

Biodiversity and Ecosystem Service Sustainability (BESS)

Science Plan 2011-2017

1. Introduction

The Biodiversity and Ecosystem Service Sustainability (BESS) programme relates to the delivery of the NERC strategy on Biodiversity. In 2008-9, a large-scale action was initiated and developed within the NERC Biodiversity Theme to address directly the Theme's grand challenge, "*To understand the role of biodiversity in key ecosystem processes*". Workshops held in December 2008 led to the development of the Biodiversity and Ecosystem Service Sustainability (BESS) programme, which is recognised as central to the delivery of two of the Theme challenges in particular:

- *Challenge 1: Improve understanding of biodiversity's role in ecosystems: processes, resilience and environmental change.*
- *Challenge 4: Enable society to predict and mitigate effects of biodiversity change on processes that sustain life.*

The BESS research programme will run initially for six years until 31 January 2017, with funding approved by NERC Council of £13 million. The BESS programme will make a significant contribution to the *Living with Environmental Change* (LWEC) programme and will promote integration between LWEC partners.

The main activities of BESS will focus on UK systems, with international partnerships supporting other sites to provide a global perspective. BESS will deliver high-quality, fundamental science which has strong strategic relevance nationally and internationally. From a natural science base, BESS will deliver a platform to bring different research communities together within the UK, to attract international scientists and to engage with new and emerging ideas and technologies. Although grounded in the natural sciences, the programme's focus on services and sustainability demands a significant interdisciplinary dimension. BESS will therefore bring together researchers from different sub-disciplines within the natural sciences with researchers from the social sciences to create a new interdisciplinary biodiversity science community.

The programme will: define the scientific basis of the linkages between biodiversity, ecosystem functioning and the delivery of ecosystem services; allow prediction of how these linkages will respond to future change scenarios; and develop new tools and indicators that are fit-for-purpose for tracking biodiversity stocks and the flows of services from those stocks, so that they can be managed within sustainable bounds. Through LWEC, BESS will work with partners in the research and stakeholder communities to develop methods and approaches to serve as a robust evidence base for the development of ecosystem service-based biodiversity and environmental policy development.

2. Research Programme Goals

The BESS programme has the following goals:

1. To define how biodiversity within landscapes underpins the delivery of different ecosystem services at a range of scales and across gradients.
2. To establish whether there are critical levels of biodiversity required to deliver different kinds of services under different driver-pressure scenarios, as well as which enhance the resilience of ecosystems to those different drivers.
3. To develop novel tools and indicators appropriate for tracking and measuring biodiversity and ecosystem services under those different scenarios.

These goals have been developed by various Biodiversity Theme leaders since 2007, with input from two substantive workshops in December 2008 attended by a full cross-section of the biodiversity research and policy community. Whilst clearly central to the Biodiversity Theme, BESS also has significant linkages with the Sustainable Use of Natural Resources (SUNR) theme, the broader LWEC ambitions, and with NERC contemporary actions that resonate with BESS, particularly Ecosystem Services and Poverty Alleviation (ESPA), Macronutrient Cycles, The Virtual Observatory, Insect Pollinator Initiative and the Valuing Nature Network, as well as dimensions of BBSRC's Global Food Security programme. BESS is contemporary with the National Ecosystem Assessment and is expected to complement the second phase of that initiative. The international linkages with BESS are highlighted in section 4.4 and throughout the text.

The programme will fund the science necessary to define the functional forms of the linkages between biodiversity and the provision of ecosystem services, allow predictions of how these linkages are likely to change in the future, and provide tools that can be used to measure ecosystem service provision and monitor trends in ecosystem services over time. In fulfilling these scientific goals, the programme will foster the development of a UK biodiversity research community with the capacity to deliver internationally excellent and strategic science. This will underpin the development of ecosystem-services based approaches to environmental management which are essential if we are to build truly sustainable societies within healthy environments in an uncertain world.

