Large Scale Biodiversity, Environmental Gradients and Ecosystem Sustainability

Report on workshop outputs from Marine and Terrestrial & Freshwater community perspectives
(15th and 16th December 2008)

Content

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Summary

This document outlines the objectives, background and outcomes of two workshops held at the Defra Innovation Centre, Reading on 15-16 December 2008. These workshops were held to help develop the 'ecosystem sustainability' priority action of the 2008 Biodiversity Theme Action Plan, to inform our understanding of biodiversity functions and processes across scales and systems. Introductory and background material are given in Section 1 and Annexes 1-4, with reports from the marine workshop in Section 2 and from the terrestrial and freshwater workshop in Section 3. Both workshops identified priority questions; assessed different approaches for addressing these questions; and commented on issues, concerns and opportunities that a large-scale study of ecosystem sustainability could offer.

The main outcomes of the two workshops were as follows.

i) All research communities (marine, terrestrial and freshwater) recognised that a large-scale, long term and collaborative biodiversity initiative would provide unique and exciting opportunities to advance scientific knowledge of ecosystem services and sustainability.

ii) No single priority research question was identified. However, both workshops emphasised the need to increase fundamental understanding of ecosystem sensitivity to change (tipping points, non-linearities and resilience) and ecosystem functioning across different scales, in order to improve management advice in a broader socio-economic context. These issues are closely linked.

iii) Focussing research effort on a single site was not favoured. Instead, both workshops preferred a nested, multi-site study that could cover a relatively wide geographic range and would include process-based experimental studies.

iv) Resource constraints, gaps in the national skills base and community cohesion were identified as issues requiring further consideration if viability and success of the programme is to be assured.

v) All research communities recognised the need for a clear, well-defined and appropriately funded work plan with defined aims and the establishment of a strong governance structure to ensure community cohesion and delivery of interdisciplinary science of societal value.

Section 1: Introduction

1 Workshop objectives

1.1 The objective of the two workshops was to start the process of identifying and outlining options for a possible future NERC research programme investment that would enable research on ecosystem sustainability and improve our understanding of biodiversity functions and processes across scales and systems. The specific aims of the workshop were to:

(i) identify the priority research questions that require a large-scale, long term approach for delivery,
(ii) consider the advantages and disadvantages of different approaches to achieving the desired science outcomes (e.g. a single site approach vs multiple experiments vs a virtual observatory), and
(iii) determine the resources required to deliver a programme of this kind that will contribute to global initiatives in ecosystem sustainability.

2 Background information

2.1 The primary challenge of the NERC Biodiversity theme is to "Improve understanding of biodiversity's role in ecosystems: processes, resilience, and environmental change." Addressing this challenge will require the generation of inter/multidisciplinary programmes and teams with expertise at all scales from molecular to landscape. However, research at large-scale and over longer time scales in particular is difficult to deliver through responsive mode type mechanisms and generally requires a more coordinated approach to investment.

2.2 Therefore, the 2008 Biodiversity Theme Action Plan identified a large-scale action as a priority for the theme. This action would be the first UK large-scale, multidisciplinary investigation of the stability of ecosystems that are linked across major environmental gradients and the associated functional role of biodiversity at the ecosystem level. This is an exciting opportunity to develop the essential paradigms that are currently lacking. Whilst the UK biodiversity research community is recognized as having world-class strengths, much of the community is not accustomed to working at cross-ecosystem scales in multidisciplinary teams to identify the interdependencies between ecosystems, traditionally pursuing independent, focused research at small scales. This action will also demand new approaches and ways of working for the biodiversity research community. Specifically, many of the questions will need to be tackled at spatial and temporal scales in which society has a stake as well as bridging the sub-disciplines within natural sciences and working at the interfaces between the natural, physical and social sciences. It is proposed to harness this intellectual capacity to achieve new synergies to facilitate major science advances by allowing the community to work through a large-scale, integrated approach.

2.3 The action should run for enough time to allow incorporation of significant environmental variation into models (e.g. interannual variability in climatic variables), and be of a spatial scale to allow comparisons to be made with large-scale studies elsewhere (in particular, the US LTER programme). It will also make a major contribution to providing policy makers with evidence needed to mitigate impacts of climate, to sustain biodiversity (meeting national obligations) and to maintain and enhance the provision of ecosystem services.

2.4 This scoping exercise will outline options for a world-leading research programme aimed at improving our understanding of biodiversity, environmental gradients and ecosystem sustainability at large scales by providing: i) a step improvement in understanding of the role of biodiversity in ecosystems; ii) marked improvement in understanding of effects of change on biodiversity and ecosystems with concomitant enhancement of ability to predict future response scenarios; and iii) a significant improvement in quality of advice to stakeholders.

3 Workshop process

3.1 There were four main sessions in each workshop:

(i) Introductory presentations and canvassing of 'opportunities', 'major issues' and 'concerns';
(ii) Presentation of a conceptual framework and the identification of priority research questions;
(iii) Group assessments of different research approaches, with plenary discussion;
(iv) Individual written comments on 'Things for NERC to consider'

4 Introductory presentations

4.1 Mark Ohman (Scripps Institution of Oceanography) provided an overview of research at biome sites within the NSF-funded Long-Term Ecological Research network (LTER, www.lternet.edu). Although mostly temperate and land-based, the 26 LTER sites together cover the climatic range from polar to tropical, with 10 sites having aquatic processes as major components. The 193,000 km^2 California Current Ecosystem (CCE) site became part of the LTER network in 2004, building on fishery-based surveys (CalCOFI; California Cooperative Oceanic Fisheries Investigations). Benthic studies are not directly included, but are covered by collaborative work.

