woodland sites (e.g. clear-felling and sequential removal) yields the greatest biodiversity benefit?

FISHERIES, AQUACULTURE AND MARINE CONSERVATION

It is widely recognized that fisheries have caused declines of target species and local extinctions of mammals, birds, fishes and invertebrates (Wolff 2000; Dulvy, Sadovy & Reynolds 2003; Jennings & Blanchard 2004) and, while aquaculture provides an increasing proportion of marine protein, there are a variety of environmental concerns arising as a consequence of this (Mills 2003). The drive to reduce fishing effort continues alongside moves towards a broader view where the wider impacts of fishing and other issues are managed in a more integrated manner. The major national, regional and international policy commitments include: achieving 'clean, healthy, safe, productive and biologically diverse seas' (Defra 2002, 2004a); the implementation of an Ecosystem Approach to Fisheries Management through the Common Fisheries Policy (Anonymous 2002); 'to achieve a significant reduction in the current

rate of biodiversity loss' by 2010; and 'maintaining or restoring stocks to levels that can produce their maximum sustainable yield on an urgent basis and where possible for depleted stocks no later than 2015' (WSSD 2002).

23. What is the biodiversity impact of the harvest of forage fish for the production of aquaculture foodstuffs?

24. What are the ecological impacts of faecal matter, pesticides and undigested food flows from aquaculture?

25. How important are caged fishes as reservoirs of parasites and pathogens that have detrimental effects on wild populations?

26. What are the direct (catch) and indirect (food supplementation by discards, prey depletion) impacts of commercial fishing on cetaceans and seabirds?

27. How large should marine protected areas be, and where should they be located to protect biodiversity and enhance surrounding fisheries?

28. What will be the impact of marine protected areas on wide ranging migratory species such as cod *Gadus morhua* L. and haddock *Melanogrammus aeglefinus* L.

29. How important are coastal, estuarine and fluvial habitats for endangered migratory fish populations (e.g. lampreys, shad, eel and sturgeon)?

30. What is the range of minimum viable population sizes for broadcast spawning marine species?

31. How long does the seabed take to recover from disturbance such as dredging, wind-farm construction and oil and gas extraction?

RECREATION AND FIELD SPORTS

Access to land and water is changing as a consequence of more leisure time and easier use of transport. Increased affluence and changes in lifestyles result in higher demands for houses, roads and other infrastructural developments. The Countryside and Rights of Way Act in England & Wales 2000 allows access to areas of heath, down, moor and common, unless there are specific reasons to prevent access. Scotland has similarly formalized public access recently.

The hunting of wild mammals with dogs was banned in England and Wales in 2004 under the Hunting Act 2004 and in Scotland in 2002 under the Protection of Wild Mammals (Scotland) Act. The legislation outlaws the hunting with dogs of fox *Vulpes vulpes* L., deer, hare and mink *Mustela vison* Schreber, as well as hare coursing. The consequences of reduced fox hunting remain to be seen (Macdonald & Johnson 1996). With respect to other field sports, Oldfield *et al*. (2003) showed that farmers with an interest in field sports were more likely to be planting new woods, so there was a positive association with field sport activity and biodiversity.

32. What are the impacts of recreational activities on biodiversity?

33. Which ecological principles should guide the choice of the list of UK species appropriate for game exploitation?

34. What overall impacts do introductions of game species for field sports (including recreational fishing) have on biodiversity?

35. What are the ecological impacts (both direct and indirect, through shifts in habitat management) of a ban on hunting with dogs?

URBAN DEVELOPMENT

The 2000 Urban White Paper projects a 19% increase in the number of households in the UK by 2021, which, if met at current densities for new developments, would require development of an area larger than Greater London (Office of the Deputy Prime Minister 2000). Urban development will have a negative impact on the ecosystems they replace but, in themselves, urban communities and landscapes are extremely heterogeneous, supporting a wide variety flora and fauna (Hope *et al*. 2003; Martin, Warren & Kinzig *et al*. 2004). Urban greenspaces and gardens account for a significant fraction of residential areas and offer a multitude of untapped conservation opportunities (Gaston *et al*. 2005). The primary contact that the majority of the UK population has with native animals and plants occurs in urban ecosystems and so it is in this context that people stand to gain most from a more diverse environment.

36. How can provision for wildlife be maximized in existing and new urban development, urban greenspace and brownfield sites?

37. What are the consequences for biodiversity of fragmentation by development and infrastructure?

38. What are the ecological impacts on semi-natural habitats and ecosystems of adjacent large developments (e.g. housing and airports)?

