UK Biodiversity Research Advisory Group

RESEARCH NEEDS ANALYSIS
for
The role of biodiversity in ecosystem function

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on behalf of the BRAG Biodiversity & Ecosystems Subgroup1

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[1] For list of sub-group members, see Section 9.

Contents

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1. The Role of the UK BRAG

1.1 Background

The UK Biodiversity Research Advisory Group (BRAG) has been charged with identifying both knowledge gaps and the research needed to fill these gaps in order to facilitate successful delivery of the UK Biodiversity Action Plan. UK BRAG's work plan 2003-2006 has had at its core, six broad cross-cutting research themes, which were determined by the Biodiversity Research Working Group (BRWG) in its report Science in Action for Biodiversity (UK Biodiversity Research Working Group, 2001). One of these themes concerned the role of biodiversity in ecosystem functioning and this served as a driver for the series of workshops that have led to this report.

The overall aim of the Ecosystem Function Sub-Group of UK BRAG is to highlight knowledge gaps and identify research to improve understanding of the mechanisms and processes that underpin ecosystem function, in order to more fully comprehend the role that biodiversity may play in maintaining such processes.

Following an initial review by sub-group members, the following broad themes have been suggested as priorities for research coordination and action:

- Linking biodiversity with ecosystem function
- Linking biodiversity, ecosystem function and the provision of services
- Evaluating changes in ecosystem function in response to environmental change
- The impact of changing ecosystem function on human well being
- Development of adaptive management strategies
- Issues of scale

1.2 Terms of Reference

In designing this strategy, the group worked to a framework that recognised:

The increasing need to ensure that ecosystem functioning research needs are addressed fully in the development of research programmes. Furthermore, it will be important to avoid overlap and ensure compatibility with current research strategies. A degree of compatibility with larger scale initiatives, within Europe or globally, should be ensured. See section 3.2 for details of existing research initiatives.

The key issues defined previously by the Biodiversity Research Working Group (BRWG) in the report Science in Action for Biodiversity (Defra, 2001). More specifically, there is a need:

“to understand the mechanisms and processes that underpin ecosystem function, in order to more fully comprehend the role of biodiversity".

"to fully understand the nature and impacts of changes on biodiversity, in particular the processes that drive the dynamic interactions between species and communities; and to determine the role of biodiversity in maintaining ecosystem function".

The discussion and recommendations of the report of the UK BRAG Socio-economic sub group (http://www.ukbap.org.uk/BAPGroupPage.aspx?id=12) on closely related issues.

The rapidly evolving scientific context since the publication of the first two reports. The publication of the Millennium Ecosystem Assessment and the major UK research programme on ‘Biological Diversity and Ecosystem Function in Soil’ (see Usher et al., 2006, for an introduction).

1.3 Current Thinking on the Role of Biodiversity in Ecosystem Function

There are two major types of processes that occur in the natural world, and on which all life on planet Earth depends: production and decomposition. Production is mainly, but not exclusively, undertaken by plants and uses simple chemicals to build up complex chemicals. Predominantly carbon dioxide (CO_2) and water are used, with much more limited quantities of nitrogen, phosphorous, potassium and calcium and trace quantities of many other elements, to produce carbohydrates (sugars and starches) fats and proteins. Decomposition is mainly undertaken by microbial and fungal species, with the assistance of animals. The decomposition process breaks down complex chemicals, including an array of pollutants, into simple chemicals that can then be re-cycled into the production process.

Both of these major ecosystem processes are undertaken by a variety of species and each process can be conceived as providing a range of ecosystem goods and services. However, despite numerous observational studies, little is known about the causal relationships between biodiversity and ecosystem processes. If biodiversity does affect ecosystem function it could have important indirect impacts on the provision of ecosystem goods and services. The Millennium Ecosystem Assessment (2005) has brought this issue into focus within the international biodiversity research community.

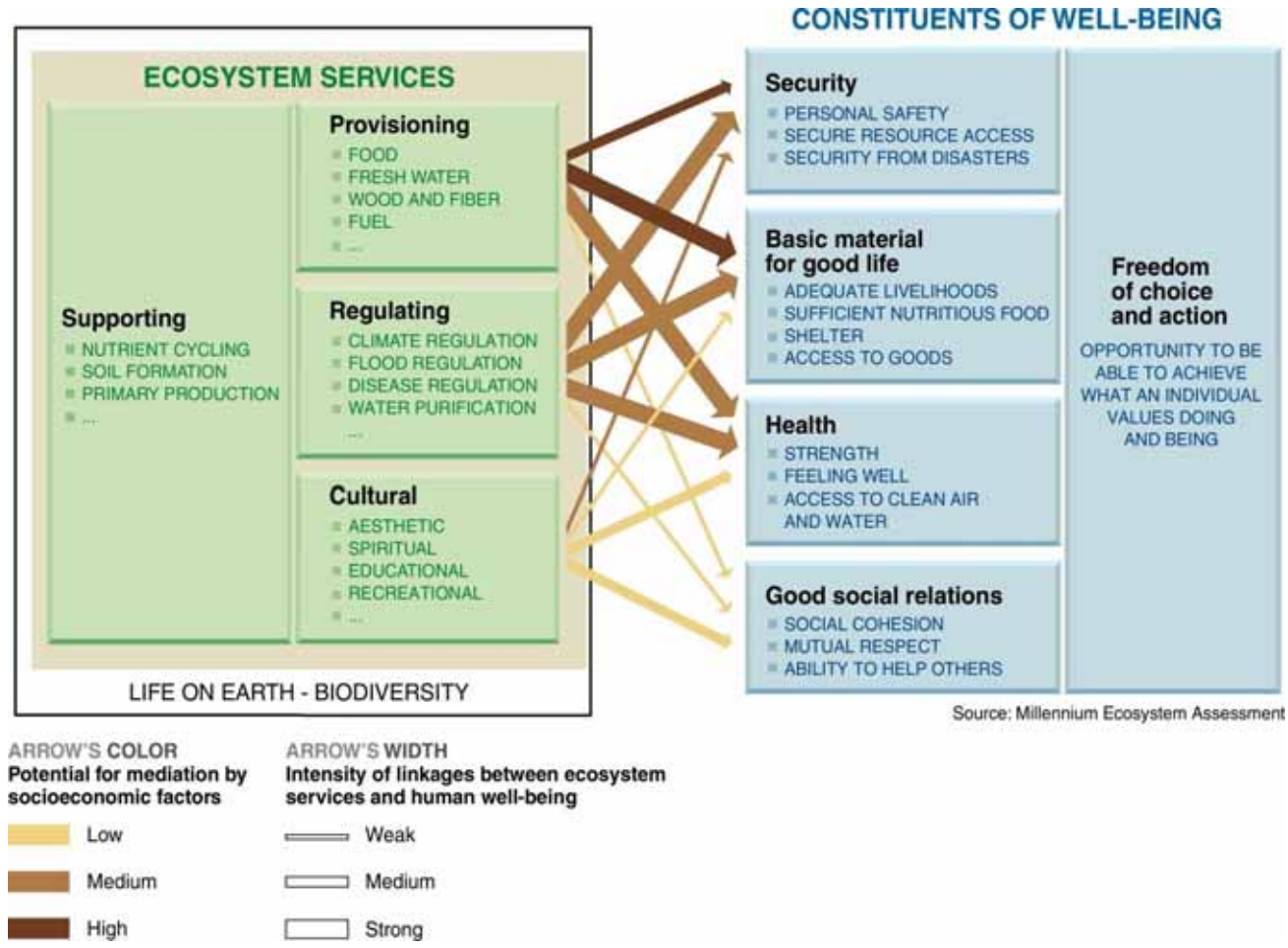

Figure 1. Linkages between biodiversity, ecosystem services and human well-being. From the Millennium Ecosystem Assessment (2005).

1.4 Definitions

Biodiversity is defined in Article 2 of the Convention on Biodiversity (CBD, 2001) as 'the variability among living organisms from all sources including *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems'. In short, this translates as the total range of the variety of life on earth.

Ecosystems: The CBD (CBD, 2001) defines an ecosystem as "a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit" (Article 2 of the Convention). In order to accommodate the Ecosystem Approach (EA) to biodiversity conservation, there is a need to recognise that "humans, with their cultural diversity, are an integral component of ecosystems".

An ecosystem may be considered as a unit within which an assemblage of living organisms interact with each other and with the chemical and physical environment, resulting in natural processes and establishment of a series of complex ecological balances. Ecosystems may operate at a wide range of spatial

and temporal scales, from long-term global systems, to very small, localised or ephemeral systems. It is the interactions and processes within ecosystems that deliver a wide range of environmental goods and services. These processes often involve activities of a wide variety of species. Currently, biodiversity action plans put more emphasis on taxa and habitats which are considered rare or threatened. However, there is a need to recognise the importance of a whole ecosystem approach to conservation, and thereby recognise the importance of more taxa and habitats than are currently listed in the UK BAP (Anon., 1995).

The term '**ecosystem function**' is interpreted differently by different people. It can be taken to mean the internal functioning of the ecosystem, such as nutrient cycling and maintaining energy fluxes, or the benefits, goods or services such as food production delivered to human beings by the properties and processes operating within the ecosystem. Ecosystem function within the current context has been defined as:

'the capacity of natural processes and components to provide goods and services that satisfy human needs directly or indirectly' (de Groot, 1992).

This implies that ecosystem functions must be considered as a subset of ecological processes and ecosystem structures that provide specific goods and services. Each function is thus the result of the sum of all the natural processes within the ecological subsystem that is defined by the service that is provided (de Groot *et al*., 2002). Ecosystem functions can be grouped, based on the four major categories of ecosystem services that bear directly on human well-being, identified by The Millennium Ecosystem Assessment (Millennium Ecosystem Assessment, 2005).

