



Introduction to Living with Environmental Change Pilot Review Reports

When establishing a major research programme such as 'Living with Environmental Change' (LWEC) with such clear relevance to the science-policy interface there is a need for identification of priority policy areas, reflection on the current baseline of evidence, exposure of knowledge gaps and hence the design of programmes of research. This need is now addressed, across many sectors, using a formal evidence-based approach. This approach is perhaps most familiar in the health services, social services and education but is now being actively used in environmental management.

The core methodology in evidence-based practice is the systematic review, involving a rigorous and objective assessment of the best available evidence on a question of concern to policy or practice. However, a systematic review is a significant investment of time and resources and, with the limited resources available it is probably not efficient to launch straight into a programme of systematic reviews without some prior estimation of their value. Consequently a funding scheme for pilot reviews was established.

The Pilot Reviews offer the opportunity to scope academic literature and public reports published on specific questions. It was intended that the reports of the reviews would: outline the existing data and highlight the trends and gaps in knowledge, contain details of the search strategy employed, provide critical appraisal of the quality of the sample of the studies and may produce a draft protocol for a full systematic review. It is hoped that the reports will provide a resource for stakeholders and follow the guidelines given for scoping studies on systematic reviews, which can be accessed at:
<http://www.environmentalevidence.org/Authors.htm>

The LWEC partners agreed six strategic objectives that will inform progress towards the design of the programmes of work that will make up LWEC. The first scheme funded the following reports and was in support of **LWEC Objective B - To manage ecosystem services for human well-being and to protect the natural environment in a changing world**. The LWEC partners were keen to support activities that cover both aspects of Objective B. These include the assessment of links and feedbacks between the natural environment, ecosystem services and human well-being; how these might continue to develop within environmental limits in the face of major environmental change; and how decision-making and local and national planning can take account of these links and feedbacks to help in the development of new social, environmental and economic opportunities. Each of the six reports that form the output of this first scheme provides an initial characterisation of the evidence base on their chosen subjects. This provides a

resource with which to judge the potential value of full systematic reviews and the likely need for primary research.

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Assessing the resilience of ecosystem service delivery: Can the Earth bounce back?

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Executive Summary

1. In March 2009, the University of Liverpool were commissioned to undertake a pilot study under the auspices of NERC's Living with Environmental Change Objective B, where the aim is to fund research that will "underpin our ability to manage ecosystems for human well-being and protect the natural environment as the environment changes". The pilot study would scope the potential for carrying out full Systematic Reviews on issues related to the resilience of ecosystems and the services they deliver.
2. Systematic Review (SR) is a tool that can be used to explore patterns in effect size across multiple studies to draw out broad patterns on sometimes complex issues. SRs were originally used in the medical and health sciences and their potential for tackling ecological/conservation issues has only been realised in recent years (Pullin & Knight, 2001) and is still being developed (Pullin & Stewart, 2006).
3. This pilot review covered the initial scoping phases of a SR and was used to:
 - (a) identify trends in data availability on the major search terms across different ecosystems;
 - (b) highlight gaps in our knowledge base;
 - (c) identify and prioritise questions that would be suitable for full SR; and
 - (d) make recommendations for the refinement of the search strategy and overall SR methodology so that it is suitable to tackle such questions.
4. Six key ecological questions were used to structure the pilot review. The availability of scientific information to answer these questions across a wide range of ecosystem classes (Deep Sea, Shelf Sea, Lakes and Forests) was explored. Issues with terminology were apparent from the outset. Potential search terms to address these issues of resistance and resilience in relation to ecosystem service delivery were chosen in consultation with independent experts (within the limits of the pilot study).
5. Available peer-reviewed scientific research increased from the Deep Sea through Shelf Sea to Lake and then Forest ecosystems. Information on the provisioning ecosystem service categories (e.g. food) were the most numerous. There is much less information on supporting services and considerably less on regulating ecosystem services. Observational, field data dominated the available, relevant material, especially in the marine and freshwater classes. Experimental studies were the least numerous. The "Quality of Evidence" of the research available for meta-analysis in the marine and freshwater was generally classified in a lower range i.e. medium (Category II) due to the inherent difficulties in performing experimental studies in aquatic environments. The terrestrial class scored higher in terms of "Quality of Evidence."
6. Gaps were revealed by the scoping study, largely falling into two categories: those that were due to real knowledge or data gaps, and those that were due to terminology issues (i.e. potentially not real gaps). Data gaps include those related to the paucity of studies in the deep sea, and more generally

7. Terminology issues were identified at several stages throughout the pilot study. In essence, it is difficult to capture information on a subject that covers some very broad concepts where practitioners use varied definitions and terms to mean the same things. In ecology, it is well known that there is confusion on the use of the term resilience (and resistance), and although there are published lists of ecosystem services, the terms required to actually capture studies relevant to particular ecosystem services would need to be very specific and different for different ecosystems. We have provided some detailed lists of relevant terms following consultation with a group of experts from the different disciplines.
8. Questions suitable for Systematic Review were identified along with a longer list of related issues that may need to be tackled before it is possible to complete some SRs. Recommendations for SRs in this area include the need to invest time in the early stages on defining and consulting on search terms, and selecting common metrics that could be used to measure effect size from potentially very different source data. Although there will undoubtedly need to be some real investment in the early stages of any SR on any topic related to resilience of ecosystems and their service delivery, it is clear that there is great potential here, and it is now time to explore this tool in helping to bridge the gap between theory and practice on a complex issue.

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1. Background

There can be little doubt that human activities have impacted on the Earth's ecosystems. In the case of 'western' agricultural systems the delivery of one major ecosystem service, food production, has been achieved by large-scale ecosystem substitution. In many less economically-developed areas, and in freshwater and marine systems, human impacts have also altered the delivery of ecosystem services. With a growing population and increasing per capita energy demands the global ecosystem will be required to deliver increased food production, freshwater, energy and waste assimilation. However, society also desires that the ecosystem maintains key levels of biodiversity and protects aspects of cultural/social importance. Thus the overarching challenge is to develop management schemes that deliver sustainable environmental use, so that 'we live within our means.' Understanding how human use of ecosystem services places pressure on the system and in particular, how the system responds to changes in the pressure is, therefore, essential in underpinning sustainable management.