39. How can sustainable urban drainage systems be optimally designed to maximize biodiversity in the urban environment?

ALIENS AND INVASIVE SPECIES

Globally, invasive non-native species are considered to be the most important threat to biodiversity after habitat loss (Mooney & Hobbs 2000). In the UK a wide variety of introduced plants and animals has caused serious environmental problems (Manchester & Bullock 2000) and there are increasing concerns over the spread of alien pathogens and novel diseases (Aldhous & Tomlin 2005) together with genes from GM organisms (Gray 2004). It is not only recent and potential alien introductions, however, that cause concern but also the invasion of large tracts of land by the native fern bracken *Pteridium aquilinum* (L.) (Birnie *et al*. 2000) and long-established introductions such as the sycamore *Acer pseudoplatanus* L. There are, in addition, concerns over the large number of domestic and feral cats in the environment.

The major policy issues concerning invasive organisms involve drafting legislation to limit the risk of their

entry, restricting the spread of species already in the UK, understanding their detrimental effects (if any), prioritizing species for study and determining whether it is possible to eliminate them or at least reduce their densities.

40. What criteria should be used to determine when to intervene to deal with invasive species?

41. How can we manage microbial ecology to control invasive plant pathogens?

42. How can we understand better the epidemiology of existing and emergent diseases within wildlife reservoirs to better protect humans and livestock?

43. What are the genetic threats to UK biodiversity posed by introgression from genetically modified organisms and what measures are available to reduce these threats?

44. What is the optimal method of managing bracken-dominated habitats for the benefit of associated biodiversity action plan priority species?

45. What are the effects of domestic cats on vertebrate populations in rural and urban environments?

POLLUTION

The manufacture and use of chemicals and materials is one approach that society uses to escape the natural constraints the environment would otherwise impose. A number of hazards and risks arise because of this. Some of these are direct (e.g. those as a result of the positive and negative effects of chemicals on organisms) and others indirect (e.g. as a result of food web and other trophic interactions) (Newton 1998). In addition, while some pollution is from point sources, as, for example, around factory chimneys and waste water outfalls, others are diffuse, for example those associated with motor vehicles and fertilizer use. A lot of progress has been made regarding assessing hazards and risks from some 'use classes' of chemicals. For example, there are internationally agreed procedures for pesticides and for the release of substances from industrial processes. Even within the agreed procedures, extensive gaps in knowledge and understanding remain and chemicals have behaved in the environment in unexpected ways. It is difficult to develop a complete strategy for dealing with new chemical threats. In addition to the uncertainties about hazards and risks, approaches to mitigation and remediation strategies need further development.

46. What impact does plastic-derived litter have on the marine environment?

47. How can one ameliorate the effects of aerially deposited nitrogen on habitats and species?

48. What are the critical thresholds for nitrogen and phosphorus inputs into waterbodies of high conservation value?

49. Of those chemicals currently or potentially released into the environment, which (individually or in combination) are now, or are likely to become, significant environmental problems, and what will these problems be?

50. What are the long-term impacts of depositing sewage sludge and other organic wastes on to agro-ecosystems?

51. How can catchment management be used to reduce diffuse pollution?

52. How will acidification of surface water from rising CO_2 concentrations affect planktonic productivity and other marine organisms?

53. What are the effects of light pollution from built development and road lights on wildlife behaviour, mortality and demography?

CLIMATE CHANGE

While habitat change, pollution, over-exploitation and invasive species are considered to be amongst the most important current drivers of biodiversity change, climate warming is expected to become increasingly important. The evidence for climate warming now appears overwhelming (IPCC 2001; King 2005). In the UK (Hulme *et al*. 2002) it is projected that the climate will become warmer by between 2 °C and 3·5 °C by the 2080s, with greater warming in the south and east than in the north and west, and with greater warming in the summer and autumn than in the winter and spring. It is also expected that high summer temperatures will become more frequent and very cold winters increasingly rare, continuing the trend that is already seen in the observed climate. Winters are, however, expected to get wetter, with heavier winter precipitation, while summers may become drier. Sea level is also expected to rise.

For policy makers to make the best informed decisions for adapting to these changes they will need significantly improved models of the effects of climate change on the distribution of species and habitats. To achieve this there will have to be much more ecological research into the climatic tolerances of species and habitats. Also, the dispersal ability of species needs to be understood, as the effect on the extinction rate could be dramatic should climate change proceed faster than species can disperse and colonize newly suitable locations. The potential to reduce the impact of climate change upon native species by adapting habitat management needs to be considered (Hulme 2005).