4.2 All LTER sites measure five core variables, relating to primary production, population dynamics of representative species, nutrient cycling, decomposition and disturbance. They provide the framework for project-based experimental studies, and actively engage in outreach. More explicit linkages to socio-economic factors are being taken forward through the Integrative Science for Society and Environment initiative. The LTER network offers many unexploited opportunities for cross-site, cross-biome comparative science that could be further developed on an international basis.

4.3 Wouter Los (Zoological Museum, Univ of Amsterdam) and Gilles Lemaire (Institut National de la Recherche Agronomique, France) summarised the status of European coordinating activities and infrastructures linking environmental and biodiversity research, through LifeWatch (www.lifewatch.eu) and ANAEE (Analysis and Experimentation on Ecosystems; www.anaee.com). These EU activities are FP7-supported as preparatory studies to enhance the wider integration of national effort, the former with emphasis on large-scale, long term observations of natural systems, the latter on experimental facilities (e.g. the ecotron, used for manipulation of soil-vegetation systems, and marine mesocosms).

4.4 UK participation in LifeWatch is currently through CEH, MBA, NHM and the Cardiff eScience Centre. The involvement of terrestrial/freshwater researchers is probably higher than the marine community, although there is the potential for both to raise their profiles

4.5 Georgina Mace (NERC Centre for Population Biology, Imperial College) outlined a conceptual framework relating biodiversity research to spatial scale. Because of the difficulty in achieving manipulation replications and controls, 'landscape' studies and those at larger scale need to be closely linked to observational research and smaller-scale experiments, using modelling approaches to develop and test regional assembly rules.

Section 2: Marine Workshop held 15 December

5. Section summary

5.1 This section relates to the 15 December meeting. It was chaired by Lloyd Peck; jointly organised by NERC Swindon Office and Defra Innovation Centre facilitators; and attended by ~ 55 researchers and research users from over 35 organisations (Annex 1)

5.2 The main outcomes and conclusions of the 15 December workshop were as follows:

(i) The marine research community welcomed the development of a large-scale, long term biodiversity study relating to ecosystem services and sustainability. Such an initiative would provide major opportunities for policy-relevant scientific advances and interdisciplinary integration.

(ii) 'High level' priority research questions were identified as understanding the role of biodiversity in ecosystem function and in ecosystem responses to natural and anthropogenic change (sensitivity, resilience and thresholds), together with improved knowledge of scaling and connectivity processes. Such ecological studies need to be closely coupled to socio-economic research to help achieve sustainable management of marine resources.

(iii) Exclusive focus on a single site was not considered the most effective approach. Instead, a nested, multi-site study was favoured, building on existing time series and developed with partnership co-funding. The new programme would need to combine experimental, observational and modelling work, contributing to, and benefiting from, international collaborations.

(iv) There were concerns regarding resource constraints, programme design and implementation, the engagement of stakeholders, and gaps in the national skills base. These issues required further consideration to ensure programme viability and success. Direct engagement with the terrestrial and freshwater research communities was also considered desirable, assuming that funding was sufficient to cover all environments.

6 Initial brainstorming

6.1 Workshop participants were asked to individually identify opportunities, major issues, and concerns (separately, on colour-coded Post-it notes) that were relevant to the workshop aims. These inputs were not collectively discussed; however, they were grouped by Defra facilitators and displayed as background for subsequent sessions. The following contributions were made, with minor editing to avoid duplication:

6.2 Opportunities:

- *Integration and collaboration* (n = 25). To be achieved by scientific synthesis at national, European and international levels; linkage between biodiversity, environmental change and human activities; linkage between experiments, measurements and modelling; opportunity to cover range of habitats in a systematic and comparable way; use of innovative informatics; temporal integration, providing context for monitoring by connecting observational snapshots to dynamic processes.

- *Community development and cohesion* (15). Development of (much needed) 'joined-up' approach to address major issues and unified goals; organisational integration between distributed research communities (NERC Centres, HEIs and governmental researchers); maximising benefits of existing sustained observations, time series and other datasets; development of networks between scientists in other disciplines and environments, including terrestrial and freshwater.

- *Scientific benefits of large-scale approach* (10). Opportunity to address both fundamental and applied questions by studying marine ecosystems at the scales on which they operate; statistical advantages of pooled datasets and meta-analyses; potential advances in developing scaling laws and understanding natural variability; opportunity for 'end-to-end' ecosystem studies, from genes to biomes, across full taxonomic and size ranges, and including humans; opportunity for tractable hypothesis-testing, covering both top-down and bottom-up interactions within food-webs.

- *Societal relevance* (8). Sustainable marine management requires reliable baseline biodiversity data and process-based understanding; importance of ecosystem approach and 'good environmental status' for UK and Scottish Marine Bills and EU Marine Strategy Framework Directive; opportunity to improve fishery management advice by connecting single-species and ecosystem models; help develop conservation policy through design of Marine Protected Areas and assessment of their effectiveness.

- *Increased effectiveness of funding* (5). Added value of addressing wide range of issues and measuring many parameters together; programmatic approach and international linkages avoid inefficient duplication of effort; involvement of many organisations widens access to, and use of, existing data; opportunity to leverage additional resources from research users and other funders.

6.3 Major issues:

- *Links to socio-economics and policy* (13). Significant stakeholder involvement is needed for programme to successfully address sustainability issues; requirement for multi-disciplinary teams; ESRC needs to be engaged, preferably as co-funder; not clear how research results would be used by policy-makers.

- *Scope and programme balance* (11). Science questions need to be prioritised; importance of interactions between different forcing factors, including links with the Earth System Science-Biodiversity theme action on ocean acidification; need for major genetic/genomic component (eg. for 'barcode' identification and molecular-based stress indicators); integration of pelagic and benthic studies, and their connections to atmospheric and land-based processes; Arctic focus highly desirable as major biodiversity changes already underway.