3. Strategic Context

Ecosystems and their biodiversity deliver products such as food, fibre and fuel, as well as a range of essential services such as climate regulation, water and soil regulation and cultural and recreational services, all important for human well-being nationally, internationally and globally. The Millennium Ecosystem Assessment (MEA, 2005) revealed that globally, and for many individual sub-regions, the majority of the world's ecosystems have become severely degraded. The ability of ecosystems to deliver goods and services sustainably in order to meet the needs and aspirations of a rapidly-growing human population, including the Millennium Development Goals, was at best in question, and at worst, compromised. A related initiative evaluating how near society is to critical thresholds for a range of environmental challenges (climate change, nutrient pollution, atmospheric pollution and biodiversity loss), argues that of all these, biodiversity loss is already far beyond a safe operating zone (Rockstrom et al., 2009). Furthermore, because of the interactions of biodiversity with other Earth system functions, biodiversity loss is likely to increase the vulnerability of ecosystems to changes in other processes, such as climate change. In addition, the retention of functional biodiversity may “prevent ecosystems from tipping into undesired states when they are disturbed” (Rockstrom et al., 2009) because of the insurance value provided by species redundancy within functional groups. The strategic importance of biodiversity for the resilience of UK ecosystems and their ability to continue to deliver desired sets of services has been cogently articulated in the UK National Ecosystem Assessment Report (NEA 2010)¹ and in the Lawton Report (2010), as well as by the European Biodiversity Platform Research Strategy (EBRP 2011), based on similar data and arguments.

The fundamental role that biodiversity plays in regulating the ecological processes (e.g. primary production, nutrient recycling) that underpin ecosystem services is acknowledged, but a quantitative understanding of biodiversity-ecosystem functioning-ecosystem service relationships is poor (NEA 2010). The ongoing conversion of natural ecosystems to human-

¹ <http://uknea.unep-wcmc.org/>

dominated systems for the production of food, fibre and energy has generated undeniable social benefits, but at a significant cost to other environmental values, including the biodiversity that underpins those products. Indeed, it is the lack of understanding and quantification of the wider role that biodiversity plays in delivering social benefits that results in the failure to adequately include its value in decision-making². There is concern that present landscape management approaches that progressively reduce biodiversity may not only ultimately reduce these benefits but in some cases lead to non-reversible ecosystem states that are socially undesirable. In addition, the potential implications of future environmental, social and policy change for ecosystem processes and landscape management are uncertain. Understanding these issues is fundamental to meeting many of humanity's greatest current challenges – food security, renewable energy, environmental protection, climate change and poverty alleviation. This is an area of high strategic importance for NERC science.

These issues are not unique to the UK, but they are brought into sharp focus here because of the highly-managed production systems that comprise most of our landscapes and which are likely to be intensified over larger extents in the future. Other, non-production, ecosystems have been equally impacted and are also likely to change markedly over the next 50 years. For most ecosystems, we have a poor or little understanding of both trends and changes in the services they deliver, or trends in their underpinning biodiversity, or both (MEA 2005, EBRP 2011, NEA 2010, Smart et al 2010). Providing the evidence base for managing this complex and changing mixture of landscapes will be a major challenge for the biodiversity research community over the next 5-15 years.

The UK's biodiversity research community is well-placed to meet this challenge, both nationally and internationally, as evidenced by the substantial community behind the National Ecosystem Assessment. We provide international leadership in the environmental, ecological, social and economic areas where greatest understanding is needed, but until now that community has often lacked the frameworks and structures within which these separate disciplines can be harnessed effectively. BESS provides a visionary framework and a research platform to bring together that community to address the research challenges highlighted above.

4 Scientific Background

4.1 The Need for a Landscape Approach

Much of the initial work on the linkages between biodiversity, ecosystem processes and ecosystem services has focused on the functional forms of the relationships between the

² This issue is being addressed through NERC's Valuing Nature Network (<http://www.valuing-nature.net>).

species richness of a taxonomic group and ecological process rates, through small-scale manipulative laboratory and field experiments incorporating rather few species, typically less than ten. Further, in order to allow unambiguous evaluation of the effect of the number of species (richness) on process rates, researchers have vigorously controlled for all other factors, including trophic complexity and natural environmental variation. Where these factors have been included, the outcomes and inferences have often been quite different. Nevertheless, meta-analyses of this literature indicate an overall positive effect of biodiversity on many ecosystem processes, with a saturation curve seeming the most parsimonious functional form at this small-scale level (Balvanera et al 2006, Cardinale et al 2006, Schmid et al 2009). Notwithstanding the high-quality science behind these studies, it is far from clear how to extend this body of work to the provision of ecosystem services at the landscape scale, where biodiversity is much richer and incorporates complex trophic feedbacks and where the physical environment runs free. In addition, at the landscape scale ecosystem services are underpinned by many processes and hence different sets of biodiversity, so that simple extrapolations are unlikely to be reliable.