A more detailed consideration of the 'goods and services' paradigm may be found in Daily (1997). Little is understood about the relationship between species richness and ecosystem function. A number of models have been proposed, based mainly on terrestrial studies. The 'null' hypothesis suggests that biodiversity has no effect on ecosystem function, but empirical studies do not support this view. The 'rivet popper' and 'redundancy' hypotheses both suggest that complex relationships exist between species richness and ecosystem functions. Although some species may be 'redundant' under present environmental conditions, forming part of the system, but contributing little to the current processes; they may provide a significant buffer to future environmental change. However, loss of these species may affect the ecosystem by reducing resilience to changes in environmental conditions. The 'rivet popper' hypothesis suggests that ecosystems are like aeroplane wings, where the function may be compromised depending on which species (rivet) or group of species (rivets) is lost. The 'redundancy' hypothesis is similar, but suggests that species representing functional types are most important in terms of conservation effort since their loss could affect the integrity of the ecosystem. A third hypothesis suggests an alternative approach. The 'idiosyncratic' hypothesis suggest that ecosystem function changes with changes in species richness, but the direction and magnitude of the change is unpredictable due to the complex interactions between individual species (for review see Naeem *et al*., 2002). As we are unlikely to be able to determine critical 'rivets' or what is redundant, some authors have suggested that biodiversity is an 'insurance policy' against the impact of future environmental change (Noss, 1995).

Ecosystem services are indispensable for both the natural environment and human beings. Humankind is dependant on a range of services without which it would not exist. Services result from collections of ecosystem processes and examples include: maintenance of soil fertility, provision of climate regulation, and cultural, spiritual and educational benefits.

The Millennium Ecosystem Assessment (Millennium Ecosystem Assessment, 2005) identifies four major categories of ecosystem services that directly affect human well-being:

- Provisioning Services
- Regulating Services
- Cultural Services
- Supporting Services

A healthy ecosystem is normally able to maintain a sustainable flow of services, which underpin human well-being while retaining resilience to perturbations. Perturbations occur across all spatio-temporal scales and are major drivers of community structure. While resilience to major perturbations is important, these may be rare events. The environment is naturally changing on a day-to-day and year-to-year basis, and so ecosystems must be resilient to all of these changes, as well as to larger perturbations and long-term directional changes, i.e. those associated with climate change.

1.5 Biodiversity-Ecosystem Functioning: a Brief Review[2]

Establishing the links between biodiversity changes and changes in ecosystem processes (and hence the services they underpin), has been a major area of research activity over the past 10 years. Much of this effort has been through a combination of field and laboratory experiments, which have proven the most persuasive to many scientists but the most contentious to others. Several such experiments, carried out in the 1990s, provided compelling evidence that primary production of grassland plant assemblages, which represent a single trophic level, was positively associated with their species richness.

However, not all ecologists agreed with the conclusions (see discussions and references in Loreau *et al*., 2001, 2002). The experimental approach has been extended to other kinds of ecosystems, including freshwater and marine, often with contradictory outcomes. Recently, Balvanera *et al*. (2006) carried out a formal meta-analysis of all such experiments. They reviewed 88 publications on 446 measured ecosystem properties that were published between 1954 and June 2004. Their analysis suggests that the apparent lack of agreement of studies regarding the existence of a relationship between biodiversity and ecosystem function (as well as the strength of that relationship and its directionality) can be largely explained by differences in experimental design and methodology. Of particular significance is the length of the species richness gradient over which the

[2] partially modified and adapted from Raffaelli & Holt (2006)

ecosystem function was measured, and the number of trophic levels between the biodiversity manipulated and that at which the ecosystem function was measured.

These studies were almost all at small spatial and temporal scales; there was a preponderance of terrestrial and primary producer studies (of the 446 individual measurements of a range of ecosystem processes, 319 were measures of primary production). Moreover, most of them did not explicitly explore the effects of what happens when species are lost from assemblages, which is a major concern for society. Instead they artificially assembled systems which contained different numbers of species. The effects of disassembly (species loss) are unlikely to be mimicked by the assembly process. There was also an emphasis on the diversity of plants and animals, so that the significance of microbial diversity for ecosystem functioning in soils, sediments and the water column is not well understood.

Little is known regarding the physiology, and therefore ecosystem function, of many of the microbial groups present in an environment. Microorganisms are the dominant organisms globally, in terms of both biomass and diversity; and their functional and genetic potential may exceed that of higher organisms (Torsvik *et al*., 1996). Many important processes which are poorly understood, but which have clear global implications, are mediated by microbial activity.

A limited number of studies have tried to link microbial diversity and ecosystem function. However, a major criticism is that they only consider broad function, such as respiration, which all microorganisms carry out. Substantial effort has been devoted to understanding the role of microbial biomass, productivity, and process rates in terrestrial and aquatic ecosystems. There has been little work on linking diversity of specific groups of species to the specific functions they perform, including controls on the abundance, distribution, and importance of microorganisms to ecosystem function.

This is partly a result of unavailable technology because only recently have a range of molecular techniques become sufficiently refined to be applied to environmental samples. These techniques can be used to investigate and compare diversity at different levels of organisation, ranging from variability within species to diversity of communities. Some theoretical and practical constraints currently hamper comprehensive studies on prokaryotic biodiversity patterns, including the difficulty of defining prokaryotic species and the discrepancy between results obtained by different molecular approaches.

Problems posed by the current stresses on global ecosystems emphasise the need for a better understanding of functional groups of microorganisms, the functioning of microorganisms in ecosystems, their tolerance and sensitivity to environmental change and interactions with functional groups of other organisms (Meyer, 1993).

This approach will provide more useful information, both from a mechanistic and a practical point of view. For microorganisms, such an approach is essential, given their enormous diversity and presumed redundancy (see, for example, chapters in Bardgett *et al*., 2005). Many high level taxonomic and numerically abundant microbial groups have no cultivated representative and we know little about their

role in ecosystems. Molecular techniques are elucidating the function of these organisms. A recent and important example is the discovery that non-thermophilic crenarchaea, which constitute 20% of marine prokaryotes and 1 – 3% of soil prokaryotes, can oxidise ammonia. They are much more abundant than previously recognised. Bacterial ammonia oxidisers and their discovery is leading to a reassessment of nitrification processes in aquatic and terrestrial ecosystems and associated processes, including nitrous oxide production.

All of these issues affect our understanding of the role and importance of biodiversity in underpinning the provision and delivery of ecosystem goods and services. These linkages are often assumed, but in practice are difficult to demonstrate. There are two major challenges. The first is the number of steps between the biodiversity undergoing change and the service of interest. The more steps, the smaller will be the perceived or expressed effect. For instance, plant species (the explanatory variable in many studies) are intimately associated with primary production so it is not surprising that a clear relationship emerges between plant species richness and primary production. In contrast, the effects of soil fauna diversity on nutrient cycling is manifested through a 'black box' of many microbial and detrital steps, each of which is subject to additional external drivers so that the link between the fauna and the nutrients is apparently weaker. The second issue is that most ecosystem services are underpinned by more than one function, so that it is difficult to attribute changes in services to specific changes in biodiversity.

Rather than trying to extend established biodiversity-ecosystem function relationships to ecosystem services by adding another link, a more productive approach would be to identify the most important processes underlying the service of interest and then explore the role of biodiversity in maintaining that process. In other words, we need to adopt both service-orientated and biodiversity-orientated approaches.

Nevertheless, for those functions which could be clearly linked to the provision of ecosystem goods and services in the analysis by Balvanera *et al*. (2006), there was clear evidence that biodiversity had a positive effect on most services.

2. Policy, Science and Practice

2.1 Introduction

Ecosystem function and its relationship to biodiversity are important for both policy and practice.

Ecosystem function is essential to delivery across many policy areas. Within the framework of sustainable development, there are numerous social, economic and environmental policies which depend on ecosystem function for delivery. Research may be required to ensure management is appropriate to sustain ecosystem function in the wider environment and for designated areas. Traditionally, agricultural and forestry research has focussed on increasing domestic crop and livestock productivity. Research is now needed to improve understanding of how policies such as the Entry Level Environmental Stewardship Scheme in England (Defra, 2005) can benefit biodiversity and ecosystem function.

Implementation of policy requires some measurement or indicator of performance, and it is often difficult to measure success of biodiversity policy directly, and hence some sort of surrogate needs to be explored. One possible approach is 'ecosystem function' which might provide a means of measuring performance of policy measures. For example, the Countryside Survey provides a historical record of various landscape features and habitat attributes for a representative sample of one km squares using a stratified random sample based on environment zones (Haines-Young, 2000). It could provide the future vehicle for measuring and comparing success of maintaining ecosystem function, provided that a method is devised to assess ecosystem function of the broad habitat types which are surveyed.

The discrepancy between our knowledge of ecosystem functioning and the implementation of policy requires a scientific review. Such a piece of work may be beyond scope of BRAG, and may be better undertaken by the Global Biodiversity sub committee (GBSC) of the Global Environmental Change Committee (GECC). There is also a need to apply a Millennium Ecosystem Assessment based approach at the sub regional level e.g. North West Europe; from which an improved understanding of the interrelationships between biodiversity and ecosystem goods and services can be derived for the UK.

Ecosystem function is also becoming an increasingly important consideration in practical land management, where the conservation of areas that support biodiversity is being compromised through processes beyond the site boundary. Research is required to determine the effectiveness of ecosystem management in maintaining the special interest of such areas. Solutions need to be identified and tested, by adopting an experimental approach to management whereby we test which system most effectively delivers the desired outcome.