- *Programme management* (10). How will overall direction, programme integration, and international complementarily be achieved? Conflicting needs for strong leadership and democratic engagement of research community; data management and informatics issues need to be addressed early on.

- *Funding issues* (4). Will funding be sufficient? What will the mechanisms be? How will technology development, contextualisation, analysis and synthesis be supported?

- *Links to terrestrial/freshwater* (3). Need for common, process-based approach to bring together marine biodiversity work with land-based studies; opportunities for cross-biome hypothesis testing.

6.4 Concerns:

- *Resource constraints* (19). Risk of insufficient funding to implement programme at necessary scale and over necessary time period to fully realise its benefits; high cost of observational infrastructure for deep ocean work (benthic and water column); long term commitment needed by all partners and stakeholders with interests; resources for data quality assurance and overall synthesis may be inadequate.

- *Programme design* (15). LTER model not directly appropriate for UK; lack of replication and risk of inappropriate site choice if all effort directed to single location; synthesis will be difficult if study is diffuse, lacks clear scientific direction and gives insufficient attention to contextualisation; need to have well-developed ideas on how results will assist sustainable management; current lack of collective focus.

- *Funding process and community engagement* (7). Risk of drawn-out programme start-up, with lack of transparency in scoping; fallibility of peer review (key components may be lost); concern that most support will go to relatively few research groups; programme-based approach not necessarily preferable to responsive mode; initial community consensus and subsequent integration may not be achieved.

- *Programme management* (5). Need for cost-effective and efficient coordination; not just a network – whole must be more than sum of parts; productive linkage between components won't be easy.

- *Data-related issues* (4). Data quality will be critical; will open data-sharing be achieved?

- *Skill shortage* (1). Are there sufficient taxonomists for programme viability?

6.5 Note that the numbers shown above should be considered as indicative. They have not been expressed as percentages since some workshop participants completed more than one note per category, whilst others contributed ideas that spanned the groupings given above. Table 1 rearranges the ordering of these groupings, to indicate that an opportunity can also be expressed as an issue or concern.

Table 1. Summary of initial brainstorming session. Sequence of major issues and concerns re-ordered to horizontally match topics also identified as opportunities, with font size indicating relative importance of the different issues (based on number of Post-it notes; Sections 3.2 - 3.4).

Opportunities	***Major issues***	***Concerns***
Integration & collaboration	Programme management	Programme management
Community development	Scope & programme balance	Programme design
Scientific benefits of large-scale approach	Links to terrestrial & freshwater	Data-related issues
	Links to socio-economics & policy	Skill shortage
Societal relevance		Funding process & community engagement
Increased funding effectiveness	Funding issues	**Resource constraints**

7. Priority research questions

7.1 Workshop participants were provided with a list of 50 pre-submitted research questions, solicited on the basis that they addressed the wider aims of the Biodiversity theme and required a large-scale, long term initiative for their delivery. These questions covered both marine and terrestrial/freshwater environments and had already been grouped been under three headings: understanding critical processes and functions; understanding trends and implications, and developing management solutions. Further synthesis, prioritisation and discussions were carried out in table-based groups of 6-8, with each table's conclusions summarised on an A3 page and orally presented by a rapporteur.

7.2 There was a very close match in the orally-delivered and written priority research topics from the seven tables, with consensus that the programme's scientific structure should be based on the following (linked) high level issues:

(i) Ecosystem sensitivity and resilience: response to pressures. What are the critical characteristics that determine how ecosystem functions (including provision of goods and services) respond to external forcing? Pressure-response behaviours of interest include stability, resilience/resistance, recovery from perturbation, and thresholds (tipping points, that may lead to regime shifts). Whilst these are the behaviours of greatest interest, it is initially necessary to improve our knowledge of the biodiversity-ecosystem function relationships. Such process-based information can then be used to produce realistic

scenarios of ecosystem responses to climate change and management (human exploitation, conservation and restoration) over relatively long timescales, simulating interactions that are likely to involve non-linear changes, emergent properties, and functional redundancy.

(ii) Scaling and connectivity, from local to global. What are the key relationships that determine ecosystem scaling over a range of latitudes, water depths and time periods? How are individual species linked to ecosystem properties, through changes in their abundance, size, genotype, gene regulation and phenotype? What are the roles of migration and dispersal in determining responses to environmental change? These questions relating to the spatial and temporal structuring of ecosystems are fundamental to model development and the design of research studies, both experimental and observational. They are also of crucial importance in distinguishing local variability from large-scale patterns (involving downscaling as well as upscaling); for the translation of sound ecological theory into practical management advice; and in providing a basis for comparative analyses with freshwater and terrestrial systems.

(iii) Developing management solutions. What state do we want our marine ecosystems to be? How can we ensure that ecosystem goods and services will continue to be delivered? Ecosystem-based management of marine resources not only requires information on reference conditions for the components of concern, but also an understanding of their natural variability and responses to human pressures; i.e. the coupling of social and ecological systems. In addition to long-standing issues related to (un)sustainable fisheries, new policy-related challenges relate to the rapid expansion of marine renewable energy, the establishment of Marine Protected Areas, and the impacts of invasive species. These topic areas provide opportunities for hypothesis testing via large-scale management 'experiments' and the development of coupled ecosystem-bio-economic models to underpin decision-making.

7.3 Table 2 below identifies the ~ 12 specific questions that featured in the written reports of the seven break-out groups, developed from the original list of 50.

Table 2. Priority research questions, as subset of list provided and grouped under three high level headings. N, number of break-out groups identifying the same or closely similar questions.