The difficulties of scaling up of processes from small-scale experimental work for application at the landscape scale have been reviewed extensively (e.g. Raffaelli and Moller 2000), and scaling often turns out to be decidedly non-linear. For ecosystem services, this issue is non-trivial, because their provision is likely to scale differently with the spatial extent and arrangement of biodiversity elements and with the trade-offs made between services. For instance, a 1000 km² block of woodland may well capture a similar amount of carbon per unit area as 100 spatially-separated 10 km² blocks, but the recreational or erosion prevention service provided by forest blocks of those two sizes will scale very differently, with a minimum block size below which recreation or erosion prevention declines markedly. Spatial scaling and the spatial pattern of biodiversity elements is especially relevant for landscapes within the UK and Europe where biodiversity is already highly fragmented and likely to become even more so under future pressure scenarios (Lawton et al., 2010). A major aim of BESS is to characterise the functional forms for the different services derived from multi-functional landscapes.

At the landscape scale, the relationships between biodiversity, functions and services will be moderated by the physical and abiotic environment. The rates of many functions are profoundly influenced by abiotic variables (e.g. temperature, water and nutrients for primary production) and where these have been included in biodiversity-ecosystem functioning experiments, they can greatly affect the form of the relationship, often through changes in the behaviour of the biodiversity components. For instance, under different near-bed current speeds, coastal -dwelling marine invertebrates switch from deposit-feeding to filter-feeding. The effects of the physical environment are likely to become more apparent in landscape-scale research than in smaller-scale studies.

4.2 Biodiversity, Natural Capital Stocks and Ecosystem Flows

Biodiversity is more than species richness, spanning genetics, species, habitats and ecosystems, as well as the linkages between these elements (Convention on Biological Diversity). All these elements and the interactions between them generate ecosystem services. To properly understand biodiversity-ecosystem processes-ecosystem services relationships, biodiversity should be viewed broadly, similar to the concept of natural capital and as articulated in the 2010 Biodiversity Theme Action Plan. In this respect, services are viewed in BESS as the flows that can be extracted from natural (biodiversity) stocks.

The ecosystem services that can be sustainably extracted by society will depend largely on the size and condition of natural capital stocks (biodiversity), and both of these dimensions will change under a range of land and resource use change scenarios. The NEA (2010) paints a bleak but accurate picture of the condition and size of those stocks at present, which face a series of challenges in the next 50 years, including further intensification of production landscapes, climate change, demographic change, changes in societal attitudes, wealth and consumption patterns, and in the policy and regulatory environment (Foresight Land Use Futures Project 2010). An aim of BESS will be to determine critical amounts of biodiversity necessary for the sustainable delivery of those goods and services desired by society in the face of such drivers of change.

4.3 Tools and Indicators for Stocks and Flows

The responses of ecological stocks and flows to landscape management interventions need to be measured using appropriate tools and indicators in order to ensure sustainable outcomes and to revise policy accordingly. The need for better tools has recently been reinforced by The European Platform for Biodiversity Research Strategy (2011) call to *“Develop standardized methods and criteria for the measurements, mapping and monitoring of biodiversity and ecosystem services at various temporal and spatial scales to better assess the sustainability of ecosystem services.”* It will be necessary to develop novel tools and indicators appropriate for tracking the status and trends in both the stocks and flows. Whilst potential indicators exist for many aspects of biodiversity, such as the area and condition of BAP habitats (Linstead et al. 2008), few of these were developed with ecosystem service provision in mind (NEA 2010). A key task of BESS will be to deliver new tools fit-for-purpose both scientifically and in relation to formulation and evaluation of policy. This will require an increased dialogue between natural and socio-economic disciplines, as promoted by the Valuing Nature Network³.

4.4 Geographical Focus

³ <http://www.valuing-nature.net>

The BESS programme will focus on landscapes within the UK. BESS will not fund programmes of work which are to be carried out entirely, or in the majority, overseas (including UK Overseas Territories). However, this does not preclude inclusion of appropriate elements of comparative work in Europe and elsewhere, for instance in applications based on space-for-time substitutions. Indeed, it will be important for BESS to link with similar work internationally. In this respect, BESS will link with the landscape-scale research being pursued within the European Long Term Ecological Research programme⁴ and its US equivalent⁵, as well as developing linkages with global programmes and initiatives such as Diversitas⁶ and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services⁷.

4.5 A Landscape Focus

BESS will focus intense programmes of activity on three or four contrasting landscape types:

- which deliver important multiple functions and services;
- which are currently subject to rapid change;
- where future drivers will have the greatest likely impact;
- where there is the most pressing need to close the knowledge gaps about biodiversity-ecosystem service linkages.