Agricultural land management is a special case, as there is a long history of research into management to promote the main ecosystem function, which is productivity. New incentives such as Agri-environment Schemes, which seek to benefit biodiversity, now need to be accounted for in terms of the ecosystem

services they provide. Notably, there has been considerable research effort in forestry in order to understand both the establishment and growth of tree species (often not of native origin) for the production of either large quantities of timber or small quantities of high-quality wood, while meeting the needs of biodiversity conservation, landscape and recreation.

Biodiversity research is topical and has the attraction of having both theoretical and practical aspects to it. Ever since the publication of E.O. Wilson's book, Biodiversity (Wilson, 1988), the scientific world has been challenged to understand why there are so many species of plants, animals and micro-organisms. There have been innumerable attempts to estimate the world's species richness by a variety of theoretical means and models of species numbers. However, the Rio de Janeiro conference in 1992 gave the subject of biodiversity added impetus, making it a very practical concern for every nation on the planet. Not only had biodiversity research a theoretical and experimental underpinning, but now it had to understand the way in which all of the variety of life contributed to the well-being of the planet and to its human population. The possibility of all sorts of exciting research avenues had become so much clearer.

2.2 Examples of ecosystem services which may be affected by loss of biodiversity.

Provisioning Services: Loss of biodiversity has been associated with the collapse of ecosystem services which have traditionally provided significant food supplies. The Atlantic cod stocks of Newfoundland collapsed in 1992 leading to the closure of fisheries. The resultant ecosystem shift suggests that recovery may not occur, or may require many years or another ecosystem shock to reverse the current system (Ash and Jenkins, 2001; Choi *et al*., 2004).

Regulatory Services: Mangrove forests have been shown to confer shoreline stability, reduce erosion, provide protection against storms, and trap sediments, nutrients and toxins (Chong, 2005). Early observations also suggested that mangroves may also have provided protection against the 2004 Indian Ocean Tsunami.

Cultural Services: Ancient semi natural woodland in Britain provides a "sense of place" for many people, e.g. the Major Oak in Sherwood Forest is an important tourist attraction, being associated with the legend of Robin Hood (Anon., 1992).

Supporting Services: Pollination of commercial crops is an important ecosystem service provided by biodiversity, but is being compromised in most parts of the world by excessive use of pesticides, as illustrated by the economics of apple cultivation in Sichuan Province, South China (Partap *et al.,* 2001) (http://www.beesfordevelopment.org). This area produces 30,000 tonnes of apples each year worth US$ 4.2 million, but nearly every apple flower has to be pollinated by hand because pesticides kill many bee colonies and other natural insect pollinators. Hand pollination is labour and time intensive, amounting to labour costs of US$ 70 per farmer. In contrast, only one or two bee colonies would

be need to pollinate the farm’s orchard, at a cost of US$7 per colony, 5 x cheaper than using human labour.

3. Specific Research Objectives

The subgroup identified a number of specific research objectives within a series of broad themes. These objectives are not exhaustive but should be considered as examples of research required to meet the headline messages. The recommendations are not listed in order of priority.

The need for two reviews was identified:

- A summary of what is currently known regarding the interactions between biodiversity and ecosystem goods and services with the aim of identifying the main gaps and target areas.

- An investigation to identify those ecosystems whose goods and services are most under threat.

3.1 Linking Biodiversity with Ecosystem Function

Position statement:

There is a lack of knowledge regarding how ecosystems function and the role of biodiversity, at both small and large temporal scales. The behaviours of systems following biodiversity loss and thresholds for functioning have yet to be identified. Key issues are the definition of thresholds of functioning, redundancy, resilience and stability.

Recommendations:

1. Develop a classification scheme of ecosystem functions, to provide a common currency understood across different ecosystems.
2. Undertake research regarding the effect of biodiversity changes or species loss on ecosystem function and the resilience and stability of ecosystem function (the difficulty of formulating a testable hypothesis needs to be recognised. It may prove impossible to answer this question, due to the many definitions of ecosystem functionality, and the large number of species in an ecosystem). Inconsistencies highlighted in previous studies require that example protocols are put forward, in order to contribute more robust evidence.
3. Establish a better understanding of the metabolic processes of various species at different stages of their life cycles and how these are expressed at the ecosystem level. In order to address this topic, focused projects need to be developed.
4. Address the interaction effects of redundancy and resilience.
5. Examine the decomposition function: how resilient is the decomposer community in various ecosystems (especially different soils and marine/freshwater sediments). Examine plant / fungal / microbial

interactions and the effects of changes in microbial assemblages. Can composition of functional groups be assessed as opposed to species?

6. Develop models to assess the importance of factors in gas regulation and primary production, genetic exchange and dispersal, nutrient cycling, and the roles of different taxa in the delivery of these processes in marine ecosystems. In particular, issues regarding biodiversity and water column (pelagic) processes should be examined.
7. Assess microbial community structure and function in a range of ecosystems, especially including scaling up from the laboratory scale to the field and landscape scales.

Commentary:

There is a need to establish baseline information for well functioning ecosystems, including the establishment of critical thresholds, and how these are being maintained in the UK. To facilitate this, a common currency or framework must be established to allow comparisons across ecosystems, and an interdisciplinary capacity must be developed (a perennial problem of interdisciplinary research is how different data sources are integrated). It is vital that we assess and identify the contribution of biodiversity to ecosystem function, and propose and test models in different systems, such as the recently developed model of carbon flows through the soil ecosystem (Fitter *et al.*, 2005).

3.2 Linking Biodiversity, Ecosystem Function and the Provision of Services

Position statement:

Loss of biodiversity is likely to have a variety of effects on ecosystem function, resilience to change, the provision of goods and services and human well-being.

Recommendations:

1. Identify the ecosystem processes, or functions, which underpin the provision of ecosystem goods and services, and the strength of the relationship between biodiversity and these processes. A range of appropriate scales and ecosystem services should be considered, while recognising that we cannot address everything.
2. Identify the environmental limits of acceptable change, i.e. to determine how much change in biodiversity will affect function of an ecosystem (and adjoining ecosystems) and its ability to provide services. This needs to consider continual and episodic degradation of habitats and the roles of species, including keystone species. Identify thresholds, where possible. Establishment of thresholds for ecosystems must be coupled with safety margins against unpredictable catastrophic events, while recognising that these events may be partly responsible for driving evolution. It is necessary to consider whether this is best tackled as a modelling exercise, or whether it is feasible to establish a large, enclosed experiment in which we alter environmental conditions across a large number of replicated plots (over a long timescale).

3. Develop tools which allow ecosystem goods and services to be valued in a meaningful way that reflects the total economic value of ecosystems, including the direct, indirect and non-use values of not only provisioning, but also regulating, supporting and cultural services.
4. Increase understanding of the links between resilience and the provision of services at a variety of scales. The effects of changes at small local and short temporal scales may be very different to those at large spatial scales and long term perturbations: the effects are likely to be scale dependent.
5. Create predictive models and test these through empirical experimentation.
6. Investigate the importance of biodiversity to the provision of ecosystem goods and services in agriculture, forestry, fisheries and the social uses of land and water (relates to recommendation 4.1.2, above).
7. Investigate the importance of soils, in particular peat, in CO_2 sequestration. What are the rates of processes in soils that provide important functions in land use management?
8. Identify and assess the importance of processes associated with wetlands. These may include carbon sequestration, pollution control, hydrology and water returns, flood energy absorption, primary productivity, biomass supported, numbers of genera/species supported, cultural interest, genetic interchange and sedimentary processes
9. Improve public understanding of biodiversity science. Perceptions of biodiversity by stakeholders may be quite different from those of natural and socio-economic scientists. Stakeholders who are better informed are likely to make better judgments.

Commentary:

The Millennium Ecosystem Assessment (Millennium Ecosystem Assessment, 2005) presents a consensus on how to think about new ways of investigating the effects of biodiversity loss on ecosystem processes at the larger scales for which society requires answers, and highlights the need to improve our understanding of what really underpins service delivery. Using the protocols and approaches developed within the MA sub-regional assessments, those ecosystem services most relevant to the UK need to be agreed. The ecosystem processes, or functions which underpin these services, need to be identified, and the strength of the relationship between biodiversity and these processes established. This is a service-orientated approach to biodiversity conservation, rather than a biodiversity-orientated one. This research need has been identified by a UK BRAG subgroup focusing on socio-economic issues (Perrings and Ferris, 2004).

3.3 Evaluating Changes in Ecosystem Function in Response to Environmental Change

Position statement:

There is a lack of data and knowledge regarding the effect of changes on ecosystem function and the role of biodiversity in the resilience of ecological-economic systems. Disturbance can, in some situations, act as a source of diversity.