At the same time, we are living in an environment that is changing, and this in itself adds complexity in terms of making predictions about the future resilience of our ecosystems and the services they deliver. In the face of climate change, decadal and shorter scale climate variability is predicted to increase, as is the intensity and frequency of extreme weather events (Easterling *et al.*, 2000; Clark, 2006) with well-described changes in temperature and precipitation adding further challenges (IPCC, 2007). Environmental change alters ecosystem properties through effects on the physical and biochemical environment and through direct effects on the biology of individuals and populations, with knock-on consequences for species and communities. Ecosystem functions, biological and system properties or processes of ecosystems are thus affected by environmental change and the provision of ecosystem services is dependant on ecosystem functions (Costanza *et al.*, 1997). Since ecosystem resilience is determined by the properties of biological components and the environment they live in (Webster *et al.*, 1975; Leps *et al.*, 1982, Pimm, 1984; 1991; Beisner *et al.*, 2003), and the resilience of ecosystem service delivery is also directly linked to these properties, we need to explore the variation in resilience seen given different scenarios of change in these properties. This would allow us to better manage for change in the future.

Systematic Review (SR) is a tool that could be used to tackle some of these issues, whereby existing data can be used to explore patterns in effect size where change in some property of resilience is measured against known levels of environmental change or human perturbation (or both) (Pullin & Knight, 2001; Pullin & Stewart, 2006). Undoubtedly there will be future scenarios for which we will be unable to predict ecosystem response, but using existing data we can at least increase our understanding of variation in resilience known to date, and use historic scenarios of change to explore possible response trajectories.

Our aim in this pilot review is to critically assess the availability of information that could form the basis of a subsequent SR of key questions that underpin our ability to manage ecosystems for human well-being and protect the natural environment as the environment changes (LWEC Objective B). Here we follow the definitions of SR as outlined by Newton *et al.* (2009) and Pullin & Stewart (2006). This pilot review covers the initial scoping phases of a SR and will be used to: (1) identify trends in

data availability on the major search terms across different ecosystems; (2) highlight gaps in our knowledge base; (3) identify and prioritise questions that would be suitable for full SR; and (4) make recommendations for the refinement of the search strategy and overall SR methodology so that it is suitable to tackle such questions.

2. Methodology

Six key ecological questions were used to structure the pilot review:

1. How do resistance and resilience vary across ecosystems subject to different levels of anthropogenic and natural perturbation?
2. Are there patterns of similarity in response to perturbations across broad ecosystem classes and how do different types of system (open *vs* closed, diverse *vs* species poor, physically harsh *vs* benign) alter these dynamics?
3. How do resistance and resilience vary with increasing departure from the initial state (i.e. increasing perturbation)?
4. How does the drawing down of an ecosystem service (e.g. food provision) alter the dynamics of ecosystems against a background of natural environmental change?
5. Are there alternative states and do these differ in some or many aspects of ecosystem service delivery?
6. How do systems with different histories of exploitation vary in their ability to continue to deliver a range of ecosystem services (see list in Table 2.1)?

We explored the availability of information to answer these questions across a wide range of ecosystem classes, initially aiming to cover those that were lightly impacted (offshore/oceanic) to systems impacted heavily but not subjected to major structural change (coastal seas, some lakes, ‘virgin’ forest and other areas managed traditionally by indigenous people) through to areas subject to large-scale and long-term habitat substitutions (agri- and urban landscapes). Unfortunately, due to the timescale of this pilot review project it was not possible to cover all the intended ecosystem types, but we managed to carry out data analysis on four of the six classes: deep sea, shelf sea, lakes and forests.

This study systematically reviewed available information using the combinations of the search terms described in Section 2.2 below, where the Millennium Ecosystem Assessment categories of ecosystem service (Table 2.1; UN, 2005) were used in relation to questions 4-6. A detailed description of the search strategy is given in Section 2.2, where the initial stage identified search terms required to highlight relevant papers for the key questions across the different ecosystem classes.

A major issue that makes the Systematic Review of the questions described above difficult, is that the terminology used by practitioners from the different fields (even within the same field) to describe the same terms can vary widely. In Section 2.1 below we explore this issue briefly and define how we interpreted the key terms used in the search strategy. In Section 4 of this report, the issue of terminology is discussed further in terms of its implications on gaps found in the searches, and how we would tackle this issue in a full-scale SR.

Table 2.1: Ecosystem service categories as taken from the Millennium Ecosystem Assessment (UN, 2005).

Ecosystem service
Supporting services
Nutrient cycling
Oxygen production
Soil formation
Provisioning services
Food
Fibre
Fuel
Water
Regulating services
Climate regulation
Water purification
Flood protection
Cultural services
Education
Recreation
Aesthetic value

2.1 Terminology issues

2.1.1 Resilience and resistance

A key term used in the questions posed around the ability of any ecosystem to bounce back is resilience. There has been a great deal of confusion about this term because it has been used differently by different authors (Gunderson, 2000). First defined by Holling (1973), it has since been used to describe both the ability of a system to maintain its structure and pattern of behaviour in the presence of stress (similar to Holling's (1973) definition), and its ability to recover from disturbances/stress (e.g. Pimm, 1984).

Here we define resilience following the second use above, as the ability of the system (population, community, ecosystem) to return to normal after a disturbance or stress period; this is consistent with the definitions used by Webster *et al.* (1975), Leps *et al.* (1982), and Pimm (1984, 1991), and is sometimes referred to as engineering resilience. Essentially, the greater the resilience of an ecosystem, the shorter its recovery or return time (Tr) following a perturbation; resilience is therefore measured as $1/Tr$. In setting search terms for resilience we recognised that in many cases it may simply be referred to as recovery time and used this as well.

We describe the original interpretation by Holling (1973) – the ability of a system to maintain its structure and pattern of behaviour in the presence of stress (Folke *et al.*, 2004; Ludwig *et al.*, 2007) as the resistance of the system. We separately searched on resistance to aim for studies that had measured that ability of a system to withstand stress/disturbance. We consider it important to distinguish the terms resilience and resistance separately, since they can both independently affect the ability of a system to bounce back given different levels of human perturbation and environmental change.

In the literature related to the topic of resilience and resistance, the basins of attraction concepts are useful to envisage these different aspects (see Scheffer and Carpenter, 2001, 2003; Beisner *et al.*, 2003; Folke *et al.*, 2004). Here, different configurations of state variables (e.g. abundance, size structure of a population) can exist within the same environment or landscape (Figure 2.1.1). For example, the resilience of a community can be described as being related to the characteristics of the basin in terms of how they act to retain the system in its present state (see Figure 2.1.1). Essentially, the energy required to shift a community out of one basin into another state relates to the ability of the system to maintain its structure and behaviour (we call this resistance), whilst the area and steepness of the basin relate to the recovery potential of the community if it is shifted within it or even outside of it (we call this resilience) (see examples in Figure 2.1.1).