The landscapes for which BESS is seeking applications are:

- **Lowland agricultural multifunctional landscapes**⁸
- **Freshwater, brackish and near-coast marine wetland landscapes**⁹
- **Upland landscapes**¹⁰
- **Urban landscapes**

All of these landscape types meet the stated criteria, but work on Upland and Urban landscapes will also need to consider additional factors.

Upland landscapes have been the focus of much work on ecosystem services in recent years in relation to environmental change and trade-offs, but most of this has not been expressly

⁴ <http://www.lter-europe.net>

⁵ <http://www.lternet.edu>

⁶ <http://www.diversitas-international.org>

⁷ <http://www.ipbes.net>

⁸ which could include woodland areas

⁹ including salt marsh, estuarine and tidal flat areas

¹⁰ Including areas in the extreme north of the UK which are relatively low elevation but which have systems characteristics of higher elevation upland areas, such as the flow country.

set in the biodiversity-function-service linkages framework of BESS. If that existing body of work can be built upon, then it will provide great added value and any BESS research in Upland landscapes will have to demonstrate that added value.

Urban landscapes are an exciting and emerging area within ecosystem services research, not least because these landscapes are where the majority of beneficiaries of most ecosystem services are located, although many of the services are produced elsewhere. The ecosystem services approach has often been applied to urban areas in the context of green infrastructure, which planners may see as a more appropriate framework. BESS research on Urban landscapes will need to be shown to be framed within the same framework and scientific structures as for other more natural landscapes and consistent with NERC funding. BESS sees potential for explorations of Urban ecosystem services within an urban or peri-urban setting or an urban-rural gradient.

BESS does not prescribe specific geographical locations for landscape types. Specific locations must be chosen according to where the best fundamental science can be achieved, and focal landscapes need not be restricted to a single location if a related network of sites is judged appropriate and can be justified. However, there is clear added value for alignment with geographical locations associated with other large-scale initiatives, such as the Defra Demonstration Catchments and Natural England's Pilot Areas, the Virtual Observatory, Macronutrient Cycles, and the Pollinator Initiative. Landscapes should also consider opportunities to establish international partnerships with similar programmes to provide a global perspective and to draw on international scientists, techniques and facilities, and to make best use of existing national capability where appropriate. In this sense, it is important that the pros and cons of using new versus existing sites are fully articulated and justified.

Offshore marine landscapes are not included within the scope of the BESS programme, and will be dealt with under a future Biodiversity Theme action. However, there is considerable expertise in the marine research community that is relevant to some of the core goals of the BESS programme, especially in the area of whole-systems modelling, and the involvement of relevant expertise from the marine community in proposals to BESS would be welcomed.

5. Research Themes

The three over-arching goals of the BESS programme will be addressed via three linked science themes:

1. Functional relationships between biodiversity and ecosystem services
2. Resilience of biodiversity-ecosystem service relationships to changing conditions

3. Monitoring and evaluation of ecosystem services

The relationships between these themes, the programme goals and other NERC activities are shown in Table 1.

The science themes are strongly linked. They will be delivered through interdisciplinary, cross-theme consortium projects, cross-theme Working Groups and through science coordination and programme management activities such as targeted knowledge exchange and outreach activities (see section 9.2)

Detailed descriptions of the themes are provided below. In the first tranche of funding, projects must address all the three themes and include at least two contrasting types of ecosystem service (from provisioning, regulating and cultural categories¹¹). It is recognised that it may not be possible to address all of the activities completely through BESS funding alone and some gaps will be filled through collaborations and links with other funded initiatives, as well as in collaboration with international programmes with similar aims.

5.1 Theme 1: Functional relationships between biodiversity, functioning and ecosystem services

This theme will quantify the linkages between biodiversity, ecosystem function and ecosystem services for multiple services delivered by the focal landscape types. There is much evidence that biodiversity underpins ecosystem functioning (Cardinale et al 2006, Schmidt et al 2009 and Balvanera et al 2006), particularly for primary producers and heterotrophs, and for some services that are directly linked to these, such as timber production and nutrient cycling. Recently, the NEA (2010) has attempted to map the importance of these and other biodiversity groups onto ecosystem services, but, due to the paucity of scientific data and information available, this could only be achieved on the basis of expert opinion on a scale of low, medium or high importance. That analysis suggests that: all services are dependent on biodiversity to some extent; 11 of the 17 biodiversity groups underpin the production of crops, livestock and fish; micro-organisms, fungi and plants play key roles in underpinning provisioning and regulatory services; and higher plants and animals play key roles in cultural services.