Recommendations:

1. Assess the impact of climate and land use change, invasive species, overexploitation and pollution on ecosystem functions through changes in biodiversity. This needs to include the impacts of gradual v catastrophic biodiversity loss (species and genetic variability) on the ecosystem's ability to function.
2. Quantify tolerance of major drivers/pressures on biodiversity, processes, services and relationships.
3. Establish the likely effect of loss of species from systems, as opposed to variation in assemblage composition, and provide empirical evidence to investigate whether 'redundancy' is an appropriate concept. Test hypotheses to attempt to identify thresholds under different environmental conditions, and to test whether a different suite of species or genotypes will play similar functional roles. Does redundancy act as an "insurance policy" so that an ecosystem will function under a variety of environmental conditions?
4. Investigate the threshold of tolerance for extreme conditions under the scenarios of climate change, and their potential effects on ecosystem function, e.g. rates of soil process such as nutrient cycling or shifts in dominant ecosystem processes of primary production and decomposition.
5. Model the potential impacts of invasive species with response to changing ecosystem function. This needs to include what makes a community/habitat prone to invasion and the ecosystem consequences of successful removal.
6. Evaluate the full economic costs and benefits of the introduction of selected critical non-native invasive species, including the indirect effects on ecosystem services.
7. Establish the different sources of disturbance and determine their impacts on ecosystem function.
8. Investigate the importance of connectivity and landscape permeability for dispersal and genetic processes such as speciation and adaptation at larger scales.
9. Develop decision-methods for uncertain and irreversible effects.
10. Research and model the effects of changes in ocean carbonate chemistry on the function of marine ecosystems. Develop understanding of how interactions between marine biogeochemical cycles and ecosystems

respond to and force global change. This should include effects on calcitic and aragonitic organisms

11. Model combined effects and interactions of higher atmospheric CO_2 levels, higher temperatures and lower O_2 concentrations.

Commentary:

There is uncertainty about the effects of biodiversity change

- on ecosystem functioning, and
- on economic activities, goods and services.

Understanding of the responses of ecosystems to change is likely to be critical in the light of a number of factors, the most important being climate change, invasive species, dramatic events, and the simplification of systems. Changes in species distributions, community structure (including invasive non-native species, disease vectors and native species), socio-economic pressures and land and water development, such as agriculture, forestry, aquaculture and urbanisation, have potential effects on ecosystem functions and services.

The impact of changes may vary according to their frequency and amplitude. This may lead to changes in resilience, and is a potential source of diversity. Furthermore, impacts at one scale may not matter at another scale (large scale chronic events cascade to lower scales, e.g. bioaccumulation impacting on ecosystem function). The MA and application of the CBD's Ecosystem Approach note that the adjacent and wider impacts must be considered, and this is also recognised in the Habitats Directive. This therefore implies that there is a need to develop ecosystem thinking.

3.4 The Impact of Changing Ecosystem Function on Human Well-being

Position statement:

There is a lack of understanding of the impact of changing ecosystem function on human well being.

Recommendations:

1. Determine if an ecosystem is fully functional and establish the degrees of functionality.
2. Explore general whole community metrics, such as body size spectra, for application in monitoring.
3. Investigate how we can manage environmental change in terms of ecosystem function.
4. Undertake a formal sub-regional assessment for UK following procedures outlined in the Millennium Ecosystem Assessment.

5. Develop interdisciplinary tools for assessing the value of impacts of changes in ecosystem function on human well-being, at a range of scales.

Commentary:

There is a need to identify and understand the impacts of changes in biodiversity and ecosystem functioning on human well-being. Provisioning, regulating, supporting and cultural ecosystem services all provide benefits to people. Estimating the value and importance of biodiversity and ecosystem function for human welfare requires collaborative, interdisciplinary research.

3.5 Development of Adaptive Management Strategies

Position statement:

How can we manage/influence ecosystem function in the face of environmental change?

Recommendations:

1. Test different (experimental) management regimes to assess which performs best.
2. Build models to allow exploration of effects of environmental changes and/or management changes on ecosystem function.
3. Review the extent to which current information will allow us to quantify ecosystem function and identify pathological states.
4. Review the effectiveness of different kinds of policy instruments – what works, what doesn't, when, why?
5. Construct spatially explicit meta-community models that allow phase transitions and multiple equilibria to be explored (trophic models).

Commentary:

Adaptation of our management practices is likely to be a critical factor in determining how well ecosystems cope with environmental change. We also need to consider what scale or ecosystem unit is important for policy and management: i.e. at a level where we can change or manage the necessary conservation practices or policies. The shortcomings, time limitations and tensions with the scale at which particular processes are operating also need to be fully explored. Any irreconcilable mismatches need to be identified, as does the practicality of defining a meaningful ecosystem unit. The indicators or metrics used to assess effectiveness may vary between systems and scales.

3.6 Issues of Scale

Position statement:

To date, much research has focused on relatively short temporal and spatial scales. We need to understand how studies at one scale can be interpreted at another scale.

Recommendations:

1. Research the relationship between biodiversity loss and ecosystem function across a range of scales, considering multiple land and water use patterns.
2. Investigate how results from one scale map onto another scale, to maximise the value of existing and future research results.
3. Overcome the mismatch between policy (often macro) and research scales (frequently micro).

Commentary:

Scale is a cross cutting issue, but the subgroup feels it is such a critical issue that it must be highlighted. It is essential that we focus research effort at the appropriate scale and consider international efforts to avoid duplication of research. From a practical and legislative perspective, we also need to consider the best ways to integrate ecosystem (regional) and site (local) based management activities.

The scale at which ecological systems should be studied will often not match the scale at which policies for managing land and water need to be delivered. Although there may be considerable pressure to address particular spatial scales from a policy perspective, the most important consideration will always be how we might seek to determine the most appropriate scale to study a particular ecological process or define the boundaries of a particular ecosystem.

4. Knowledge Transfer Activities

4.1 Policy

Ensure that the importance of biodiversity, ecosystem functioning and goods and services in delivering sustainable ecosystem futures is understood by policymakers; Kate Trumper (Parliamentary Office of Science and Technology) is currently drafting a briefing note on this for MPs. Defra has just produced a final draft on their response to the MA and is also involved in the International Mechanism of Scientific Expertise on Biodiversity (IMoSEB) process. Defra has recently commissioned several projects establishing and agreeing a definition of an ecosystem-based approach and ecosystem services and reviewing how to embed the principles of this approach - including environmental limits and values – into decision- and policy-making processes.

There may be a need to broker multiple funded work areas. A difficulty lies in the fact that different ecosystem services act at different scales, and therefore different funding agencies may be required for different levels of scale.

4.2 Communication

Once the research strategy is prepared, it will require launching as part of an implementation process and continual promotion as it develops.

There is a need to promote results of research undertaken under this strategy, not just though publishing papers and materials on a website, but through presentation of the information at conferences and especially to target audiences such as stakeholders, government agencies and those involved in policy development and decision making. It is important to ensure that the research effort links with other initiatives, both to broaden and disseminate the knowledge base, and strengthen partnerships and collaboration.

The UK research community needs to address these issues if we are to respond appropriately to initiatives in this area, such as the MA, IMoSEB, the CBD's Ecosystem Approach and national sustainability targets. There is also a need to integrate all the various sources of information so that there is a 'one stop shop', which could take the form of a metadatabase and website with information, research projects, organisations, sources of research funding, policy areas, links to other sites with information on biodiversity, ecosystem function, services, and values. The UK Clearing House Mechanism (hosted by JNCC) is being redeveloped to provide information on:

- and be a place to post and find out about case studies, programmes and projects (on-going and completed),
- organisations and their areas of specialism
- research and project funding
- policy with particular reference to legislation and policies in the UK and devolved administrations, and

- other types of information such as monitoring techniques and indicators

It is hoped to launch the site in Summer 2006.

It is also important to attract public interest and participation and to use free sources of information e.g. Wildlife Trusts, volunteers. One of the particular aspects of the work to halt the loss of biodiversity in the UK, and indeed to start increasing biodiversity, is that it is not dependent upon one group of 'professionals'. There is a huge variety of people involved with actions from national to the most local of levels. For this reason, it becomes extremely important that the results of research are not only explained in scientific and policy terms, but also in ways that are accessible and easily understood by just about everyone in the UK.

Effective communication will require a specifically designed communication strategy to ensure recognition of opportunities and provide the different levels of communication required for different target audiences. Timing to coincide with key events and integrate with other initiatives will also be important. A communication strategy will need to demonstrate important biodiversity contributions to ecosystem functions that provide services, e.g. the key role of microorganisms in our soils, how these influence farm productivity, and hence how the food that we eat depends upon many species which are unseen (and might still be scientifically unknown).

5. Funding

5.1 Background

Consideration must be given to the funding sources and requirements for effective implementation of any research strategy. As the strategy is developed and implemented, there will be a progressive demand for funding. Studies of ecosystem function are likely be large scale, long term and involve multidisciplinary approaches or collaboration between a wide range of interested parties, which could extend to different countries, at European or global levels. Such studies will therefore require a high level of commitment from sponsors, and the research strategy must include provision to ensure that it attracts and sustains such interest and support. Innovative research ideas may be focused simultaneously on both theoretical development and practical/policy application, but must include the design and implementation of an effective communication plan and attention to detail in project funding proposals. The necessity of providing potential sponsors with a business case, to help them secure funding, is a concept that will need to be developed by the research community.

5.2 Potential sources

Sources of funding have been identified below, but each of these potential sponsors may offer funding for different projects and research proposals under different aspects of their respective internal remits. Not all sponsors will support the same projects. For example, research with aims and objectives that could support policy may attract government funding, projects of a more scientific investigatory nature ('Blue Skies' research) may attract funding from research councils, while more specifically focused studies may attract support from related NGOs, such as the RSPB, or charities. However, ecosystem research projects provide great opportunities for building partnerships and collaborative efforts. They also have potential to overlap with existing or planned work. Considering funding options will enable the efficient use of available funding and development of effective partnerships. The research priorities given in Section 3 will have to take funding considerations into account on a project by project basis.