Research questions (combining those that are closely similar)	N
Ecosystem sensitivity and resilience: response to pressures	
• How does biodiversity, complexity and ecosystem function affect resilience, stability and delivery of ecosystem services over different spatial and temporal scales?	5
• Can we determine how and when disturbance will severely affect ecosystem functions, resulting in non-linear behaviour (thresholds and tipping points)?	4
• What is the importance of genetic diversity for ecosystem resilience?	4
• What are the key natural and anthropogenic drivers affecting ecosystems?	3
• What is the extent of community adaptation to natural and anthropogenic change?	2
• Is functional capacity and stability more important than biodiversity?	2
Scaling and connectivity, from local to global	
• What processes (and at what level) link populations and ecosystems across local, regional and larger scales, including responses to natural and anthropogenic gradients?	5
• What are the commonalities (and differences) between marine and terrestrial ecosystems?	1
Developing management solutions	
• How can we use knowledge on biodiversity to improve ecosystem services?	3
• How should Marine Protected Areas be planned and assessed?	2
• What are the effects of management on biodiversity?	1
• What are the impacts of invasive species?	1

8. Evaluation of different research approaches

8.1 Workshop participants were divided into breakout groups to consider the practicalities of three different approaches that could be used by a large-scale biodiversity research programme: single site; multiple sites, few (4-6); and multiple sites, many (30-50). Two groups considered each option, setting out their ideas on wall posters and flip charts; in addition, a seventh group was given an 'unconstrained' scenario. The charts were displayed for additional comments to be appended by all workshop participants.

8.2 The outcomes of these discussions are summarised in Table 3, and presented to plenary by group rapporteurs. Both single site groups were unconvinced that such an approach was scientifically-optimal, a view endorsed by the wider meeting. Thus that approach attracting no supporters when put to plenary vote. Opinion was divided in the approximate ratio of 2:1 between the 'few' and 'many' multiple site options.

8.3 In group discussions (Table 3) and in plenary the point was made that the concept of 'site' was crucial to programme scoping yet had not been unambiguously defined. It could refer to a relatively large area within which detailed studies are carried out at many locations, each of which may also be regarded as sites. The US LTER 'biome sites' were of that dual nature, with the CCE being larger than the Irish Sea and Celtic Sea combined, and covering many different habitats and environmental conditions.

8.4 Furthermore: i) site stability and identity (boundary definition) varied greatly from pelagic to soft- and hard-bottom benthic habitats, and from deep water to coastal ecosystems; and ii) transect-based sampling (e.g. the Continuous Plankton Recorder survey) did not necessarily match a site-structured approach. Linear surveys were, however, well-suited to the study of large-scale environmental gradients, and could be related to the regional-to-global synoptic approaches of remote sensing and biogeochemical modelling.

8.5 Such considerations did not diminish the need for a large-scale, integrated UK programme of marine biodiversity research. Nevertheless, a key conclusion of the workshop was that the choice between single-site and multiple-site approaches was (for the marine environment) essentially a false dichotomy. Instead, nesting of research effort was required, with local, process-based studies and experiments occurring within a much larger observational framework. The programmatic linkage across the scales would then be hypothesis- and model-driven, transcending site specificity not only through standardised sampling, experimental protocols and data management, but also through European and international collaborations.

9. Final brainstorming

9.1 At the end of the meeting there were concluding table-based discussions of an open-ended nature. The main issues raised were: how the programme would fit wider social context and policy needs; the benefits of using existing sites (NERC-supported and others) as the 'programme backbone'; the need to invest in new technology; the importance of maintaining taxonomic expertise; the need for cross-disciplinarity; and the desirability of early delivery of high profile science outcomes (to ensure continued support over ~10 yr programme lifetime).

9.2 All workshop participants were also asked to individually identify the single most important "issue for NERC to consider" on Post-it notes. Whilst these comments and suggestions were relatively diverse (and some participants had left the meeting by then), the following groupings could be made:

- *Relevance to sustainability agenda* (12). Assessment of human impacts and role of biodiversity in delivering goods and services requires strong socio-economic component, with wide stakeholder/ research user engagement (via other Research Councils, Defra, devolved government etc); role of LWEC in promoting interdisciplinary approach and ensuring programme value is fully realised.

- *Linkage to National Capability* (7). Need to build on existing investments in time series, sustained observations/monitoring programmes, technology development, data management and modelling, including use of historical datasets.