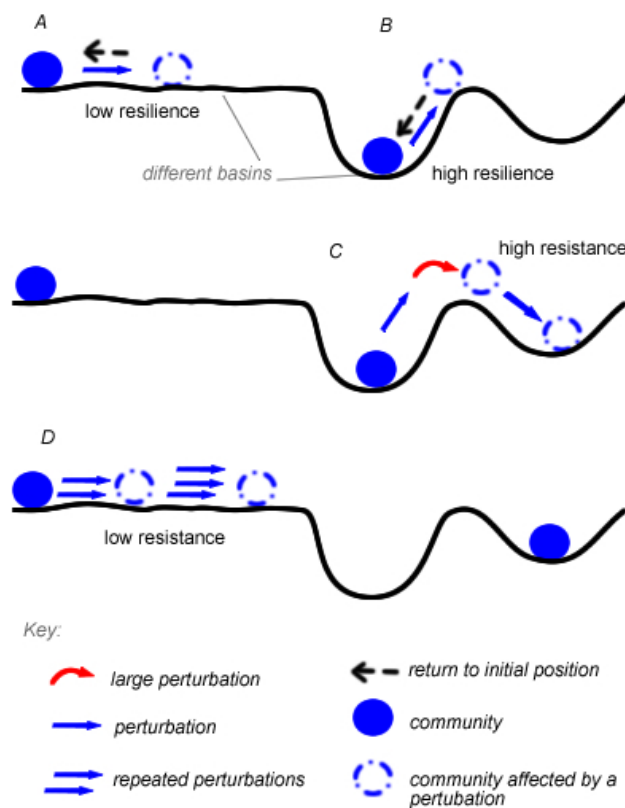


Figure 2.1.1: Schematic of the change(s) in a community based on the system structure (basins). A is less likely than B to recover, especially when subject to repeated perturbations (D). A community in a steeper basin (B) requires larger perturbation to induce a change (C) i.e. movement to another basin (after Beisner *et al.*, 2003; Begon *et al.*, 1990).

In framing the SR questions in Section 4.3 of this report we consider whether the evidence-base described in Section 3 could provide the sorts of study data required to tackle questions on resilience and resistance, as we have defined them here.

2.1.2 Alternative stable states

Conceptually, when discussing the presence of different basins of attraction there is an inherent acceptance of the existence of alternate stable states. When a community is subject to a perturbation and moves to an alternate state, whether or not it returns to the initial state when the perturbation ceases, depends on the structure of the basin in which it is currently residing (Figure 2.1.2 B). If the parameters which govern the state variables' interactions and dynamics change (e.g. environmental changes in climate drivers) this can result in new locations of the alternate stable states (basins) within the landscape (Figure 2.1.2.C).

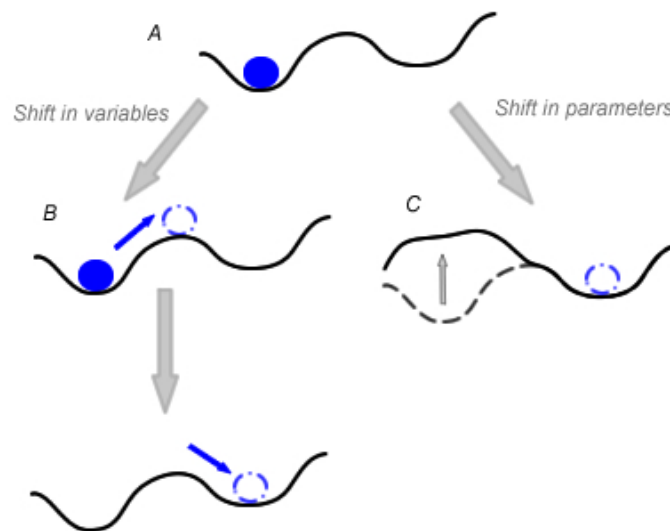


Figure 2.1.2: A → B. A community when subject to a large perturbation moves into a basin of attraction which is stable due to resistance and resilience characteristics. A → C, The parameters which define the landscape change resulting in movement of the community [key as figure 2.1.1.] Beisner *et al.* (2003).

In terms of the interests of this pilot review, we have mentioned alternative states in Question 5, because we recognise that it is often attractive to manage to a particular successional stage (which could be termed a state), but we do not know enough about the differences in these alternative states in terms of differences at the level of ecological functioning and provision of ecosystem services. Also we do not often know enough about the different levels of resilience and resistance of ecosystems given different states, and this is also important in terms of managing change. We used search terms on alternative stable states specifically, but recognise that in some studies, shifts in ecosystem or community structure may have been described without the use of these specific terms. In such cases, regime shift may have been used and we have also searched on this term although we do not consider these two phrases to necessarily be equivalent.

2.1.3 Ecosystem services

Ecosystem services have been defined by the Millennium Ecosystem Assessment (UN, 2005) as “the benefits people obtain from ecosystems. These include

provisioning services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services, such as nutrient cycling, that maintain the conditions for life on Earth”. Some terms for types of ecosystem function are used interchangeably in the literature with types of ‘ecosystem services’ (e.g. nutrient recycling, productivity and food provision) (UN, 2005; Frid et al. 2008). The term ‘services’ is more specifically used in environmental economics (Costanza et al, 1997).

In searching for papers covering any one of the ecosystem services, we used the terms set out by the categories given in the Millennium Ecosystem Assessment (see Table 2.1), and searched for these in conjunction with particular aspects of ecosystem resilience and human use. We are aware that in many cases, studies may have been carried out where aspects that would be covered by a broad term such as recreational benefits, will have been measured, but not recorded in association with this term. For example, within the initial database searches performed on provisioning service search terms ‘food’ and ‘fuel’ returned few relevant references, thus more specific terms such as ‘fish’/‘fisheries’ and ‘timber’ were used for the appropriate ecosystem class. We comment on the need to widen the search terms to pick up such literature in a full scale Systematic Review related to this in Section 4 of this report.