Funding bodies which may provide support for research in this area include:

- Biotechnology and Biological Science Research Council (BBSRC)
  http://www.bbsrc.ac.uk/Welcome.html
- British Council
  http://www.britishcouncil.org/
- Department for International Development (DfID)
  http://www.dfid.gov.uk/research/
- Department for the Environment Food and Rural Affairs (Defra)
  http://www.defra.gov.uk/wildlife-countryside/resprog/
- Economic and Social Research Council (ESRC)
  http://www.esrc.ac.uk/

- Engineering and Physical Sciences Research Council (EPSRC)
  http://www.epsrc.ac.uk/default.htm
- Environment Agency
  http://www.environment-agency.gov.uk/science/922284/
- Environment and Heritage Service, Northern Ireland (EHS)
  http://www.ehsni.gov.uk/natural/natural.shtml
- Esmée Fairbairn Foundation
  http://www.esmeefairbairn.org.uk/
- The Leverhulme Trust
  http://www.leverhulme.org.uk/about/introduction/
- Medical Research Council (MRC)
  http://www.mrc.ac.uk/index/current-research/current-overview.htm
- Natural Environment Research Council (NERC)
  http://www.nerc.ac.uk/
- Office of Science and Technology (OST)
  http://www.ost.gov.uk/research/index.htm
- The Royal Society
  http://www.royalsoc.ac.uk/page.asp?id=1111
- Scottish Executive Environment and Rural Affairs Department (SEERAD)
  http://www.scotland.gov.uk/About/Departments/ERAD
- Welsh Assembly Government
  http://www.countryside.wales.gov.uk/fe/master.asp?n1=366&n2=740
- Countryside Council for Wales
  http://www.ccw.gov.uk
- English Nature
  http://www.english-nature.org.uk/
- Scottish Natural Heritage
  http://www.snh.org.uk/

6. Prioritising Research Areas and Time Frame

Research into ecosystem function has potential for such a broad scope, that a method of determining priorities must be devised. The focus must be on how biodiversity contributes to ecosystem function, and ways of measuring the sustained functionality and capacity to deliver the goods and services required.

The subgroup recommends a review to determine the finer points of this outline, setting research objectives and to reach an appropriate method for prioritising the research requirements.

	Recommendations	No votes	Priority
3.1	**3.1 Linking Biodiversity with Ecosystem Function**		
3.1.1	Develop a classification scheme of ecosystem functions.	2	3
3.1.2	Undertake research regarding the effect of biodiversity changes or species loss on ecosystem function and the resilience and stability of ecosystem function.	7	1
3.1.3	Establish a better understanding of the metabolic processes of various species at different stages of their life cycles and how these are expressed at the ecosystem level.		
3.1.4	Address the interaction effects of redundancy and resilience.		
3.1.5	Examine the decomposition function: how resilient is the decomposer community in various ecosystems (especially different soils and marine/freshwater sediments). Examine plant / fungal / microbial interactions and the effects of changes in microbial assemblages. Can composition and functional groups be assessed as opposed to species?	3	3
3.1.6	Develop models to assess the importance of factors in gas regulation and primary production, genetic exchange and dispersal, nutrient cycling, and the roles of different taxa in the delivery of these ecosystem processes in marine systems. In particular, issues regarding biodiversity and water column (pelagic) processes should be examined.	2	3
3.1.7	Assess microbial community structure and function in a range of ecosystems, especially including scaling up from the laboratory scale to the field and landscape scales.	4	2
3.2	**3.2 Linking Biodiversity, Ecosystem Function and the Provision of Services**		
3.2.1	Identify the ecosystem processes, or functions, which underpin the provision of ecosystem goods and services, and the strength of the relationship between biodiversity and these processes. A range of appropriate scales and ecosystem services should be considered.	5	1

	Recommendations	No votes	Priority
3.2.2	Identify the environmental limits of acceptable change which determine how much change in biodiversity will affect function of the ecosystem (and adjoining ecosystems) and its ability to provide services? This needs to consider continual and episodic degradation of habitats and the roles of species, including keystone species. Identify thresholds where possible. Establishment of thresholds for ecosystems must be coupled with safety margins against unpredictable catastrophic events.	5	1
3.2.3	Develop tools which allow ecosystem goods and services to be valued in a meaningful way that reflects the total economic value of ecosystems, including the direct, indirect and non-use values of not only provisioning, but also regulating, supporting and cultural services.	4	2
3.2.4	Increase understanding of the links between resilience and the provision of services at a variety of scales. The effects of changes at small, local and short temporal scales may be very different to those at large spatial scales and long term perturbations: the effects are likely to be scale dependent.	4	2
3.2.5	Create predictive models and test these through empirical experimentation.	2	3
3.2.6	Investigate the importance of biodiversity for supporting, provisioning, regulating and cultural services in agriculture, forestry, and fisheries.	3	3
3.2.7	Investigate the importance of soils, peat in particular, in CO2 sequestration. What are the rates of processes in soils that provide important functions in land use management?	1	3
3.2.8	Identify and assess the importance of processes associated with wetlands. These may include carbon sequestration, pollution control, hydrology and water returns, flood energy absorption, primary productivity, biomass supported, numbers of genera/species supported, cultural interest, genetic interchange and sedimentary processes	1	3
3.2.9	Improve public understanding of the role of biodiversity and the need for research in this area. Perceptions of biodiversity by stakeholders may be quite different from those of natural and socio-economic scientists. Stakeholders who are better informed are likely to make better judgments.	2	3

	Recommendations	No votes	Priority
3.3	**3.3 Evaluating Changes in Ecosystem Function in Response to Environmental Change**		
3.3.1	Assess the impact of climate and land use change, invasive species, overexploitation and pollution on ecosystem functions, through changes in biodiversity. This needs to include the impacts of gradual v catastrophic biodiversity loss (species and genetic variability) on the ecosystem's ability to function.	4	2
3.3.2	Quantify tolerance of major drivers/pressures on biodiversity, processes, services and relationships.		
3.3.3	Establish the likely effect of loss of species from systems, as opposed to variation in assemblage composition, and provide empirical evidence to investigate whether 'redundancy' is an appropriate concept. Test hypotheses to attempt to identify thresholds under different environmental conditions, and to test whether a different suite of species or genotypes will play similar functional roles. Does redundancy act as an "insurance policy" so that an ecosystem will function under a variety of environmental conditions?	5	1
3.3.4	Investigate the threshold of tolerance for extreme conditions under the scenarios of climate change, and their potential effects on ecosystem function, e.g. rates of soil process such as nutrient cycling or shifts in dominant ecosystem processes of primary production and decomposition	2	3
3.3.5	Model the potential impacts of invasive species with response to changing ecosystem function. This needs to include what makes a community/habitat prone to invasion and the ecosystem consequences of successful removal.	2	3
3.3.6	Evaluate the full economic costs and benefits of the introduction of selected critical non-native invasive species, including the indirect effects on ecosystem services.		
3.3.7	Establish the different sources of disturbance and determine their impacts on ecosystem function.		
3.3.8	Investigate the importance of connectivity and landscape permeability for dispersal and genetic processes such as speciation and adaptation at larger scales.	1	3

	Recommendations	No votes	Priority
3.3.9	Develop decision-methods for uncertain and irreversible effects.	1	3
3.3.10	Research and model the effects of changes in ocean carbonate chemistry and on the function of marine ecosystems. Develop understanding of how interactions between marine biogeochemical cycles and ecosystems respond to and force global change. This should Include effects on calcitic and aragonitic organisms	1	3
3.3.11	Model combined effects and interactions of higher atmospheric CO_2 levels, higher temperatures and lower O_2 concentrations.		
3.4	**3.4 The Impact of Changing Ecosystem Function on Human Well-being**		
3.4.1	Determine if an ecosystem is fully functional and establish the degrees of functionality.	1	3
3.4.2	Explore general whole community metrics, such as body size spectra, for application in monitoring.	2	3
3.4.3	Investigate how we can manage environmental change in terms of ecosystem function.		
3.4.4	Undertake a formal sub-regional assessment for UK following procedures outlined in the Millennium Ecosystem Assessment.	4	2
3.4.5	Develop interdisciplinary tools for assessing the value of impacts of changes in ecosystem function on human well-being, at a range of scales.	3	3
3.5	**3.5 Development of Adaptive Management Strategies**		
3.5.1	Test different (experimental) management regimes to assess which performs best.		
3.5.2	Build models to allow exploration of effects of environmental changes and/or management changes on ecosystem function.	1	3
3.5.3	Review the extent to which current information will allow us to quantify ecosystem function and identify pathological states.	1	3
3.5.4	Review the effectiveness of different kinds of policy instruments – what works, what doesn't, when, why?	2	3
3.5.5	Construct spatially explicit meta community models that allow phase transitions and multiple		

	Recommendations	No votes	Priority
	equilibria to be explored (trophic models).		
3.6	**3.6 Issues of Scale**		
3.6.1	Research the relationship between biodiversity loss and ecosystem function across a range of scales, considering multiple land and water use patterns.	2	3
3.6.2	Investigate how results from one scale map onto another scale, to maximise the value of existing and future research results.	2	3
3.6.3	Overcome the mismatch between policy (often macro) and research scales (frequently micro).	2	3

Table 1. Summary of recommended research. Participants were asked to vote for the ten research recommendations they considered to have the highest priority. The recommendations were then ranked based on the number of votes they received. Priority 1 reflects recommendations which received 5, 6 or 7 votes, Priority 2: those which received 3 or 4 votes and Priority 3: those which received 1 or two votes. These results are presented for information only and do not necessarily represent the view of UK BRAG.

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8. Glossary

Ecosystem services are the benefits people obtain from ecosystems. The Millennium Ecosystem Assessment identifies four categories of services:

Provisioning Services: The products obtained from ecosystems, such as food, fibre, fuel and fresh water.

Regulating Services: The benefits obtained from the regulation of ecosystem processes, such as climate, disease and water regulation.