Table 3. Summary of group-based discussions on programme approach

	Single site	Multiple sites: few (4-6)	Multiple sites: many (30-50)	Unconstrained*
Key features	*Not considered a useful approach.* "If we must" then site needs to be large, and carefully chosen to have wide applicability.	Could either be based on very different ecosystems or similar habitats widely separated (that may have different biotas).	High replication; regional to global approach covers very many natural and human drivers; spatial scales may also serve as (proxy) chrono-sequence for climate change	Ideally would cover full taxonomic range over full habitat/ ecosystem spectrum (estuary to deep sea, polar to tropical)
Priority research questions	Focus on process studies. Unsuitable for scaling/connectivity questions; limited value for management	Pressures/responses and management issues. Scaling not so well addressed.	All priority research issues potentially covered	All questions covered
Feasibility	Would be possible, but not scientifically desirable	Could build on existing observatories and time series, tailored to fit wider buy-in (by Defra, JNCC *et al*)	Doable, with nesting of effort - and building on existing observatories and time series (including Arctic and Antarctic)	Aspirational, but could be done if geopolitical will and international buy-in.
Main deliverables in 5-10 yr	Site-specific analyses of main drivers and processes – but problem in extrapolating	Baselines and some trend data; improved under-standing of natural and human-driven change; new models for forecasts	Comprehensive datasets for observing, understanding and managing changes in marine ecosystems; much more robust models	Major scientific advances and evidence base for sustainable use of marine bioresources
Resources; value for money	Cost depends on site size. Value only realised if fully networked with other (non UK) effort	Cost of £2-3m pa ? (excluding observational infrastructure, cruise costs and major experimental facilities, e.g. mesocosms)	Cost of £3-5m pa? (with exclusions as at left). Yet value for money, since would answer key questions, whilst providing many opportunities for leverage and outreach	Cost of £10m pa? Would need joined-up government support and strong link to climate change research
Scope for inter-national linkages	Matches (Pacific) US LTER biome approach, but limited scope for Atlantic comparisons at this scale	Multiple UK sites improves opportunities for European collaborations, e.g. via MarBEF network	Excellent opportunities for very wide range of links (via MarBEF, CoML, LTER, LifeWatch, Diversitas, IMBER etc)	UK could develop world leadership in this area
Main advantages	High resolution data for model parameterising; simpler management; interdisciplinarity easier to achieve	Could cover range of habitat types, with good supporting data	Comprehensive coverage and good replication improves confidence in outcomes; more likely to deliver novel insights and meet future needs	Flagship programme to answer science questions and meet UK and EU policy needs
Uniqueness	Very detailed studies, e.g. via manipulations and instrumented arrays; high local replication	Benefit of inter-site comparisons to identify and test patterns, trends and relationships at different scales	Mix of intensive and extensive, maximising benefits of nesting; flexibility; meeting both science and policy agendas	World leading – covering all spatial and temporal scales
Limitations	"Eggs all in one basket": difficulty in assessing wider applicability of results; site selection won't be easy; risk of making poor choice	Limited replication; not covering all ecosystems; problem of wider spatial and temporal extrapolation	May be constrained by available finances, e.g. reduced scope for experi-mental manipulations ; full suite of physical data unlikely at all sites; complex management	Could funding be found? Insufficient taxonomists; shortage of research ships; no controls for climate change or ocean acidification
How limitations would be overcome	Develop as part of wider European/ international network	Careful site selection, sampling design and choice of experiments; close links with modelling; funding support for collaborative work at non-UK sites	Co-funding and internationalising; careful design; close links with modelling, remote sensing and transect-based underway data collection	Joined-up government; investment in training; greater ship-sharing

*"unconstrained" interpreted by the group primarily in financial terms

- *Scaling issues* (5). Cross-scale, integrative approach required to address large-scale policy and societal issues through small-scale experiments and site specific studies; need for representative sites; importance of global context.

- *Funding concerns* (5). Importance of 10 year vision; how will resources be bid for and allocated?

- *Linkage to other NERC themes* (3). Programme needs to closely connect to other NERC themes (primarily Sustainable Use of Natural Resources, Climate System, and Earth System Science); also link to proposed Arctic initiative.

- *Programme scoping* (2). Need for more thorough assessment of key questions and long term goals, that will then have implications for programme structure.

- *Programme governance* (2). How will the programme be managed? How will links be made with terrestrial and freshwater work?

- *Training and capacity building* (2). National need to train more marine taxonomists.

9.3 A single day is a relatively short period for a diverse group of individuals to discuss and agree on a national research programme covering complex issues and a broad range of organisms, habitats and ecosystems. Nevertheless, it was considered that good progress was made in the marine scoping exercise, with the main conclusions and outcomes of the 15 December workshop summarised in the introductory Section Summary

Section 3: Terrestrial and Freshwater Workshop held 16 December 2008

1 Section **Summary**

1.1 This report presents the main issues, themes and questions raised at the second workshop (held 16th December 2008), which involved leading UK scientists and policy makers with interests in freshwater and terrestrial biodiversity.

1.2 The main outcomes and conclusions of the 16th December workshop were as follows:

(i) The Terrestrial and Freshwater community saw this as an opportunity to develop a cross-disciplinary, collaborative research programme that would address common question(s) encompassing different scales and ecosystems.
(ii) The workshop participants emphasised the need for strong governance of the programme of work to ensure community cohesion and effective delivery of agreed research aims.
(iii) A single, 'high level 'over-arching research question was not identified but five broad and inter-related areas of research that would benefit from a large-scale approach were identified. These were: tipping points, non-linearities and resilience; ecosystem functioning, redundancy and adaptation to drivers; management; scaling issues; and ecosystem services.
(iv) Focus on a single site approach was not favoured. Instead, a multi-site approach incorporating a nested experimental design was the preferred option. This approach would: ensure cross ecosystem relevance and comparisons;, that gradients and scaling issues were addressed, and would enhance statistical power to detect attribute and model environmental responses.

2 Initial brainstorming

2.1 Following the introductory presentations, the participants were asked, as individuals, to identify a single *opportunity* that a large-scale initiative might provide, a *concern* regarding the action and a *major issue* that they felt the action should address / consider. Comments for each were collected on the day and subsequently grouped to identify common themes for each category. These are summarised below.

2.2 Opportunities (n=60)

- *Cross system integration / comparison* (n=15). To be achieved by: linking biodiversity and ecosystem function and landscape structure through interdisciplinary research; from genes and individuals through groups, populations, communities and ecosystems; cross-site and cross-scale comparisons through standardised measurements; bioinformatics enhancements and availability of much larger data sets (including linking existing monitoring and research sites).

- *Interdisciplinary collaboration* (n=13). Advantages include: applying a co-ordinated 'systems' approach to understand ecosystem function; bringing together observations, models and experiments to understand large-scale processes; developing common approaches across the terrestrial, freshwater and marine communities; enabling a more effective interface with socio-economic sciences for policy.