54. Which species are likely to be the best indicators of the effects of climate change on natural communities?

55. Which habitats and species might we lose completely in the UK because of climate change?

56. What will be the ecological impacts of changing agricultural patterns in response to climate change?

57. What time lags can be expected between climate change and ecological change?

58. What is the likely relationship between the extent of climate change and the pattern of species extinction?

59. How does climate change interact with other ecological pressures (e.g. invasive species and habitat fragmentation) to create synergistic effects?

60. How can we increase the resilience of habitats and species to cope with climate change?

61. How well suited is the current UK protected area system for conserving biodiversity in the face of climate change, and how can it be enhanced in light of this?
62. How will changes to oceanographic conditions as a result of climate change affect marine ecosystems?
63. What actions are required to recreate the full range of coastal landscapes, habitats and species distributions to compensate for their loss, for example as a result of sea-level rise?

ENERGY GENERATION AND CARBON MANAGEMENT

With concerns over carbon emissions from fossil fuels and their impacts on world climate, there are pressures to increase the contribution of renewable energy to the energy market. In the UK, there is a government commitment to achieve a 10% renewables target by 2010 (DTI 2003). It is currently believed that wind energy will provide a substantial proportion of the renewables total (Carbon Trust 2003), but the construction of marine and terrestrial wind farms at a range of sites is raising considerable concerns in relation to their impacts on biodiversity and the landscape (Garthe & Huppop 2004). The cultivation of crops for biofuels could also have considerable impact on biodiversity and the landscape, although it is not clear whether this will be positive or negative.
64. What are the consequences of biofuel production for biodiversity at field, landscape and regional levels?
65. What are the potential impacts of (a) terrestrial and (b) marine wind farms on biodiversity?
66. What are the comparative biodiversity impacts of newly emerging types of renewable energy, such as wave energy?
67. How can soil carbon be retained and further carbon sequestered in the soil?

CONSERVATION STRATEGIES

Much conservation activity has traditionally been targeted at single species. Many conservation NGO are taxon-based and have their own priority species. It is also the case that species status is relatively easily measured and monitored, and some species groups have become indicators of our performance in meeting targets for biodiversity conservation.

For many species it remains a challenge to understand changes in their status and the factors that have brought about decline (e.g. moths; Conrad *et al*. 2004). For others, such as farmland birds and butterflies, attention has turned to the impact and/or effectiveness of broad policies (such as agri-environment schemes) in terms of reversing decline. The emphasis on species action plans in the UK Biodiversity Action Plan (Anonymous 1994) brings into focus the challenge of integrating species and habitat conservation. The scale of action becomes important, with concerns about policies at the ecosystem or landscape scale undermining efforts at the species level.
68. How can biodiversity action plans be designed to take account of larger scale population processes?
69. How can we best measure favourable conservation status for each of the species and habitats listed within the EU's Habitat Directive?
70. How effective is the current UK protected area network for protecting wildlife under current conditions?
71. With what precision can we predict the ecological impact of different policy options and the ecological effects of management action?
72. At an international scale, what are the ecological implications of conservation actions and policies adopted within the UK?
73. How effective as indicators of overall biodiversity are current indicators (especially birds)?
74. Why are common moths declining and are their declines driving declines in other taxa (e.g. bats)?
75. What scale and type of land-use change is required to halt the decline of biodiversity by 2010 (EU heads of state committed to this in the 2001 EU summit in Göteborg)?
76. Are there reliable ways to predict the long-term sustainability of populations of poorly known species (e.g. most invertebrates) using a knowledge of life history and other ecological characteristics?

HABITAT MANAGEMENT AND RESTORATION

Historically, habitat destruction and fragmentation have been viewed as the major factors driving biodiversity loss (Robinson, in press), but much of the change in the contemporary UK landscape is now caused by change in the management of semi-natural habitats. The challenge for conservation is to manage complex landscapes in a way that retains and enhances biodiversity value. One unresolved issue is how to prioritize intensive management of designated sites against extensive management of the wider landscape.

A great deal of current management practice is based on traditional techniques that did not originally have conservation objectives. Their effectiveness is often unknown and may be little more than myth (Sutherland *et al*. 2004). Habitat restoration is becoming a popular objective (Perrow & Davy 2002) but it is unclear what restoration can and cannot achieve for biodiversity conservation and there is uncertainty over the impact of using restoration plans to mitigate development.
77. What are the costs and benefits of concentrating conservation work on designated sites in comparison with spreading efforts across the wider countryside?
78. What are the ecological consequences of 'wilding' (that is, conservation of sites using only, or very largely, natural processes) as a long-term conservation strategy?
79. What are the consequences of different moorland management techniques (especially burning, cutting and grazing) for the upland economy, carbon storage, water quality and biodiversity?