Cultural Services: The non-material benefits obtained from ecosystems, such as spiritual, recreational and educational benefits.

Supporting Services: The services necessary for the production of all other ecosystem services, such as soil formation, nutrient cycling and primary production.

Resilience: the ability of an ecosystem to regain structural and functional attributes that have suffered harm from stress or disturbance.

Species redundancy: the presence of multiple species which play similar roles in ecosystem dynamics.

(Society for Ecological Restoration International, 2004)

9. Sub-group membership

Dr. Roger Catchpole	English Nature
Dr. Richard Ferris	JNCC
Professor Mary Gibby	Royal Botanic Gardens, Edinburgh
Professor Jim Harris	Cranfield University
Dr. Michel J. Kaiser	University of Wales, Bangor
Dr. Davy McCracken	Scottish Agricultural College
Dr. Diana Mortimer	JNCC
Dr. Helen Pontier	Defra
Professor Jim Prosser	University of Aberdeen
Professor Dave Raffaelli	University of York
Dr. Hubert Rees	Centre for Environment, Fisheries & Aquaculture Science
Dr. Martin Solan	University of Aberdeen
Professor Michael B Usher	University of Stirling
Dr Allan Watt	Centre for Ecology and Hydrology, Banchory

10. Appendices

I. List of abbreviations

BRAG	Biodiversity Research Advisory Group
BRWG	Biodiversity Research Working Group
CBD	Convention on Biological Diversity
Defra	Department for Environment, Food and Rural Affairs
EA	Ecosystem Approach
Eftec	Economics for the Environment Consultancy Ltd
EHS	Environment and Heritage Service, Northern Island
EN	English Nature
EPBRS	European Platform for Biodiversity Research Strategy
EU	European Union
GBSC	Global Biodiversity Subcommittee
GECC	Global Environmental Change Committee
GIS	Geographical Information System
IEEP	Institute for European Environmental Policy
IMoSEB	International Mechanism of Scientific Expertise on Biodiversity
MA	Millennium Ecosystem Assessment
NERC	Natural Environment Research Council
NRA	Natural Resource Accounts
OSPAR	The Convention for the Protection of the Marine Environment of the North-East Atlantic (The OSPAR Convention)
PEBLDS	Pan European Biological and Landscape Diversity Strategy
RAMBLERS	Rapid Assessment of Marine Biodiversity in Relation to Environmental Degradation and Remediation
RSPB	Royal Society for the Protection of Birds
UKBAP	UK Biodiversity Action Plan
UKPopNet	UK Population Biology Network
UNESCO	United Nations Education, Scientific and Cultural Organisation

II. A selection of projects of interest

Centre for Ecology & Hydrology:

Drivers of Countryside Change: Final Report; Roy Haines-Young & Sandra McNally, Centre for Ecology & Hydrology, 2001. ISO /IEC 13250 Topic Maps; Information Technology Document Description and Processing Languages Second Edition; ISO 13250 prepared by Joint Technical Committee JTC1, Information Technology, Subcommittee SC34, May 2002 (checked January 2006)

Defra:

Pressures on Natural Resources. Final Report 20th March 2006 Project T (CTE0509)

Integrated Science for Integrated Management - Developing the Capacity for Adaptive Ecosystem Management (AE1148)

Evaluating ecosystem models as tools for policy development on biodiversity (IF0103)

The Implication for the Marine Environment of CO2 Releases (ME2107)

AMBLE (Assessment of Marine Biodiversity Linked to Ecosystems (ME3109).

The future of healthy ecosystems (SD0306).

Do Farm Management Practices Alter Soil Biodiversity And Ecosystem Function? Implications For Sustainable Land Management - Non R&D (SP08012).

England's terrestrial ecosystem services and the rationale for an ecosystem-based approach (NR0107).

The Parrett Catchment: a case study to develop tools and methodologies to deliver an ecosystem-based approach (NR0111).

Defra Horizon Scanning projects:
http://www.escience.defra.gov.uk/horizonscanning/fstMain.asp

"The future of healthy ecosystems" (CTHS0303)

Institute for Environmental Policy (IEEP):

Kettunen, M and ten Brink, P. (2006). Value of biodiversity- Documenting EU examples where biodiversity loss has lead to the loss of ecosystem services. Final report for the European Commission. Institute for European Environmental Policy, Brussels, Belgium. 131 pp.

NERC Thematic Programme:

Biological Diversity and Ecosystem Function in Soil (1997 – 2007, £6,014,000 spent on supporting about 30 individual projects). (http://soilbio.nerc.ac.uk/) The focus of the research programme was on a single upland grassland soil, located at Sourhope, in the Cheviots in Scotland, just north of the border with England).

Scottish Executive Environment and Rural Affairs Department:

Consequences of soil biological diversity for the functioning and health of agricultural soils in relation to N cycling processes. II. Carbon and nitrogen fluxes among major plant and soil pools, using natural abundance stable isotopes. Scottish Crops Research Institute (SCR/588/02).

Consequences of soil biological diversity for the functioning and health of agricultural soils in relation to C cycling dynamics and resilience (This project has made significant progress towards a better understanding of the consequences of reducing the biodiversity of soil communities and also the factors which affect the composition of those communities). Scottish Crops Research Institute (SCR/542/00).

Interactions between the structure of soil habitats and biological processes (The aim of this programme of work is to quantify the impact that soil structural heterogeneity has on the soil-plant-microbe system) Scottish Crops Research Institute (SCR/525/99).

III. Detailed commentaries for research themes

Linking Biodiversity with Ecosystem Function

Agricultural ecosystem functions have been extensively studied, with a focus on provisioning services e.g. production of food. New research must also assess the impact of contemporary agricultural systems on the delivery of other goods and services such as clean water, biodiversity and flood regulation. It is important that any research attempts to recognise all services provided by ecosystems.

An assessment of the UK's maintenance of ecosystem diversity is an urgent research priority. The assessment will require the development of new metrics. This work would also contribute to better understanding of ecosystem health and how to measure this.

As Levin (1992) noted "the problem of relating phenomena across scales is the central problem in biology and in all of science". This continues to be the case at both a theoretical and practical level. Scale can be characterised by the simple concept of grain and extent. Grain refers to the finest spatial resolution that might be considered in a study (e.g. minimum mapping unit) while extent defines the size of the study area. When any comparison or aggregation between different studies is being made, it is important to match the grain to the extent of the available information.

As a result, considerable difficulties are often experienced when any synthesis of different studies is attempted. Much of the problem with generalising findings comes from inadequate definition of training and test datasets. Furthermore, some statistical reviewers have difficulty accepting new developments, and this can impede the uptake of useful tools. This challenge needs to be met if the relationship between biodiversity and ecosystem function is to be understood within terrestrial ecosystems. The influence of scale on the distribution and dynamics of vegetation has a long history of research and offers some of the most useful insights into these issues (e.g. Delcourt *et al*., 1983).

Some ecosystems provide unique challenges, and it is critical that scale issues are considered in order to overcome experimental difficulties. For example, developing tools to assess the condition of marine habitats and species has been particularly challenging, largely due to the lack of time-series data across habitat types. This is recognised as an immense challenge in the temperate marine environment due to the extreme fluctuations in the abundance and distribution of marine species between seasons, sometimes day-to-day, depending on the environmental conditions, and across biogeographic regions.

In addition to the standard species-specific approaches to monitoring in the marine environment, we should consider integrating the measurement of community metrics such as biomass and body-size spectra, which capture the

structure and functional health of communities in a relatively simple but comparable manner. These metrics are relatively inexpensive and do not require high levels of taxonomic skills, but tell you immediately if, for example, all the large-sized biota in a habitat have declined and been replaced by smaller bodied opportunists (see Defra-funded RAMBLERS project CDEP 84/5/295). However, the decline of taxonomy as a discipline is a worry in general for biodiversity assessments.

Traditional species concepts and definitions do not apply to bacterial and archaeal communities, which are now characterised by molecular analysis of extracted nucleic acids. Links between community structure and function therefore require consideration and harmonisation of conceptual and methodological approaches to analysis of bacterial and archaeal diversity, and the levels of resolution required for discrimination of ecotypes need to be established.

Linking Biodiversity, Ecosystem Function & Provision of Services

We need to improve our understanding of the relationships between society, biodiversity, and ecosystem functioning. This requires an integrated, holistic approach like the Ecosystem Approach (*sensu* CBD). It implies:

- interdisciplinary research across the natural and social sciences, and
- extension of focus beyond the protected area network to all landscapes where biodiversity supports environmental services.

The socio-economic dimension of the Ecosystem Approach needs to be developed. There is a need to develop and apply methods to value biodiversity's contribution to changes in ecosystem processes and functioning.

Defra is currently working to develop thinking around an ecosystems approach for the natural environment which could help establish this work and lead to more holistic policy making on air, land (including soil), water and biodiversity. This work includes consideration of the value of the natural environment in terms of ecosystem services.

The economic equivalent of ecological monitoring involves Natural Resource Accounts (NRA) for biodiversity. Accounts have been developed for a few biological resources, but not for the diversity of species. Therefore, we need to develop NRAs for biodiversity as a portfolio of natural assets to assure the resilience of ecosystems.

Supporting activities: We need to undertake science outreach to improve understanding of the linkages between biodiversity and ecosystem functioning and the impact of biodiversity loss on the supply of goods and services. A review has been undertaken by Eftec (Economics for the Environment Consultancy) on behalf of Defra. *The Economic, Social and Ecological Value of Ecosystem Services: A Literature Review* highlights the importance of the natural environment ecosystem services (http://www.defra.gov.uk/wildlife-countryside/natres/ecosystem.htm) (Eftec, 2005).