- *Community building* (n=12). Opportunity to: provide / create a lively and open research community involving different disciplinary views; generate cross ecosystem generalisations (ecological 'laws'); lead to synergism and more rapid progress towards a common 'holistic' vision and shared research needs; landscape scale research involving stakeholders to quantify, value and conserve biodiversity.

- *Tackle big questions / Address global issues* (n=11). Opportunity to improve understanding of large-scale drivers of ecosystem change that require long-term experimentation; provide an understanding of the baseline variation inherent in ecosystems both in space and time, and in so doing enable the UK to engage with the international science agenda to make progress to mitigate the effects of environmental change.

- *Link to policy* (n=6). Opportunity to raise the profile of biodiversity to policy makers, through linking it to large-scale land-use and other societal issues and through development of scenario testing to aid policy decisions.

- *Funding* (n=3). The initiative was seen as a means of securing / stabilising funding for large scale monitoring and experiments, with the opportunity to work with and leverage resources from other partners.

2.3 Concerns

- *Programme focus and governance* (n=30). Risk of insufficient focus and lack of consensus in formulating the programme of work; lack of agreement on definitions of biodiversity and ecosystem services. Could be difficult to make the programme inclusive if it could only cover limited components of biodiversity or ecosystem function due to scale constraints / omissions; vested interests and silos could compromise common goals; and the governance structure might be insufficient to ensure co-ordination and synthesis, resulting in poor targeting of large sums of money.

- *Inefficient data gathering / management* (n=10). What is the right balance between observation, modelling and data-basing? What are the right attributes to measure to ensure utility, including data compatibility and comparability?

- *Research focus* (n=8). What is the right balance between flexibility of research objectives and focus of the research hypothesis being addressed, and how will that be achieved? What is meant by large scale and long-term in this context?

- *Funding continuity / security* (n=6). Will sufficient funds be available? Will insufficient funding compromise the opportunities for success? One participant suggested that the action should be developed as a stand-alone programme that then encourages external collaboration, rather than developing a collaborative programme from the outset.

- *Creative opportunities* (n=3). Would a community level programme stifle individualism and would scientific quality suffer as a result?

- *Valuing Biodiversity* (n=3). Policy relevance, e.g. valuing biodiversity, should not be lost or overlooked as the programme develops.

2.4 Major Issues

- *How do we collaborate and integrate?* (n=15). Is a large-scale platform approach efficient and manageable? Can existing long-term and large-scale monitoring and research activities be integrated and built on? Will there be sufficient support for bioinformatics?

- *Dependencies* (n=15). How do we understand the dependencies? The comments grouped here were mixed but raised concerns that specific linkages might be overlooked. These include links between: resilience and genetic diversity; genomic expression and environmental change; behaviour and life-history traits; biodiversity and biogeochemical cycles; biodiversity and extreme events; biodiversity / ecosystem function and landscape heterogeneity and connectivity; biodiversity / ecosystem restoration and ecosystem services; and the processes operating at the interfaces of ecosystems.

- *Multi-disciplinarity* (n=6). How do we incorporate socio-economics to meet policy needs? Need for early integration through consideration of socio-economic drivers, theory and human behaviour to meet policy / end-user requirements.

- *Scales* (n=5). How do we ensure the scales are right? Scaling dependencies are difficult to address and could be overlooked. Can the initiative be sustained for a sufficient length of time to generate 'added' value?

- *Climate Change* (n=2). How do we focus on climate change? How ecosystems can be manipulated to cope with climate change?

- *Funding security* (n=2). How can sufficient long-term funding be ensured?

2.5 Summary

The opportunities, concerns and major issues can be grouped under five headings. Interestingly,the five headings under the each of the three categories share common themes (Table 1).

Table 3: Summary of the broad themes identified among the opportunities, concerns or major issues comments. Related themes that emerged from each set of comments are shown on the same line with font size indicating the relative importance of each theme (based on numbers of Post-it notes).

Opportunities	***Concerns***	***Burning Issues***
Community building	**Programme focus & Governance**	**How to collaborate & integrate?**
Interdisciplinary collaboration	Creative opportunities	**How to understand the dependencies?**
Cross system integration / comparison	Inefficient data-gathering / management	How to ensure the scales are right?
Link to policy	Valuing Biodiversity	How to incorporate socio-economics to meet policy needs?
Tackle big questions / Address global issues	Research focus	How to focus initiative to address impacts from climate change?
Funding	Funding continuity /security	How to ensure future funding?

2.6 The main issues arising from this exercise suggest that a large-scale, ecosystem sustainability action would:

- provide an opportunity to build a collaborative, interdisciplinary community to address a common ecological question across different ecosystems and scales; and
- require strong governance of the science programme and data to ensure linkages are recognised and interpreted to address the question / hypothesis.

3 Priority questions to be addressed by a large-scale platform

3.1 In advance of the workshops all attendees, from both the marine and terrestrial / freshwater communities, were invited to submit three priority questions that might be addressed by an ES Action. The 50 questions submitted were provided to each group divided under three headings:

(i) understanding critical processes and functions;
(ii) understanding trends and implications;
(iii) developing management solutions.

3.2 Participants, working in eight groups, of no more than eight, were asked to refer to the list of questions and identify up to five priority questions that could be addressed working across the scales outlined in the presentation. The groups were also asked to summarise the reasoning behind each question.