2.2 The review strategy

2.2.1 Exploration of search terms

Pullin and Stewart (2006) identify the issue of balancing sensitivity and specificity in formulating strings of search terms for a SR. In order to hone search term initial searches on key words were carried out to explore the volume of returns generated as individual searches. In this initial exploration we focused on terms at the ecosystem, community and habitat level, identifying cross discipline terms (cdt) and terms which would need to be constrained with Boolean search strings in the next level of searching (section 2.2.2 High Level). The summary of the volume of papers returned in this initial search is presented in Appendix 1. The terms resistance and resilience need to be combined with other search terms to yield relevant results. Additionally generic disturbance terms, such as natural or anthropogenic perturbation, when searched individually, resulted in a large number of returns but when combined with resistance or resilience terms few results were identified. Thus a combination of resistance or resilience, with specific perturbation terms (e.g. pollution), would be needed to best scope the available research.

2.2.2 High level search

Search terms relating to resistance and resilience and anthropogenic and non-anthropogenic (natural) perturbations (Table 2.2.2.1), in addition to the ecosystem service terms, were identified to address the six key ecological questions using electronic internet databases (e.g. Web of Science). These search terms were ratified by experts.

For each Ecosystem Class (I) searches were carried out on the bolded Ecosystem Classes as shown in Table 2.2.2.1.

Table 2.2.2.1: Terms for different ecosystem classes under consideration.

Deep Sea	Coastal shelf seas	Lakes & freshwater systems	Natural forests (temperate & tropical)	<i>Agro-ecosystems Tropical & temperate</i>	<i>Semi-natural cultural landscapes</i>
“Deep sea” “Sea mounts”	“shelf sea*” “Coastal shelf sea*”	Lake “Freshwater systems” <i>Rivers</i> Streams	“natural forest” <i>Woodland</i> Scrubs	<i>Farm</i> <i>Field</i>	<i>Prairie</i> <i>Steppe</i> <i>Savannah</i> <i>Moor</i> <i>grassland</i>

(alternate terms are supplied for future analyses).

The following Boolean search(es) (Table 2.2.2.1 with Table 2.2.2.2) were carried out for each of the ecosystem classes considered, where the exact terms used are listed in Table 2.2.2.3 (A to D).

1) I (Table 2.2.2.1) AND combinations shown in Table 2.2.2.2

Table 2.2.2.2: Decision tree to optimise search terms permutations

II		III		IV		V
Ecosystem state	AND	Anthropogenic perturbation	OR	Natural perturbation	depending on no' returns if: searching II and III / IV = less than 20 returns, utilise: II AND V Greater than 20 returns III/IV AND V	Ecosystem Service categories

Papers returned by the search permutations were listed by first author and then subset for assessment as follows:

- < 35 returns, all references were assessed;
- 35-100 papers returned, 20% were selected randomly to be assessed;
- 100-350 papers returned, 10% were selected randomly to be assessed.

A random number generator was used to determine the papers to be assessed (<http://www.random.org/>). This procedure provided an upper limit of 35 references per search to be further assessed.

2.2.3 High level selection

References returned by search engine searches were assessed according to the seven criteria in Table 2.2.3.1. Criteria 1, 2, and 3 were largely covered within the search terms used as these had been designed to balance sensitivity and specificity, using the procedures described in 2.2.1 and 2.2.2. Some papers were still identified as off-topic

Table 2.2.2.3: Search terms used in the High Level search

A: Ecosystem State terms

Boolean identifier	Ecosystem state		
II	Resistance	Resilience	Changing state
	Resistance	Resilience	Alternat* stable state
	Sensitivity	Recovery time	Regime shift

B: Anthropogenic perturbation terms

Boolean identifier	Anthropogenic perturbations	
III	Marine/Freshwater	Terrestrial
	Fishing/fisheries	Pollution
	Pollution	Agriculture
	Fertili*ation	Forestry
	Acidification	Fertili*ation
		Flooding
		Acidification
		Invasive species.

C: Natural perturbation terms

Boolean identifier	Natural perturbations *	
IV	Marine/Freshwater	Terrestrial
	Temperature change	Temperature change
	Temperature variability	Temperature variability
	Temperature trends	Temperature trends
	Climate change	Climate change
	Climate variability	Climate variability
		Grazing
		Fire

* can be natural and/or anthropogenically driven

D: Ecosystem service terms

Boolean identifier	Ecosystem services			
IV	Supporting	Provisioning	Regulating	Cultural
	Nutrient cycling	Food/fish/fisheries	Climate regulation	Education
	Oxygen production	Fibre	Water purification	Recreation
	Soil formation	Fuel/timber	Flood protection	Aesthetic value
		Water		

because their subject content was irrelevant (e.g. where the search term I and resistance [II] returned a paper on antibiotic resistance); these papers were not selected for further analysis.

Table 2.2.3.1: Criteria to be applied in the initial high-level selection (Pullin & Stewart, 2006).

Criterion	Criterion description	Yes/No
1	Is information on one of the selected ecosystem classes present?	✓
2	Is there information on search terms related to at least one of the key questions	✓
3	Is there sufficient information on the type of study, modelling, survey, experimental?	✓
4	Is there appropriate statistical rigour (randomization, replications, rigorous analysis)?	✓
5	Is there appropriate meta-data supplied?	✓
6	Would the paper provide information for future meta-analysis? Are raw data or summaries of raw data available?	✓
7	Has the information been peer reviewed? E.G. refereed journal articles, externally examined theses (Masters and PhD, not honours). Reports and conference proceedings will therefore typically be excluded. Raw data sets, that form the basis for peer-reviewed manuscripts, will be accepted.	✓

All others papers were downloaded into an Endnote database and assessed first by reading the abstract (potentially leading to the paper being determined irrelevant) and, if necessary, then the whole paper. This determined if the material presented followed the criteria 4 to 7 (Table 2.2.3.1). Any papers fulfilling all of these criteria were identified as data rich/statistically rigorous experiment-based papers that would be suitable to carry out a Systematic Review (*sensu* Pullin and Stewart, 2006).

During the High Level search, the references were coded to allow the type and quality of research and its relevance to ecosystem resilience and the resilience of ecosystem service delivery to be assessed. Coding included information on whether papers were based on data derived from:

1. experiments (papers presenting results from experiment-treatment based studies),
2. field studies (papers dominated by observational data),
3. modelling (papers where the reported results are based on models),
4. meta analysis (papers reporting formal meta analyses).

Papers which were deemed not relevant at this stage included those that were reviews, conference proceedings, project reports, off topic subjects, or methodological or management advisory notes. These papers were left in the database under a general code that would allow for further mining of the database at a later stage should the SR process be developed to include data from project reports, for example.