80. What measures of habitat condition should we use to measure habitat change in protected areas?
81. How should ditches, dry and wet, be managed for the greatest benefit for biodiversity?
82. What hedgerow structure and what type of hedge management produce the greatest wildlife benefits?
83. How do recreated habitats differ from their semi-natural analogues?
84. How can we effectively prioritize the most important large-scale ecological restoration projects that could be undertaken in the UK?
85. What is the most appropriate and ecologically sustainable way of dealing with excess nutrients during terrestrial and freshwater habitat restoration?
86. What are the implications of changing deer densities for agriculture, forestry and biodiversity in different landscape types?
87. In reintroductions, does local provenance matter? Will the use of non-local stock cause loss of local genetic variation, outbreeding depression or genetic rescue of depauperate gene pools?

CONNECTIVITY AND LANDSCAPE STRUCTURE

Agricultural intensification and other land-use changes have been responsible for the loss of huge amounts of natural habitat in lowland Britain and currently most native species persist only in remnant habitat fragments. Nature reserves (including sites of special scientific interest) have been established to support individual populations of threatened species and/or representative habitat fragments. The smaller the reserve, the harder it has been to maintain habitat in the right condition to maintain all constituent species (Warren 1993). Once locally extinct, the same species have often failed to recolonize even if habitat condition is restored (Coulson *et al*. 2001), especially when reserves are surrounded by heavily modified agricultural landscapes. New opportunities in farm- and regional-scale land management and habitat restoration are provided by entry and higher level environmental stewardship (replacing existing agri-environment schemes), associated with the decoupling of subsidies from agricultural production (Sutherland 2004).
88. What are the lag times between habitat fragmentation and the loss of species of different taxonomic and functional groups?
89. Is it better to extend existing habitat patches or create further patches within the landscape?
90. How should we manage landscape mosaics for the conservation of diverse taxa that operate on different spatial scales?
91. What are the relative merits of different indices of habitat connectivity? Which of them best predict conservation value?
92. What is the value of linear habitats, such as hedgerows, railways, road verges and riparian strips, as corridors for dispersal between fragmented habitat patches?
93. For species where the concept is applicable, how can 'source' and 'sink' populations (Pulliam 1988) be identified and how should their status affect conservation management?
94. How important are core vs. peripheral areas in the conservation strategy of a species?
95. How reliant are animal and plant populations in small nature reserves on the maintenance of habitat in surrounding non-protected areas?

MAKING SPACE FOR WATER

In 2003, 95% of UK rivers were of good or fair biological quality and less than 5% had poor or bad status, a significant improvement since the beginning of the 1990s. Diffuse pollution sources such as pesticide and agricultural run-off still represent potential threats to river ecology. Wetlands have sustained significant losses in the past centuries. It is estimated that fenland habitats have decreased from 3380 km^{-2} in the middle of the 17th century to about 10 km^{-2} today and the area of undisturbed lowland raised bog is estimated to have declined by 94% (UK Biodiversity Group 1999).

Under legislation imposed during the past 10 years, it will be necessary to protect and enhance rivers and wetlands for wildlife and society. This will raise a series of technical and operational challenges, and large-scale protection and enhancement schemes will require participation from all parts of society.
96. What have been the consequences of past and present riparian engineering works, such as weirs, culverts, gravel removal, habitat fragmentation and damming, on biodiversity within and alongside rivers?
97. What would be the ecological implications of large-scale river and floodplain restoration schemes in the UK, and would they be more cost-effective than traditional hard flood defences?
98. What are the likely consequences for biodiversity of changes in water quality and sedimentation in rivers?
99. What methods most accurately measure 'ecological status' in the EU Water Framework Directive?
100. How can flood control be assisted by appropriate habitat management and restoration, and what are the impacts on biodiversity?

Discussion

A structured dialogue between policy makers and scientists has produced 100 ecological questions for researchers to relate to the broader concerns of policy makers, framed in such a way that the scientists think they can answer them, either on their own or through interdisciplinary collaborations. These questions are specific to the UK and to consensus amongst the group of organizations and individuals involved. Many of these will resonate with the interests of others here and in north-west Europe and the EU. Of course, other countries will have their own priorities that they wish to

address, reflecting specific environmental, social and economic concerns. There can, however, be no doubting the generic importance of the broad subject areas as they relate to such topics as habitat modification, invasive species, over-exploitation, pollution and climate change.