3.3 Priority Question: Feedback

- In their feedback, the rapporteurs identified 37 questions, but only rarely made reference to the list of questions provided. The priority questions identified were diverse, and, whilst they can be 'binned' into five broad areas, they do not readily translate into an over-arching framework or researchable question for the action. Many of the questions are pertinent to more than one research area. The questions, grouped under each primary research area and

their cross links to the other research areas are shown in Annex 1. The five research areas are summarised below:

- *Non-linearity / tipping points / resilience* (n=11). What is the role of cryptic diversity in resilience? How does the degree of local adaptation affect resilience to environmental change? How do we manage resilience at the landscape scale? How do we identify and model critical thresholds and tipping points, as well as the critical dynamics that lead to non-linear responses?

- *Ecosystem functioning / redundancy / adaptation to drivers* (n=10). What is the role of biodiversity in ecosystem functioning and how are both affected by multiple drivers? How do you quantify and manage species and systems ability to adapt? What is the role of redundancy in these processes?

- *Management* (n=8). How do we improve methods to predict the responses of biodiversity and ecosystem services to environmental change and what constitutes appropriate management practices?

- *Scaling issues* (n=4). How do we improve our ability to work across biological, spatial and /or temporal scales? These questions have direct relevance to most other research areas.

- *Ecosystem services* (4). What is needed to improve understand ecosystem services and the processes that underpin them so that better strategies for management for ecosystem services at landscape scales can be employed?

4 Evaluation of different research approaches

4.1 The participants were randomly assigned to one of seven groups and asked to discuss and comment on 10 aspects of an experimental approach. Two groups each independently discussed: a single site approach; a 4-6 multi-site approach, or a 30-50 multi-site approach. The seventh group was given *carte blanche* to develop an 'unconstrained' approach.

4.2 The 10 aspects considered for each approach were: its key features; which priority research areas it could address; its feasibility; the likely deliverables in 5-10 years time; the resources necessary for success; scope for international linkages; its main advantages; any unique attributes; any limitations and suggestions of how these might be overcome. One person from each group then gave a summary of the group discussions. These are summarised below and in Table 4.

4.3 **General themes in the feedback**: Workshop participants stressed that the overarching research question or framework for the action would strongly influence the final experimental design. Most groups also indicated that they would adopt a nested experimental design as this would add statistical power and help address issues of scaling and comparability across the landscape.

Table 4. Summary of group-based discussions on programme approach

	Single site	Multiple sites: few (4-6)	Multiple sites: many (30-50)	Unconstrained
Key features	Needs to incorporate defined gradients – transects & contrasts. Nested design using sub-plots. Allows scaling for relevance for organism – ecosystem.	Potential to work across gradients in a limited number of habitats. Larger sites allow nested design. Within and between site comparisons.	Potential to: work across multiple environments, gradients, & nested scales; incorporate replication and hence have UK relevance.	Would incorporate multiple nested scales & be interdisciplinary. Basal, standardised measures at each site with scope for flexible add-ons at different sites. Observation and interpretation to lead manipulations. Would cover natural gradients.

	Single site	Multiple sites: few (4-6)	Multiple sites: many (30-50)	Unconstrained
Priority research questions	Identifying tipping points & understanding functionality and redundancy at different biological scales, especially along gradients. Possibility of looking at adaptation responses.	Identify thresholds of ecosystem response. Ecosystem function. Scaling issues. Management issues.	Non-linearity Scaling Ecosystem function Management (some services)	This approach could address each of the priority areas; tipping points, ecosystem function, management issues, scaling challenges and ecosystem services.
Feasibility	Both groups felt that this approach was feasible. The necessary expertise in a range of disciplines including ecology, hydrology, geomorphology, soil scientists. Modelling & social sciences.	Both groups indicated that this option was feasible. It could build on existing data sets, sites & initiatives and would need to incorporate a high level of modelling and meta-data analysis.	Feasibility will be determined by the scale of the Action and the research priority. Could build on existing networks.	The approach was seen to be feasible, but only if it were run for longer – a minimum of 15 years. It would build on existing capabilities.
Main deliverables in 5-10 yr	These would be dependent on the site chosen but could include scale (gradient / catchment) dependence of impacts. These would influence management strategies.	Proactive community, inc stakeholders (5 yr) Modelling infrastructure. Identification of thresholds. Characteristics associated with rapid adaptation. Data capture and products.	Management advice (<5 yr) Broad scale understanding (5 yr) Process understanding (10 yr)	Collaborative UK community. Cross-ecosystem baseline measures, linkages and modelling framework. Information to aid landscape design and to model management scenarios.
Resources; value for money	One group estimated 6 PDRA and £9M for recurrent, equipment, co-ordination and data management. One group did not give any estimate of resource needs and simply stated '*probably not value for money*'.	Both groups estimated a cost of £10 M over 5 yr. Value for money: would produce less science (papers) but would address multiple questions across unprecedented scales.	Both groups' estimates were for £20-40 million pa over 10 years. (N.B. one specified a minimum of £30 M)	It was proposed that this would need to open ended, with the main funding being for data and infrastructure (co-ordination / management). Large-scale manipulations proposed to be costed outside of NERC.
Scope for inter-national linkages	The groups proposed linkages with LifeWatch and ANAEE. The results would have relevance for the WFD.	Good – would complement EU & US initiatives, especially if standardised measures collected and data protocols.	Good – would link with ANAEE, experimentation could complement requirements for EU frameworks.	Good – would link with international modelling / data and observation networks (inc LifeWatch & ANAEE). Links to climate, agricultural production, hydrology, etc models.
Main advantages	Logistically easy to acquire deep, but narrow, knowledge of one site, through manipulations. Initial data focus would ensure that the question evolves from the community and drives the research – but avoids undue influence by 'vested interests'.	Experimental design – replication, nested sites exploiting existing gradients. Leverage of additional resources from stakeholders.	Experimental design feasible Leverage of other funding & sites Cross ecosystem comparisons Gradients and design will yield strong conclusions Inclusive of many researchers & stakeholders	Combines existing observations with opportunity for curiosity -led, innovative experimental design. Flexibility.
Uniqueness	One group proposed that a unique habitat that	Between & within site comparisons, integration	Representative-ness Scale easily	National scale understanding and