In the endnote (Appendix 2) database and the overview Excel file (Appendix 3) additional notes were included for the field, experiment and model papers pertaining to the data type and the main metric measured.

The overview of all the relevant papers identified were assessed to determine (a) a prioritised list of questions that could be addressed through a formal SR, and (b) gaps and uncertainties, leading to the identification of questions where further research may be required.

2.2.4 Final selection

Finally, the experimental papers selected in each ecosystem class which pertained to the resilience and recovery search terms, and fulfilled all the criteria in Table 2.2.3.1, were assessed using the criteria outlined in Table 2.2.4.1.

Table 2.2.4.1: Criteria to formally assess the ‘quality of evidence’ as taken from the hierarchical approach described by Pullin & Knight (2003).

Quality of evidence	
I	Strong evidence obtained from at least one properly designed; randomized controlled trial of appropriate size.
II-1	Evidence from well designed controlled trials without randomization.
II-2	Evidence from a comparison of differences between sites with and without (controls) a desired species or community
II-3	Evidence obtained from multiple time series or from dramatic results in uncontrolled experiments.
III	Opinions of respected authorities based on qualitative field evidence, descriptive studies or reports of expert committees.
IV	Evidence inadequate owing to problems of methodology e.g. sample size, length or comprehensiveness of monitoring, or conflicts of evidence.

2.2.5 Expert Workshop

As part of the scoping study, a workshop (12th May 2009 at the University of Liverpool) was organised with experts invited from various disciplines including ecology (theoretical and applied) with expertise from a wide range of ecosystem classes, ecological economics with relevance to ecosystem service approaches, and different types of analytical approaches (Table 2.2.5.1).

Structured in three sessions around a framework of the scoping study results, the experts attending the workshop discussed:

- Initial exploration of key questions and priorities for systematic review on the resilience of ecosystem service delivery
- Delivery of ecosystem services – what are they? Which are delivered by which ecosystem(s)? What kinds of studies might provide evidence?
- Measuring change in resilience of ecosystems – how is it done? How is this linked to ecosystem service delivery? What kinds of studies might provide evidence?

Thus the experts examined the results of the scoping study, discussed and identified where, and why, gaps in literature were found in the scoping study, and agreed on key

questions that could be tackled in a full SR based on their knowledge. The detailed results of the workshop are incorporated in the discussion section of this report (Section 4) and the workshop agenda is provided as Appendix 4.

Table 2.2.5.1: Attendees at the LWEC/University of Liverpool Expert Workshop.

Expert	Affiliation	Expertise
Mr. Salman Hussein	Scottish Agricultural College, Edinburgh	Ecological economics, ecosystem services (marine)
Dr. Pushpam Kumar	University of Liverpool	Economics, MEA author, ecosystem services (terrestrial)
Prof Robert Marrs	University of Liverpool	Applied plant biology; ecosystem approach.
Dr. Martin Mortimer	University of Liverpool	Plant population biologist; development and application of agro-ecology in tropical and temperate agro-ecosystems.
Dr. Andy Plater	University of Liverpool	Lakes and coastal ecosystems; geomorphology; Holocene comparisons
Dr. Leonie Robinson	University of Liverpool	Applied marine ecology; benthic ecology; fishing effects
Dr. Matt Spencer	University of Liverpool	Quantitative biology; system modelling; freshwater and marine
Dr. Catherine L. Scott	University of Liverpool	Applied marine ecology; ecosystem approach
Dr. Paul Somerfield	Plymouth Marine Laboratory	Ecology of marine communities, disturbance responses and anthropogenic impacts; nonparametric multivariate methods for the analysis of community data.
Dr. Tom Webb	Sheffield University	Macroecology – what determines the distribution and abundance of species at very large scales; terrestrial and marine
Dr. Fred Worrel	University of Durham	Agricultural pollution, especially pesticide and nitrate pollution; carbon biogeochemistry especially of peats and rivers; contaminant hydrology

3. Results

3.1 High level overview

3.3.1 Summary analysis (total numbers)

1168 references were returned based on the search strings specified in Section 2.2.2 of this report. The endnote library (Appendix 2) does, however, contain 1229 downloaded references. Extra references were included as during the exploratory phase search strings were performed which were subsequently not used in all ecosystem classes (nor are reported here), but information may prove useful at a later date.

The number of returns per string was variable ranging from zero to thousands, but as a general pattern, available information increased from the Deep Sea through Shelf to Lake and Forest¹ ecosystems (Appendix 1 and 2 (Table 3.1.1.1)).

Table 3.1.1.1: Number of references returned (including reference subsequently deemed not relevant).

	Ecosystem class	Number of references
A	Deep sea	57
B	Shelf sea	209
C	Lake	413
D	Forest	742
E	Replicates across classes	253
A+B+C+D-E	Total	1168

253 references were identified as ‘repeats’ i.e. came up in multiple searches (Table 3.1.1.2). Of these, 16 were identified as ‘repeats’ with an incidence of three or more, and of those, 62.5% were review documents (and are not considered in section 3.1.2.).

Table 3.1.1.2: Matrix of ‘repeat’ returns.

	Deep Sea	Shelf	Lake	Forest
Deep Sea	11			
Shelf	9	21		
Lake		2	64	
Forest		1	3	142

¹ Qualifier: the number of returns from a search string subsequently generates different research strings through the decision tree (see methods) e.g. Deep Sea AND resistance AND pollution generated a small number of returns therefore later search strings looked at Deep Sea AND ecosystem service (e.g. nutrient cycling) rather than Deep Sea AND resistance AND Nutrient Cycling.

The highest number of crossovers was between the Deep Sea and the Shelf Sea ecosystem classes. This mainly highlights that there is less of a discrete separation between the Deep Sea and Shelf Sea compared to the other considered ecosystem classes. The number of repeats increased within each class, from Deep Sea to Forest, due to the increased number of references returned in subsequent ecosystem class searches.

3.1.2 Overview analysis (multiples considered)

In the patterns described below, identified references are only identified and described once (i.e. no double counting of the identified repeats). Results now include the consideration of multipliers dependant upon the number of returns, where applicable. For example, “Deep Sea” AND “Fisheries” searches yielded a total of 208 references, therefore a sub-sample of 21 references was assessed and a 10x multiplier applied to the results. Papers identified as meta-analyses or not relevant (e.g. off topic) are not described here.