It is important to understand how changes in biodiversity will result in changes in ecosystem function, and recognise that resilience is a service provided by biodiversity. It is therefore important to avoid decoupling ecosystem function from the delivery of goods and services. We need to understand how services can be delivered without degradation of natural capital, and how biodiversity plays a role in delivering this, i.e. sustainable management. In some cases the need to conserve biodiversity as a good (cultural and aesthetic) might be a reason for its maintenance or restoration.

There is also a need to consider what goods and services people are interested in, and determine what ecosystem functions deliver them. However, we need to recognise that the need for goods and services is determined by the social and economic environment in which people live. Given the complexity of the goods and services provided by the environment and the diverse land use patterns across the UK, how can we provide information on the impact of changes to biodiversity and/or ecosystem function to policy makers at scales which reflect their areas of interest?

Evaluating Changes in Ecosystem Function in Response to Environmental Change

The impact of climate change and changing land use on biodiversity loss is likely to be especially important, in respect of conclusions from EPBRS Aviemore conference (EPBRS, 2005b). Earlier UK BRAG work on invasive species highlighted the issues of invasive species and the links between ecosystem function and ecosystem goods and services (Ferris and Bainbridge, 2005). Research undertaken collaboratively between social and natural scientists should explore the links between biodiversity changes, ecosystem processes and the production of valuable goods and services (Perrings and Ferris, 2004). Therefore, research should identify decision-rules for problems involving uncertain, irreversible costs (implementation of the precautionary principle) (Perrings and Ferris, 2004).

Some of these research needs and knowledge gaps have been identified by Haugan *et al*. (2006), in a report produced by an intercessional working group commissioned by OSPAR (OSlo PARis Commission).

Development of Adaptive Management Strategies

Previous and current studies examining management strategies should be noted. The UKPopNet catchment project (Project 2b: Large-scale upland manipulation experiment – feasibility study http://www.ukpopnet.org/) aims to move towards testing the effectiveness of experimental management regimes; while the Canadian National Parks Service has assessed each Park in terms of the effects of climate change and what management responses would be needed (Scott & Lemieux, 2003; Scott & Suffling, 2000).

One of the most critical aspects for research is the development of appropriate models. Whereas there may be no single best method for

managing an ecosystem under environmental change, optimal or near optimal methods can be explored by the use of scenario modelling. Thus, one of the urgent research requirements is to build suites of models which can then be used to explore outcomes under various climate scenarios and policy responses. An example of a model developed recently to explore the flow of carbon through a soil decomposer ecosystem is described by Fitter *et al*. (2005) and its reliance on a huge amount of data is described by Irvine *et al*. (2006).

Issues of Scale

Given the inevitable mismatch between science and policy, there is a clear need to understand and accommodate the issues that are associated with the extrapolation of results between different spatial and temporal scales. For example, many ecological processes are either nonlinear or exhibit critical thresholds, where there is an abrupt change in the response variable. Clear conceptual frameworks need to be adopted (e.g. hierarchy theory - Allen and Starr, 1982), and the consequences of integrating measurements across different scales also need to be understood (e.g. eclipsing – Suter, 1993), while always keeping in view the precautionary approach. This last issue is most commonly related to multivariate indices, where changes in one measurement can mask the response of more critical variables. For example, while macroclimatic patterns might determine species distributions at a continental scale, microclimatic variability will be more important at finer spatial scales.

A previous UK BRAG subgroup concerned with Habitat & Ecosystem Management identified the following three research needs in relation to scale issues (Ferris *et al*., 2005).

1. Understanding landscape/ecosystem processes and their impacts on sites, at a range of scales.

2. Many decisions about actions and interventions will be made (and need to be made) at the site/local scale. We can also recognise that some actions and decisions need to be based on a consideration of a portfolio of sites and how they interact. Above this individual habitat, site or multi site approach there are landscape scale influences and processes across a number of habitats. These processes need to be understood and predictive models developed in order to aid decision making. The main factors that need investigation are recruitment, mortality and dispersal (immigration and emigration), and are likely to be linked to the distribution of suitable habitats, to the functional connectivity matrix between sites and the permeability of the intervening countryside.

3. Management interventions need to enhance ecosystem resilience in the face of environmental change, allowing for shifts in species distribution. This requires management which takes account of landscape-scale processes impacting on sites/habitats/ecosystems, such as fragmentation, connectivity, and the dispersal capabilities of associated species. It

should, however, be noted that the flow of individuals is just one of several ecological processes that require quantification and specific management interventions.

IV. The Research landscape

The role of UK BRAG

The Biodiversity Research Advisory Group is the national group charged with identifying and promoting biodiversity research priorities. The overall purpose of the UK BRAG is to provide advice to the community of biodiversity research funding bodies, research users and research institutions about biodiversity research priorities and co-ordination in the UK. This group reports to the UK Biodiversity Standing Committee and is chaired by Peter Costigan, Defra Living Lands and Seas Science Division. JNCC provides the Secretariat for the group.

In order to focus the research requirements, consideration must be given to existing initiatives of relevance to ecosystem function.

Biodiversity Research Themes addressed by BRAG

The research themes identified by UK BRAG are:

4. Conservation of genetic and native species diversity
5. Impacts of introduced species
6. Role of biodiversity in ecosystem function
7. Monitoring of biodiversity and evaluation of actions
8. Management of habitats and ecosystems
9. Developing tools to optimise policies to favour biodiversity

Understanding the change in the physical flow of ecosystem benefits resulting from biodiversity loss involves identifying and quantifying a chain of causality between changes in ecosystem function, ecosystem services and human well-being. Such work requires close collaboration between experts in different disciplines across both natural and social sciences. This research strategy must be developed with reference to the socio-economic research strategy developed by UK BRAG (Perring and Ferris, 2004) to allow full and meaningful analysis. The latter presented 12 priorities for research, of which nine included an understanding of the role of ecosystem functioning:

- Test the role of biodiversity in sustainable development
- Understand the relationship between biodiversity change and the production of goods and services
- Develop the socio-economic dimensions of an ecosystem approach
- Understand people's perceptions of the value of biodiversity
- Improve application of existing decision methods

- Develop decision methods to deal with uncertainty, irreversibility and threshold effects
- Understand the consequences of the movement of species on changes in regional and global trading systems
- Identify the social rate of return on environmental investments
- Develop natural resource accounts for biodiversity as a portfolio of natural assets to ensure the resilience of ecosystems

GECC (GBSC)

The Global Environmental Change Committee is a coordinating committee for the research agenda on global environment issues, chaired by Howard Dalton (Defra Chief Scientist) and reporting to Sir David King (Office of Science and Technology, Chief Scientist). Its biodiversity subcommittee (the GBSC) focuses on the UK research agenda to support input to the various biodiversity-related conventions and initiatives such as the Millennium Ecosystem Assessment (2005). The remit of the GBSC is to inform UK science strategy relating to biodiversity and sustainable use at the global level, including the implications for human society. The focus of the sub-committee is on the science underlying the key global issues and implications for research strategy. The GBSC is chaired by Miles Parker, Defra Science Directorate and JNCC provide the Secretariat. For more information see http://www.ukgecc.org/dvl_Biodiversity.htm

Convention on Biological Diversity (CBD) and the Ecosystem Approach

The CBD defines the ecosystem approach as "…..a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. Application of the Ecosystem Approach will help to reach a balance of the three objectives of the Convention. It is based on the application of appropriate scientific methodologies focused on levels of biological organisation which encompass the essential processes, functions and interactions among organisms and their environment. It recognises that humans, with their cultural diversity, are an integral component of ecosystems." (CBD, 2001). Thus, in the ecosystem approach the relationships between humans, biodiversity and the products derived from services supplied by ecosystems are articulated at the ecosystem scale.

As a party to the CBD, the UK is committed to the implementation of the Ecosystem Approach. All Parties are asked to:

- apply the ecosystem approach, taking into account the principles and guidance contained in the annex to Decision V/6
- develop practical expressions of the ecosystem approach for national policies and legislation and to implementation activities, with adaptation to local, national, and regional conditions

- strengthen capacities for the application of the ecosystem approach, and provide technical and financial support for capacity-building
- promote regional co-operation in applying the ecosystem approach across national borders
- facilitate the exchange of experiences, capacity building, technology transfer and awareness raising to assist with the implementation of the ecosystem approach
- create an enabling environment for the implementation of the ecosystem approach, including development of appropriate institutional frameworks

The UK has taken steps to apply the Ecosystem Approach, for example providing support to the CBD Secretariat to develop the Ecosystem Approach sourcebook (www.biodiv.org/programmes/cross-cutting/ecosystem/sourcebook/home.shtml) and developing such a resource for the UK based on information in the existing UK Clearing House Mechanism (http://www.chm.org.uk).

The UK has contributed to promotion of regional co-operation through its active support for the Pan European Biological and Landscape Diversity Strategy (PEBLDS) process (http:/www.strategyguide.org).

The report on the *'Ecosystem Approach: coherent actions for marine and coastal environments'* (Laffoley *et al*., 2004), was a major UK contribution towards the development of a European Marine Strategy. The ideas on improving coherence were widely accepted by the Commission, Member States, Accession countries and other stakeholder groups. The report contributed towards the development of the Commission's green paper on maritime issues (European Commission, 2006).

With UNESCO, the UK has helped fund regional workshops in Africa, Asia and Latin America on the application of the Ecosystem Approach. Further workshops with developing countries are under discussion for 2006.