However, we do not know the form of the quantitative relationships between biodiversity, functions and services at the landscape scale where trophic complexity and biological diversity are both spatially and temporally heterogeneous and fluctuations in abiotic factors

¹¹ "Supporting services" are regarded here as functions.

will be important. For instance, whilst much is known about trends in the flows of products such as food, fuel and timber), our understanding of the stocks of microbial and associated soil biodiversity that underpin the delivery of these products remains poor (NEA 2010). In contrast, we know much about the behaviour and dynamics of the stock of iconic biodiversity, such as wild flowers, trees, birds, butterflies and bees, that provides aesthetic and cultural services in landscapes, but we only have a hazy understanding of the formal linkages between these services and the benefits they provide (NEA 2010).

5.1.1 Theme 1a Relationships between biodiversity, functioning and services for key landscapes

Research in this area will need to take a services-orientated perspective, documenting the dominant and characteristic services produced by a focal landscape, the functions which support those services and the biodiversity or sets of biodiversities that underpin those functions, but this will be challenging. Services are often underpinned by several ecosystem functions, but there are obvious key functions for a service which can be distinguished from more general functions. For example, the service of fruit production is underpinned by the key functions of primary production and pollination, whilst other functions (soil formation, nutrient cycling and decomposition) are subsumed within these higher-order functions.

Consortium research projects on each focal landscape type will need to include at least two contrasting types of ecosystem service, from the provisioning, regulating and cultural categories¹². It is recognised that the specific services in each of these categories will have different importance in different landscapes and there will be variation within landscapes in different parts of the UK.

5.1.1.1 Technical approaches to Theme 1a

There are various ways in which these landscape scale issues can be approached, including: large-scale experimental-manipulations; empirical/observational approaches based on critical analyses of extensive time series; space-for-time substitutions within focal landscapes; all of these with associated experiments of smaller-scale processes. Different questions and landscapes may lend themselves to different approaches or to combinations of approaches. Empirical/observational analyses can be as persuasive as well as scientifically rigorous as experimental manipulations (MacLean 2008). The approaches described here are not prescriptive although they are strongly encouraged.

Making use of sympathetic estate. For intensive research campaigns at the landscape scale, there must be an agreement with existing land holders. Establishing working relationships

¹² Supporting services are regarded here as functions.

with land-owners requires time and considerable patience, even when those land-owners are enthusiastic about the research proposed. The timescale for the BESS programme is such that establishing such relationships *de novo* may be difficult. Landscapes where owners are known to be sympathetic to BESS research include estates managed by private individuals or business, by the Forestry Commission, by conservation NGOs such as the Royal Society for the Protection of Birds and the National Trust, by Wildlife Trusts, as well as the larger protected areas administered by Natural England, the Countryside Commission for Wales and Scottish Natural Heritage. Also, Natural England has recently launched its Ecosystem Service Pilot areas and Defra has its Demonstration Catchments. In addition, the Centre for Ecology and Hydrology (national capability) has on-going research in locations (Environmental Change Network) that contribute to the wider European Long-Term Ecosystem Research Network. Some of those landscapes already have large-scale management interventions in place, or planned, as well as extensive data series. Where these locations are relevant to delivering BESS science, they could be extended as platforms to address BESS questions.

Substituting spatial for temporal gradients. Landscape-scale dynamics are usually associated with longer temporal scales, and this is especially true for identification of the slow variables that characterise threshold changes in ecosystem behaviour, as well as for understanding the new dynamics that result from the re-arranging of ecological interactions as species ranges shift differentially under climate change (Montoya and Raffaelli 2010). These dynamics could be approached by using spatial gradients in place of temporal gradients within a landscape type.

5.1.2 Theme 1b Characterising functional forms, critical levels and thresholds

A major challenge for BESS will be to quantify the functional forms of the relationships between biodiversity, functions and services in order to detect critical levels of biodiversity stocks, possibly thresholds which are not easily reversed. Meta-analyses of the literature on biodiversity, functioning and services strongly suggest a saturation curve with an inflection point at relatively low diversities. However, much of this literature is based on highly controlled, small-scale experiments concerned with single functions and a limited set of biodiversity (often a single trophic level). The functional forms of the relationships at landscape scales with their greater biodiversity complexity and increased spatial heterogeneity are largely unknown and extrapolation from smaller-scale studies would be unwise. Furthermore, the inflection point at which further biodiversity loss severely compromises ecosystem functioning and service delivery is likely to be different for different functions and services (see section 4.1), a vital consideration when managing for trade-offs between multiple ecosystem services within a landscape.