A. Deep Sea

Overall, the Deep Sea class was data poor compared to other ecosystem classes (but comparable to Shelf Sea in terms of experiment based research). Of the low number of papers returned (64 in total; breakdown given in Figure 3.1.2.1) these were dominated by observational (field study) papers which were predominantly about subjects related to ecosystem service delivery from the deep sea.

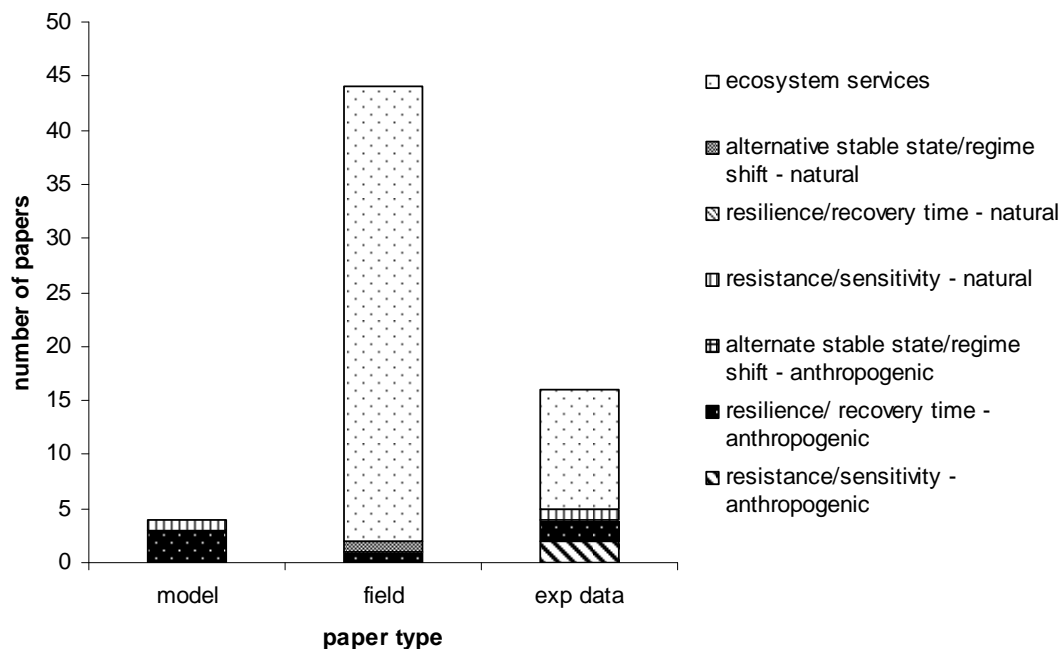


Figure 3.1.2.1: Deep Sea: Distribution of paper types based on broad search terms, where: ‘Ecosystem services’ are those listed in Table 2.2.2.3, ‘Anthropogenic’ terms are those perturbations listed in Table 2.2.2.3, and ‘Natural’ terms are those perturbations listed in Table 2.2.2.3.

B. Shelf Sea

Similar to deep sea papers, the results were dominated by observational papers linked with the ecosystem service category (Figure 3.1.2.2). Modelling papers were dominated by existing meta-analyses and food web ecosystem level research. Overall there were around 7 times as many relevant papers available (467 in total) when compared with Deep Sea searches.

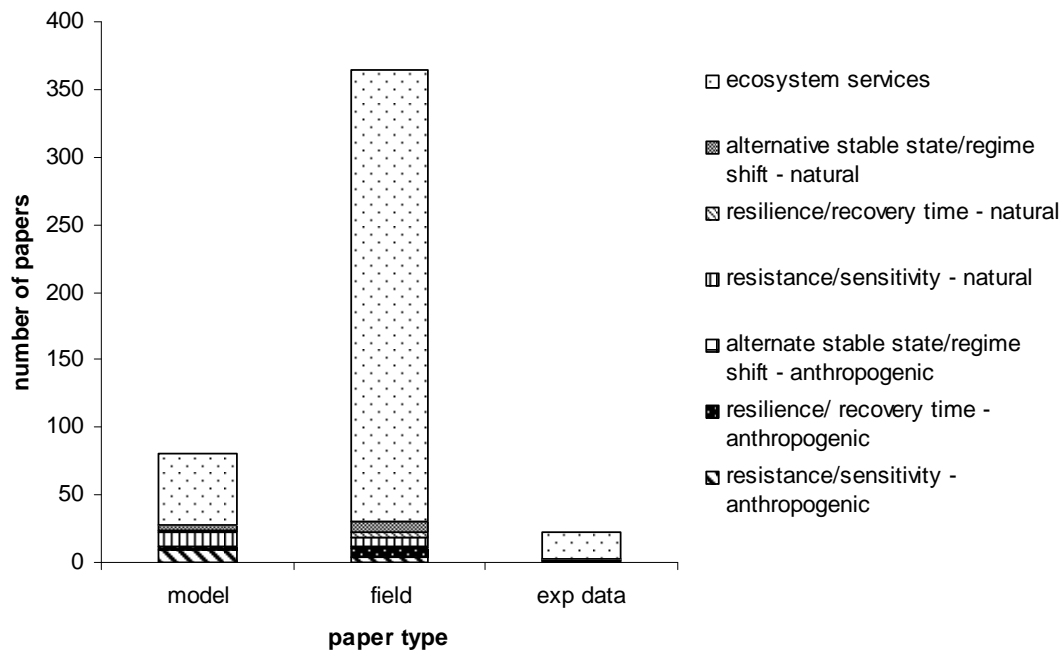


Figure 3.1.2.2. Shelf Sea: Distribution of paper types based on broad search terms, where: ‘Ecosystem services’ are those listed in Table 2.2.2.3, ‘Anthropogenic’ terms are those perturbations listed in Table 2.2.2.3, and ‘Natural’ terms are those perturbations listed in Table 2.2.2.3.

C. Lake

The knowledge base for lake-based studies increased relative to the marine systems in the freshwater ecosystem class (Figure 3.1.2.3; a total of 687 papers compared to 531 for both marine). The results were also dominated by field study-observation papers.

Various anthropogenic search terms were investigated (Table 2.2.2.3) within the lake ecosystem class [I], the effects of acidification[III] and eutrophication[III] with respect to the resistance/sensitivity ecosystem state terms[II] provided the highest amount of experimental and field data.

In the natural drivers’ assessment, the research available on climate change and climate variability yielded the highest amount of field and modelled data.