THE QUESTIONS

More than a thousand questions were initially submitted for consideration by the workshop (see Appendix S1 in the supplementary material). Some of the questions had already been answered, highlighting the issue of effective communication between scientists and policy makers. Questions ranged from the specific to the general. During the initial screening process, those involved in policy development tended to vote for the more general or generic questions. Subsequent discussions between the researchers and policy makers often resulted in more narrowly focused questions becoming subsumed within a rewording of broader, generic questions. For example, questions relating to an individual taxonomic group would be translated into a question about the impact of some particular factor on biodiversity in general, or a question about a specific habitat would be broadened to a range of habitats. Inevitably this results in some questions that are far less likely to have a specific answer. The conflict between the general and the specific created tensions that was not easy to resolve in drawing up some of the final questions. This is an extremely important outcome of this exercise.

There is clearly a need to recognize that generic questions embrace a number of specific questions, the answers to which will vary in their relative importance to policy makers. This highlights the need for scientists to extract the underpinning specific question before proceeding. There will then be a subsequent need to repackage the answers to the specific questions to provide an answer to the generic question that will be of use to the policy maker. This will require an on-going dialogue between scientists and policy makers.

To gain an understanding of how the process of short-listing influenced the type of question posed, each question in the initial list of 1003 questions and the final 100 was categorized according to what type of answer was being sought. Thus, 48% initial and 44% final questions sought greater understanding or predictive power, 26% and 34%, respectively, sought measures of impact of anthropogenically induced changes, 11% and 13% sought measures of effectiveness of management interventions to support biodiversity conservation, 13% and 6% sought appropriate methodology, and 2% and 3% sought to optimize management. A further 89 initial questions were not ecological and were completely eliminated. As ecological science progresses we expect fewer questions seeking understanding and more seeking impact assessment and effectiveness of interventions.

FROM SCIENCE TO POLICY

In considering the delivery of evidence-based policy, Bullock, Mountford & Stanley (2001) argued that: (i) the advice and decisions of policy makers should be based upon the best available evidence from a wide range of sources; (ii) all key stakeholders should be involved at an early stage and throughout the policy's development; and (iii) all relevant evidence should be available in an accessible and meaningful form. This represents a move towards an analytical–deliberative process in decision making (Norton 2005).

Inevitably, most individual researchers and research papers make only a small contribution to the policy debate, and a final policy decision is rarely taken on the basis of a single piece of experimentation or observation, rather it is the full body of work upon a topic that is important. Bringing together evidence from a wide range of sources has led to the increasing use of analytical techniques such as meta-analysis (Côté *et al*. 2005) and a need for unbiased synthesis of material so that it presents the best-available evidence in a format accessible to policy makers and other end users. Systematic reviews of the kind developed in the health services are important here (Pullin & Knight 2001) and recent web-based initiatives (e.g. www.conservationevidence.com and www.cebc.bham.ac.uk) have been designed to gather together the evidence from applied science in a form that is accessible to end users (Sutherland *et al*. 2004).

This in itself is insufficient. A serial approach to science and policy deliberation where there is a one-way flow of information from scientists towards policymakers (Norton 2005), even if that is evidence based, does not allow for uncertainty or a reassessment of the way a particular problem is formulated. The discussions reported from the workshop demonstrated clearly the mismatch between problem formulation by the scientists and the policy makers, and the consequent need for an analytical–deliberative process. This requires all key stakeholders to be involved in the policy development process from an early stage in the formulation of the problems to be addressed, and all the relevant evidence being made available and communicated in a clear and accessible form, together with the uncertainty. An example of how this process works is provided by the *Foresight* report on future flooding (Evans *et al*. 2004a,b), which was developed with recursive interactions between a range of stakeholder groups and was heavily drawn upon by Defra in its *Making Space for Water* policy document (Defra 2004b).

The role of the scientist in the developing policy arena is in part to provide the best evidence available to inform the development of policy, to help monitor how successful current policies are working, and to provide solutions to unexpected events and policy failures. Inevitably there is scientific uncertainty in all of these areas (Sutherland 2006). Communication of that uncertainty is critical (May 2001; www.ost.gov.UK/

policy/advice/guidelines_2000) but dealing with that uncertainty falls within the remit of policy. It is also clear that the scientist cannot remain distinct from the policy process in providing the evidence base. Identifying the questions to be addressed in a dialogue between scientists and policy makers represents just one small part of the analytical–deliberative process. It is, however, an important one in that little emphasis is generally placed on correct problem formulation in the policy-decision process (Norton 2005).

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Supplementary material

The following supplementary material is available as part of the online article (full text) from http://w.w.w.blackwell-synergy.com.

Appendix S1. The 1003 questions submitted.