The issue of thresholds is particularly pressing. The possibility of tipping points or thresholds of biodiversity stocks is at least plausible for a number of ecosystems and in some cases has

been demonstrated unequivocally (Walker and Sait, 2008, Leadley et al., 2009, Haygarth and Ritz 2009, Scheffer 2009). Detecting thresholds is extremely difficult since the underlying variables responsible for bringing systems to a tipping point are characteristically slow and insidious, so that it has often only been possible to identify them retrospectively after the threshold has been passed. Recent work (Groffman et al., 2006, Scheffer 2009) points to potential novel approaches associated with increasing variability in key ecosystem parameters as thresholds are approached, and these and other approaches need developing.

5.2 Theme 2: Resilience of biodiversity-ecosystem service relationships to changing conditions

Biodiversity-functioning-service relationships have been greatly challenged by human activities as biodiversity has been progressively lost and, at least in the UK, fragmented and squeezed into a managed landscape. Foresight Land Use Futures (2010) identifies six major drivers of changes in land-use over the next 40 years which will impact on biodiversity, ecosystem functioning and services:

Demographic change. Population increases combined with a disproportionately increasing demand for housing and infrastructure as more people choose to live alone.

Economic growth and changing economic conditions. Notwithstanding the current economic downturn, continued economic growth implies an increase in consumption and consequent demands on our land, exacerbated by the rising global demand for food.

Climate change. There are already direct effects of climate change on species and habitats, and moves towards a low carbon economy and other adaptations to climate change will have an impact on land management.

New technologies. Farmers have been able to increase yields of food substantially over the last 50 years, often with accompanying loss of biodiversity, although future, new technologies could allow more environmentally-sensitive production gains.

Societal preferences and attitudes. Societal preferences for what the land is for and how it should be managed to deliver multiple ecosystem benefits will continue to change.

The policy and regulatory environment. The impact of UK and European policy on land-use has been profound, and future regional, national and European policy is likely to have further major impacts on land use.

The precise outcome for biodiversity and ecosystem services of the interactions between these drivers is highly uncertain, but will involve considerable challenges for the sustainable management of landscapes.

The research within this theme is concerned with predicting the relationships between biodiversity, functioning and the delivery of services under likely future pressures, including those reviewed by the Foresight Land Use Futures (2010), but not exclusively. It is

recognised that specific landscape types may respond differently to those pressures and that there may be additional pressures which are landscape-specific and which may not figure in the Foresight analysis. Key related topics within this focus include: how the linkages determined in Theme 1 will change under future combined multiple stressors; the resilience of biodiversity stocks to the changes in ecosystem service flow demands; and the potential for managing or engineering resilience to keep service delivery options open for the future.

The research and approaches required for Theme 2 will build on the outcomes from Theme 1 on the fundamental relationships between biodiversity, functioning and services. Exploring the effects of future changes in stocks of biodiversity and changes in the flows of services demanded by society will require a combination of predictive modelling based on the parameters and relationships defined by Theme 1, direct landscape experimentation where this can be achieved, and space-for-time analyses supported by experiments on smaller-scale processes, for instance using microcosm, mesocosm and ecotron-type approaches.

This theme will demand interdisciplinary working across the natural and social science boundaries, especially in the design of models, analyses and experiments that can properly capture the stressors themselves as well as likely socio-economic consequences, responses and feedbacks (Table 1). Close working across the disciplines can be challenging and effective mechanisms need to be put in place to ensure its success (see Implementation Plan). In this respect, close working and collaboration with participants within NERC's interdisciplinary programmes Valuing Nature Network and ESPA are encouraged.

5.3 Theme 3: Monitoring and evaluation of ecosystem services

There is an urgent need to develop effective tools and approaches for tracking the performance and behaviour of biodiversity stocks and ecosystem flows across space and over time to assess the sustainability of ecosystems and to allow for adaptive management (EBRP 2011). Indicators may be ecological, environmental, economic or social, or combinations of all of these, so this activity will require interdisciplinary input across the natural and social sciences (Table 1).

Whilst indicators of some elements of biodiversity (stocks) exist, these tend to be for particular species—in particular, those iconic elements that underpin cultural diversity (NEA 2010). These may not be so appropriate in the BESS context as alternative indicators such as functional groups which can be linked to specific functions and services. Tools and indicators that reflect socio-ecological variables may also be especially useful.