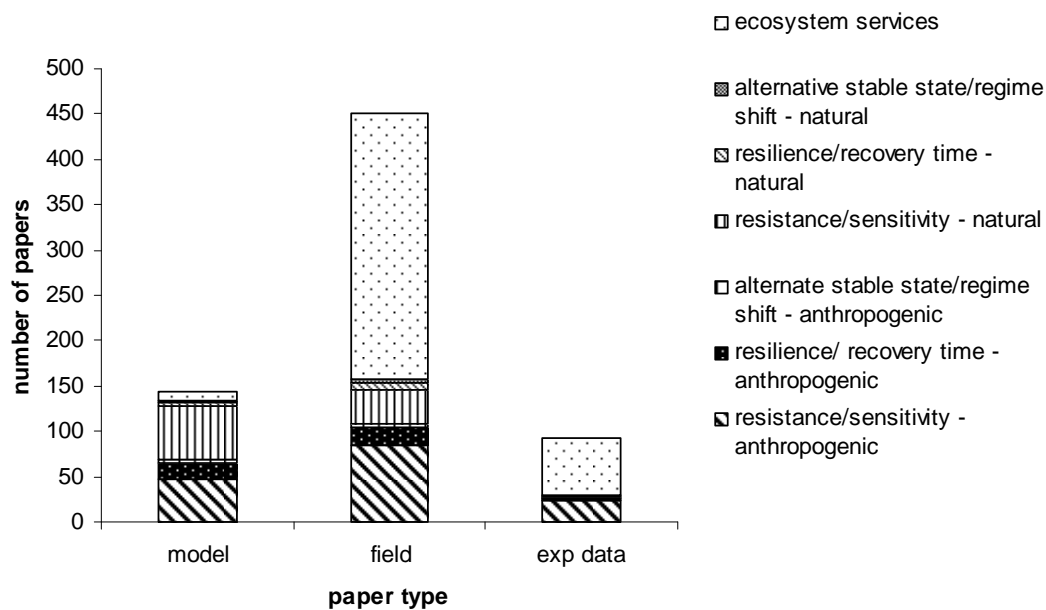


Figure 3.1.2.3. Lake: Distribution of paper types based on broad search terms, where: ‘Ecosystem services’ are those listed in Table 2.2.2.3, ‘Anthropogenic’ terms are those perturbations listed in Table 2.2.2.3, and ‘Natural’ terms are those perturbations listed in Table 2.2.2.3.

D. Forest

More papers were available pertaining to the forest ecosystem class compared to any of the other ecosystem classes (Figure 3.1.2.4). Information available on experiment-based papers was less numerous than the other two paper categories, but unlike the other classes, model and field-based papers were equally numerous.

The papers returned from searches on ecosystem services appeared lower in terms of their proportion of overall returns than was found for the other ecosystem classes. However, this is an artefact of the search strategy developed in Section 2.2.1.2, as specific search-string options were based on the number of papers returned in an investigation within the ecosystem class (Boolean searches i.e. I and II with III/IV). For the Forest ecosystem class, there were sufficient returns so that search strings with ecosystem state (relating to resistance [II] or resilience [II]) were performed with different anthropogenic [III] or natural [IV] perturbations, with an ecosystem service [V] also included. As such, very specific references were acquired albeit often with low returns. Thus we can better identify how specific ecosystem services are affected by perturbations, however, with a low sample size (see section 3.1.3.D). Clearly, in a full-scale SR it would be possible to undertake less specific and more sensitive searches to generate more hits on ecosystem services.

Due to the greater number of research papers produced, specific research on the effects of natural [IV] and anthropogenic [III] drivers with reference to ecosystem state terms was also possible. Research into the resilience and resistance of forests to fire effects was the most widely reported (field and experimental papers) followed by

research into the effects of pollution. The effects of climate change on forest ecology and biology was the most widely reported natural driver studied.

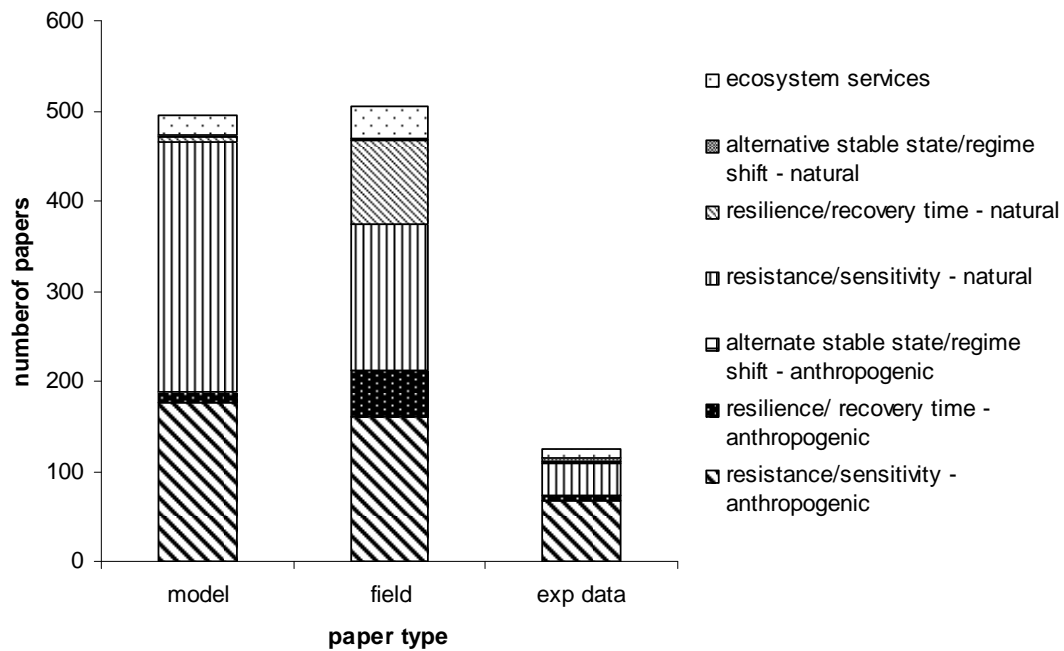


Figure 3.1.2.4. Forest: Distribution of paper types based on broad search terms, where: ‘Ecosystem services’ are those listed in Table 2.2.2.3, ‘Anthropogenic’ terms are those perturbations listed in Table 2.2.2.3, and ‘Natural’ terms are those perturbations listed in Table 2.2.2.3.