	Single site	Multiple sites: few (4-6)	Multiple sites: many (30-50)	Unconstrained
	could be the focus of such a study in the UK is heather-dominated uplands. The other groups indicated that there was nothing unique about this approach.	of multivariate data. Value for money. Landscape scale relevance.	incorporated. Statistical power Coherent signals - fundamental truths or errors	relevance of analyses.
Limitations	Site choice is central to success. The time frame might be too short. The results would be dependent on pseudo replicates and would not have general relevance.	Site identification. Management of manipulations. Insufficient time for clear signals. Sample size / replication limitations.	Costs of or control over manipulations, if bringing in other stakeholders. Probably only shallow study possible.	Insufficient money for the number of sites Effort could be spread too thin.
How limitations would be overcome	Both groups recommended comparing the site with other sites. The exploitation of gradients within the site might increase the relevance of the results to some degree.	Involve good statistical team from outset. Appoint a good project leader. Collaborate /integrate with other initiatives (inc international). Incorporate natural gradients and measures of natural variation.	Control of sites. Nested experimental design will give greater depth, as would fewer sites.	International collaboration. Leverage of external funds to undertake policy relevant manipulations.

- **The single site approach:** The single site approach resulted in relatively few written comments from both groups. It was not supported by either group. This is largely because it was seen to be limited, both in terms of replication and the range of ecosystems that could be incorporated, and hence it would not have UK wide representative-ness.

- **The 4-6 multi-site approach:** The 4-6 multi-site approach stimulated a large number of comments from both groups that discussed it. One group was very enthusiastic about the ability to link this with ongoing agri-environment schemes and that this would have direct policy relevance and provide opportunities to leverage additional support. The other group was less enthusiastic due to concerns over control of any manipulations / treatments. Both groups recognised the strengths of the approach and listed several options to overcome all of the perceived limitations.

- **The 30-50 multi-site approach:** The 30-50 multi-site approach stimulated an intermediate number of written comments. It was noted that this approach provides an opportunity to incorporate replication and so build in UK wide relevance but would be expensive if implemented in full. As with the 4-6 multi-site approach concerns were raised over control of sites and manipulations / treatments.

- **The unconstrained approach:** The approach developed had at its heart the assertion that the UK is a biodiversity data rich country with much of this being provided by a range of disparate (research community - voluntary organisations) bodies. The aim would be to make this existing system work better through a strong investment in data, data management and data integration. This in turn would support a powerful modelling framework to encourage and enable research across multiple nested scales. Manipulation of sites would be '*costed outside of NERC(?)*'.

4.4 **Discussion**: A straw poll of participants showed that no one favoured the single site approach; there was a minimal level of support for the 30-50 multi-site approach (n=3); there was some support for the 4-6 multi-site approach (n=13) and the remaining (n=ca 30) participants favoured the approach promoted by the 'unconstrained group'.

5 Final Brainstorming

5.1 **Feedback at the end of the day:** The participants in eight groups of no more than eight participants discussed the day and gave verbal feedback. There were several widely supported messages:

- The initiative should be driven by the science rather than the delivery mechanism.
- Despite the progress that had been made on the day, more work would be needed to identify the highest priority over-arching question(s) or research framework.
- Once the question has been identified an expert panel should consider the best experimental design to address that/those question(s).

5.2 One participant commented that the workshop participants represented different sectors of the UK biodiversity research community, who are not used to working together because they typically ask questions in different ways and use different experimental approaches.

5.3 **'… things NERC should consider'**: All participants were asked to identify 'things NERC should consider'. These have been collated under four areas, the first three of which centre on identifying an appropriate research area for the action:

- *Identifying 'the' question* (n=12). These comments reiterated the feedback from the third session (see 5.1), i.e. that the overarching research question needed additional scoping, and that the question would determine the approach adopted.

- *Policy relevance* (n=5). The focus of any action should have societal / policy relevance.

- *Constructive suggestions / comments* (n=18). Suggestions for consideration in developing a large-scale action included: the need to work across spatial and temporal scales; the need for this to deliver real advances in understanding in five years; the effects of environmental changes, e.g. climate and habitat connectivity on biodiversity, should be the focus of the action; relevant research on-going in non-NERC Institutes should be considered, and the goals would need to be considered carefully to match the budget available and timescale proposed.

- *Other comments* (n=3). A small number of participants suggested that the proposed funds should be redirect to responsive mode.

5.4 The main conclusions and outcomes of the 16 December workshop are summarised in the introductory Section Summary

Section 4: Annexes – provided as separate pdf files

1 ANNEX 1: Workshop attendees

2 ANNEX 2: Delegate pack – marine workshop (15th Dec)

Includes introductory letter, briefing note and evidence collected from providers of current ecosystem scale approaches that was provided to workshop attendees prior to the workshops to provide a starting point for discussions

3 ANNEX 3: Delegate pack – terrestrial and freshwater workshop (16th Dec)

Includes introductory letter, briefing note and evidence collected from providers of current ecosystem scale approaches that was provided to workshop attendees prior to the workshops to provide a starting point for discussions

4 ANNEX 4: Pre-collected questions

Prior to the workshops, participants were asked to provide questions relating to a large-scale study of ecosystem sustainability. These were collated into three areas (i) Understanding critical processes and functions, (ii) Understanding trends and implications and (iii) Developing management solutions. These questions were used at the workshops as a starting point for discussion.