Many indicators exist for various dimensions of ecosystem stocks and flows, but none have been designed or recorded with ecosystem services in mind (Linstead et al. 2008). Thus, there are no obvious direct measures for many ecosystem services such as erosion prevention or climate regulation, and proxies have to be used at present (Layke 2009). Criteria for good indicators are well-established: existence of a reference value; the availability of time-series; ability to adapt to different spatial scales of assessment; sensitivity to change (responsiveness, but not too responsive); low cost of recording; ease of understanding by all managers and stakeholders; and ease of measurability. Many of the indicators of ecosystem services currently in use by local government and other institutions are measures of yields (of trees, crops, livestock or water). The proper use of these indicators and their interpretation requires knowledge of the stocks from which these yields are extracted in order to assess whether those flows are sustainable (Layke 2009). A key focus of BESS is to develop new indicators for stocks and flows. There is much to be gained by incorporating historical data into new indicators, wherever possible. Such long-term data are invaluable for assessing an indicator's direction and rate of approach to an acceptable environmental limit so that informed policy decisions can be made.

6. Interdisciplinary Needs

The BESS programme is unlikely to be successful without significant interdisciplinary collaborations between researchers from the biophysical (especially Earth Observation), ecological, environmental and socio-economic communities, as well as directly engaging with the stakeholder community from the start. This is not straightforward to achieve: it will not happen simply by putting a suitable mix of people together around a shared problem or question. The BESS Directorate will work together with all BESS-funded projects to invest in building inter-disciplinary capacity within this area in order to fully address the questions posed and to meet the goals of the programme. Whilst contributions from the social and economic sciences are fundamental to the delivery of the goals of the BESS programme (Table 1), it should be emphasised that as BESS is a NERC-funded programme, the natural sciences component is expected to dominate (80% or more of costs). All the research proposed, whether natural or social science, is expected to be at the cutting edge of developments in its respective field.

7. Relationship to Other Initiatives

BESS has clear linkages with other UK initiatives. These include the following NERC programmes: Ecosystem Services and Poverty Alleviation; Valuing Nature Network; The Virtual Observatory; Macronutrient Cycles; and the Pollinator Initiative. There are also potential links to the Defra Demonstration Catchments and Natural England's Pilot Areas

programmes as well as the UK Environmental Change Network, which contributes to the wider European Long-Term Ecosystem Research Network. BESS is expected to be congruent with the aims of a second phase of the National Ecosystem Assessment, and will be a major contributor to the Living with Environmental Change (LWEC) programme (see Annex 1).

8. Key Opportunities

There are key opportunities for BESS to work closely with private industry and landowners, agencies and NGOs through the use of sympathetic estate, as well as with UK agencies, including Defra, through its demonstration catchments and with Natural England through its Pilot Areas. There are also opportunities on the international scale (see section 4.4).

9. Acknowledgements

Much of the Science Plan has been evolved over the past 2 or 3 years through workshops, such as those at Defra in 2008, and ad hoc working groups brought together by the Biodiversity Theme leader(s), as well as constructive input from NERC Science and Innovation Strategy Board. Most recently, the BESS Programme Advisory Group (PAG) has played a major role in refining the focus of the programme, including the challenging areas around landscape type selection, and thanks go to all the PAG members: Tim Benton (University of Leeds), Jenny Gill (University of East Anglia), Jim Harris (Cranfield University), Jan Hiddink (University of Bangor), Mark Reed (University of Aberdeen), Andy Stott (Defra), Ruth Walters (Natural England), Phil Warren (University of Sheffield), Alan Watt (NERC Centre for Ecology and Hydrology).

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Table 1. The delivery of BESS programme goals through the research themes.

Activities are shown in normal type. Potential approaches are shown in *italics*, these are indicative rather than prescriptive. Potential links to other NERC initiatives and programmes are indicated in [square brackets]: VO, Virtual Observatory; VNN, Valuing Nature Network; ESPA, Ecosystem Services and Poverty Alleviation; MC, Macronutrient Cycles; PI, Pollinator Initiative.

Programme goal	Theme 1: Functional relationships between biodiversity and ecosystem services		Theme 2: Resilience of biodiversity-ecosystem service relationships to changing conditions	Theme 3: Monitoring and evaluation of ecosystem services
	Theme 1a: Relationships between biodiversity, functioning and services for key landscapes	Theme 1b: Characterising functional forms, critical levels and thresholds		
To define how biodiversity within landscapes underpins the delivery of different ecosystem services at a range of scales and across gradients	Identify relationships between biodiversity and ecosystem function, and between ecosystem function and ecosystem services for key landscapes at a range of scales	Characterise the functional forms of biodiversity-ecosystem service relationships in different key landscapes at a range of scales		
	<i>Large-scale, experimental-manipulative approaches; substitution of spatial for temporal gradients</i> [MC; PI]	<i>Large-scale, experimental-manipulative approaches; substitution of spatial for temporal gradients</i> [MC; PI]		
To establish whether there are critical levels of biodiversity required to deliver different kinds of services under different driver-pressure scenarios, as well as which enhance the resilience of		Establish evidence for critical levels of biodiversity stocks in biodiversity- function- service relationships Evaluate the sensitivity of any thresholds, and hence the resilience of biodiversity-	Define responses and resilience of biodiversity-ecosystem service relationships, including consideration of thresholds and trade-offs between different services, in relation to changes in major drivers: demographic	Develop appropriate measures of biodiversity, ecosystem function and/or ecosystem service that can be used to indicate the state and resilience of biodiversity-function-service systems with