EPBRS

The European Platform for Biodiversity Research Strategy (EPBRS) produces recommendations for research on biodiversity at its biannual meetings and developed an "Action Plan for Biodiversity Research" (EPBRS, 2005a). The plan identifies the knowledge needed to halt the loss of biodiversity in Europe and elsewhere, and to improve understanding of the drivers and ecological, economic and social consequences of biodiversity change. It offers targets for changes in the funding and organisation of biodiversity research in Europe to enable science to help halt the loss of biodiversity. Its recommendations include:

- understand the interaction between biological diversity and ecosystem function and resilience, and assess trends in key functional groups, for example pollinators
- improve knowledge of goods and services provided by ecosystems
- quantify the contribution of biodiversity to livelihoods and further understand how changes in biodiversity and ecosystem functions influence livelihoods
- assess and predict changes in ecosystem functioning due to unsustainable use including marine biodiversity not directly targeted by fishing
- improve understanding of how the use of natural resources affects biodiversity, ecosystem goods and services and the resilience of ecological-economic systems
- develop indicators of sustainable management of renewable resources, ecosystem integrity and ecosystem goods and services, vulnerability of livelihoods, and funding to biodiversity
- improve and assess strategies for promoting sustainable livelihoods, lifestyles and poverty alleviation in the context of biodiversity conservation

The 2005 EPBRS meeting at Aviemore, UK considered biodiversity and climate change adaptation. The recommendations for research priorities to quantify climate change impacts on species, habitats and ecosystems are:

- improve our understanding of the effects of climate change on biodiversity as it acts through changes in the physical and chemical environments. This requires monitoring of abiotic factors and interactions with other drivers, at a range of spatial and temporal scales. Key features in terrestrial environments include CO_2, land use and nitrogen; and in marine environments, temperature, salinity, stratification, pH, currents, upwelling, stability and wave regime events.
- quantify and forecast the responses of genotypes, species, habitats, ecosystems, landscapes and seascapes at all relevant spatial and temporal scales. This requires: (1) enhanced understanding of the underlying mechanisms driving, and being driven by, these processes, (2) greater knowledge of the interactions among climate change and ecosystem components, structure, function and services; (3) improved quantitative comparison of observational, experimental and modelling approaches; (4) extended open access to data.
- improve understanding of the capacity of species and ecosystems to adapt to climate change. This should include assessment of the sensitivity and vulnerability of species and habitats, and consequences for ecosystem functions.
- increase research efforts to develop methods to restore, maintain or improve the ecological functioning of protected areas, landscapes and

seascapes for biodiversity conservation, and increase the coherence of Natura 2000 and other protected area networks. Develop strategies to increase ecosystem resistance and resilience

Recommendations from the same meeting on research on socio-economic aspects of adaptation strategies are:

- further develop methodologies for evaluating adaptation and conservation policies. Refine methods for taking into account the socio-economic aspects of ecosystem goods and services, including consideration of the ethical, epistemological and methodological issues inherent in valuation of the natural world, and the ways in which valuations differ across stakeholder groups, cultures, space and time.
- improve understanding of the ways in which human factors influence the effectiveness of adaptation policies. Research is needed to understand how governance structures and human perceptions, values and attitudes impact on policy effectiveness; and to support development of improved systems of governance, including for seas and coasts, taking into account ecosystem goods and services.

EU Research Framework Programme

BiodivERsA (www.eurobiodiversa.org) is an ERA–Net project which aims to develop partnerships and cooperation in biodiversity research funding and practice across Europe.

MarBEF (www.marbef.org) is an EU funded Network of Excellence comprising researchers from across the natural and social sciences that focuses on marine biodiversity and ecosystem functioning. A major part of the MarBEF programme is concerned with the relationship between marine biodiversity and the ecosystem processes that underpin the delivery of marine goods and services. This is linked directly with innovative research that aims to 'value' the ecosystem goods and services provided through biodiversity.

DIVERSITAS

DIVERSITAS (http://www.diversitas-international.org) is a major international, inter-disciplinary science programme, one of four sister initiatives within the Earth System Science Partnership. Two of the three core projects, ecoSERVICES and bioSUSTAINABILITY, address the relationships between biodiversity, ecosystem functioning and ecosystem services, the social drivers of biodiversity change and the science needed for the sustainable use and conservation of biodiversity. (The third project, bioDISCOVERY, is concerned with the discovery and monitoring of biodiversity). The DIVERSITAS science plan therefore has strong resonance with the subject material within the present document.

UKPopNet

UKPopNet (www.ukpopnet.org) is a network of institutions founded by the universities of Aberdeen, East Anglia, Leeds, Sheffield and York, and NERC's Centre for Ecology & Hydrology. Funded by NERC and English Nature, UKPopNet's research programme aims to integrate population, community and ecosystem biology and researchers, practitioners and policy-makers. Most relevant to the present document are two activities that will be funded as part of a recently awarded contract extension.

The sustainable landscape theme. Three contrasting projects within this theme will compare the impact of management under a 'business as usual scenario' with one that aims to optimise the management of the uplands for ecosystems services such as potable water, biodiversity and carbon storage experimental manipulation at the landscape (catchment) scale.

Linking biodiversity and ecosystem services: processes, priorities and prospects. This project aims to:

identify linkages between biodiversity patterns and ecosystem services at a large (geographic) scale
assess the role of current conservation provision in delivering ecosystem services as well as biodiversity goals
assess how linkages between biodiversity patterns and services provided by natural systems might change over the next 25-50 years

Defra Science and "A Draft Vision for the Natural Environment"

The UK Government Sustainable Development Strategy (Anon., 2005) sets out a commitment to develop an integrated policy framework for the natural environment.

A more joined-up approach to policy-making and delivery is needed, with an increasing focus on the maintenance of healthy and resilient ecosystems. This means taking an ecosystem-based approach to conserving, managing and enhancing the natural environment; which balances environmental, economic and social considerations to achieve sustainable development.

Through the CBD (CBD, 2001), the UK is also committed to implementing the Ecosystem Approach, where practical, in assistance to other countries, and to facilitate implementation across national borders.

Several recent or current Defra funded projects address knowledge gaps at the ecosystem scale. Full details can be found at: http://www.defra.gov.uk/science/default.htm. Some examples are listed below:

- Integrated Science for Integrated Management - Developing the Capacity for Adaptive Ecosystem Management (AE1148)
- Evaluating ecosystem models as tools for policy development on biodiversity (IF0103)

- The Implication for the Marine Environment of CO_2 Releases (ME2107)
- Assessment of Marine Biodiversity Linked to Ecosystems (AMBLE) (ME3109).
- The future of healthy ecosystems (SD0306).
- Do Farm Management Practices Alter Soil Biodiversity And Ecosystem Function? Implications For Sustainable Land Management - Non R&D (SP08012).
- Rapid Assessment of Marine Biodiversity in Relation to Environmental Degradation and Remediation (RAMBLERS) (AE1137) CDEP 84/5/29

Horizon Scanning activities

Horizon scanning is defined as the systematic examination of potential threats, opportunities and likely future developments which are at the margins of current thinking and planning (Defra, 2002).

Horizon scanning as part of research planning is becoming increasingly important to many different organisations, and concerns related to biodiversity, ecosystem function, goods and services are often raised. The research strategy for the UK BRAG Ecosystem Function subgroup should include consideration of proposals for research that emerge from horizon scanning activities. Horizon scanning for research requirements is undertaken by both Defra (www.defra.gov.uk/science/how/horizon.htm) and SEERAD (http://www.scotland.gov.uk/Topics/Research/15597/Horizon), and is likely to form part of the Planning Research currently being developed by Environment and Heritage Service in Northern Ireland (www.ehsni.gov.uk/natural/research/listview.asp?RID=461). It is also undertaken by research councils such as NERC.

A recently completed project under Defra's Horizon Scanning initiative was a scoping study (Raffaelli *et al*., 2006) that aimed to identify the primary indicators of ecosystem health and to assess their value as measures of both ecological and socio-economic sustainability. It included:

- assessment of the concepts of "health" in the ecosystem context and their relation to the resilience of ecosystems;
- review of the modelling approaches available for predicting changes in key indicators;
- preliminary exploration of potential approaches for UK ecosystems; and
- identification of the ecological goods and services associated with each indicator and evaluation of their socio-economic importance to, *inter alia*, agriculture, forestry, fisheries, water supply; recreation and conservation.

The work is highly relevant to UK policy in terms of:

- identification of potential future sources of environmental stress;
- understanding current and future provision of critical ecosystem services and the limits within which those services may be sustained; and
- evaluating the socio-economic consequences of changes in ecosystem health.

In the context of global climate change and shorter-term change in the UK rural landscape, understanding the functioning of ecosystems, and how their health and performance can be measured and monitored over time, is of critical importance.

The NERC Soil Biodiversity Programme

The NERC 'Soil Biodiversity Programme' was an integrated programme of research on the biological diversity of soil biota and the functional roles played by soil organisms in key ecological processes. The programme ran from 1997 - 2004. The NERC invested £5.85m in the programme, which supported 30 research projects and contracts, involving around 120 scientists in universities and NERC centres and surveys. Details and a list of publications resulting from this research can be found at: http://soilbio.nerc.ac.uk/. As a result, soil ecosystems in the UK are well studied and represented within the scientific literature.

NOTE: Other innovative government funded research projects have been undertaken, which have revealed the importance and complexities of studies of ecosystem function, particularly in marine ecosystems and an upland soil (Usher & Davidson, 2006) or defining environmental limits for sustainable development (Eftec, 2006).

Defra has announced a call for funding (CTE0606), which includes several of the areas flagged here, including the valuation of the services provided by terrestrial ecosystems, the application of the ecosystem approach to terrestrial ecosystems in the context of ecosystem health, and the application of GIS-based approaches for exploring such questions.