<p>ecosystems to those different drivers</p>	<p>function-service relationships, to specific drivers and pressures Determine the implications of different functional forms and thresholds for trade-offs between different ecosystem services</p>	<p>change, economic conditions; climate change; new technologies; societal preferences; and policy and regulation.</p>	<p>respect to specific critical thresholds</p>
<p>To develop novel tools and indicators appropriate for tracking and measuring biodiversity and ecosystem services under those different scenarios</p>	<p><i>Multi-scale manipulative studies; ecological and ecological-economic modelling; input-output analysis; investment analysis [MC; PI; VNN]</i></p>	<p><i>Small- and large-scale manipulative experiments; integrative socio-economic-ecological analysis and modelling; mixed quantitative-qualitative approaches; scenario analysis; risk analysis [VNN; ESPA]</i></p>	<p><i>Identification of existing or novel simple or integrative indicators; novel data collection methods including potential for remote data collection [VO]</i></p>
<p>To develop novel tools and indicators appropriate for tracking and measuring biodiversity and ecosystem services under those different scenarios</p>	<p>Develop novel theoretical and empirical approaches to identify probable existence of thresholds in different biodiversity-ecosystem service relationships where data are limited</p>	<p>Identify key biodiversity or ecosystem function indicators that can be used to determine when a system is under stress in relation to specific drivers, and thus develop the capacity to identify such critical points in advance</p>	<p>Develop frameworks, tools and indicators that can be used in a scientific and policy context to monitor ecosystem service provision and identify trends over time relative to any critical thresholds and in response to changes in external drivers Evaluate likely consequences of trade-offs between different services from multi-functional landscapes.</p>
<p>To develop novel tools and indicators appropriate for tracking and measuring biodiversity and ecosystem services under those different scenarios</p>	<p><i>Characterisation of threshold-type biodiversity-function-service relationships; identification of simple or integrative indicators;</i></p>	<p><i>Integrative socio-economic-ecological analysis and modelling; stock-flow-yield modelling</i></p>	<p><i>Explore utility of existing data, including historical datasets for developing, onto novel</i></p>

<i>interdisciplinary socio-economic approaches; modelling.</i> [VNN]	[VNN; ESPA]	<i>indicators; scenario analysis; time series analysis</i> [VNN; ESPA]
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Annex 1 - Further information on relevant initiatives

Ecosystem Services and Poverty Alleviation (ESPA):

<http://www.nerc.ac.uk/research/funded/programmes/espa/> and <http://www.espa.ac.uk>

Valuing Nature Network: <http://www.nerc.ac.uk/research/funded/programmes/valuation/> and <http://www.valuing-nature.net>

Virtual Observatory:

<http://www.nerc.ac.uk/research/funded/programmes/virtualobservatory/> and <http://www.environmentalvirtualobservatory.org>

Macronutrient Cycles:

<http://www.nerc.ac.uk/research/funded/programmes/macronutrient/> and <http://macronutrient-cycles.ouce.ox.ac.uk>

Insect Pollinators Initiative:

<http://www.nerc.ac.uk/research/funded/programmes/pollinators/>

Defra Demonstration Test Catchments: <http://www.lwec.org.uk/activities/demonstration-test-catchments/>

Natural England's Pilot Areas programmes:

<http://publications.naturalengland.org.uk/publication/4084624>

UK Environmental Change Network: <http://www.ecn.ac.uk/>

European Long-Term Ecosystem Research Network: <http://www.lter-europe.net/>

National Ecosystem Assessment: <http://uknea.unep-wcmc.org/>

Living with Environmental Change (LWEC): <http://www.lwec.org.uk/>

US Long Term Ecological Research (LTER) Network: <http://www.lternet.edu/>

Diversitas: <http://www.diversitas-international.org/>

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services:

<http://www.ipbes.net/>