3.1.3 Ecosystem service papers

A. Deep Sea

Deep Sea ecosystem service [V] search strings were uncomplicated, simply linked to the ecosystem class [I] under question, and there were few, 64 in total, returns (indicating not much research and/or a poor choice of Deep Sea search terms). Many search strings yielded no results. Overall, search strings resulted in few returns apart from when using Deep Sea AND Fisheries. In terms of peer-reviewed papers, the volume of papers returned decreased from fisheries through oxygen production, nutrient cycling to all others (Figure 3.1.3.1). The identified papers were dominated by observational field studies rather than modelling or experimental work papers (Figure 3.1.2.1).

Of the papers returned on fisheries, three types of study were found:

- Studies on the effects of fishing on biodiversity and community structure (impacts to the wider ecosystem)
- Studies on how the environment affects fish stock species (e.g. through change in food supply – indirect effects)

- Studies on the effect of fishing on commercial species (e.g. stock/population dynamics)

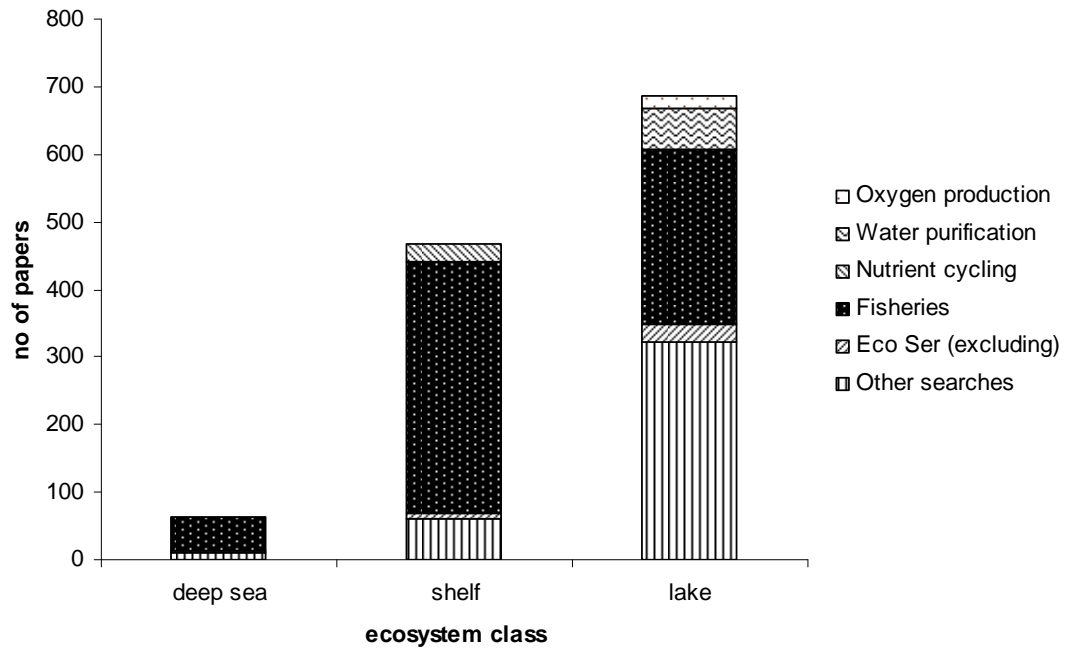


Figure 3.1.3.1: Number of papers relating to different ecosystem service categories for the Deep Sea, Shelf Sea and Lake ecosystem classes.

B. Shelf Sea

Shelf Sea ecosystem service strings were uncomplicated in a similar manner to the Deep Sea searches due to the small number of overall total returns. The cumulative total (487) is greater than the Deep Sea returns, however, individual search strings generally resulted in low returns. Within the shelf sea-based papers, the ecosystem service “fisheries” provided the highest number of returns and the volume of papers returned decreased from fisheries, through nutrient cycling and oxygen production, to all others (Figure 3.1.3.1). There was seven times more fisheries information in the shelf sea class compared to the deep sea system and the types of paper fitted into the same three groups as described for the Deep Sea searches above.

For the studies returned from the nutrient cycling search strings, these were dominated by field studies where observed changes in nutrient levels or cycles were reported from sampled systems, sometimes under different levels of anthropogenic pressure.

C. Lake

The amount of returns for all Lake search term permutations were greater compared to the marine ecosystem classes (687), so that state ecosystem terms (e.g. resistance/sensitivity and resilience [II]) could be investigated against ecosystem service searches [V]. The individual searches of ecosystem services [V] against Lake [I] were also performed to thus allow comparison with the marine and fresh water classes. The fisheries ecosystem service was again the most widely reported ecosystem service. However, Lake fisheries based research, based on volume of

papers, was less than Shelf Sea but five times greater than Deep Sea fisheries information.

Due to the high volume of papers that were available, papers that were specific to sensitivity and resilience linked with fishing were identified. Overall, however, the subsample breakdown was dominated by field observation papers which reported on fish stock population dynamics. *This was identified as a known gap as lake ecosystem or community change experimental data exists as lakes are often used as giant mesocosms for the purpose of experimental manipulations.*

As stated the volume of papers produced relating to ecosystem services was dominated by fisheries, the next most numerous ecosystem service category was water purification where paper returns were a quarter of fisheries linked papers (Figure 3.1.3.1). Similar to the lake fisheries research, the available information was dominated by reports of field data of observed/sampled changes in the ecosystem or community under study. Unlike the lake AND fisheries searched information a small number of papers linked to experimental work were obtained.

D. Forest

The handling of the terrestrial class search strings was different to the aquatic class as the forest class search strings provided the highest volume of papers. Thus complex search strings (I and II and III/IV and V) were possible following the decision tree methodology (Table 2.2.2.1). If uncomplicated strings had been performed a larger volume of papers would have been identified. Relatively speaking a smaller number of papers were identified but specific papers were selected (Figure 3.1.3.2) unlike the aquatic ecosystem classes.

Ecosystem services provided by the forests linked to searches which included recovery time, altered states and regime shifts, albeit there were very low returns on these specific searches.

Given the terrestrial nature of the forest ecosystem class, direct comparison with the aquatic ecosystems was difficult. However the “provisioning” ecosystem services (i.e. water and timber) provided the most information, similar to fisheries as a “provisioning service.” These ecosystem service studies relating to water and timber were dominated by observational/ field studies (Figure 3.1.3.2).

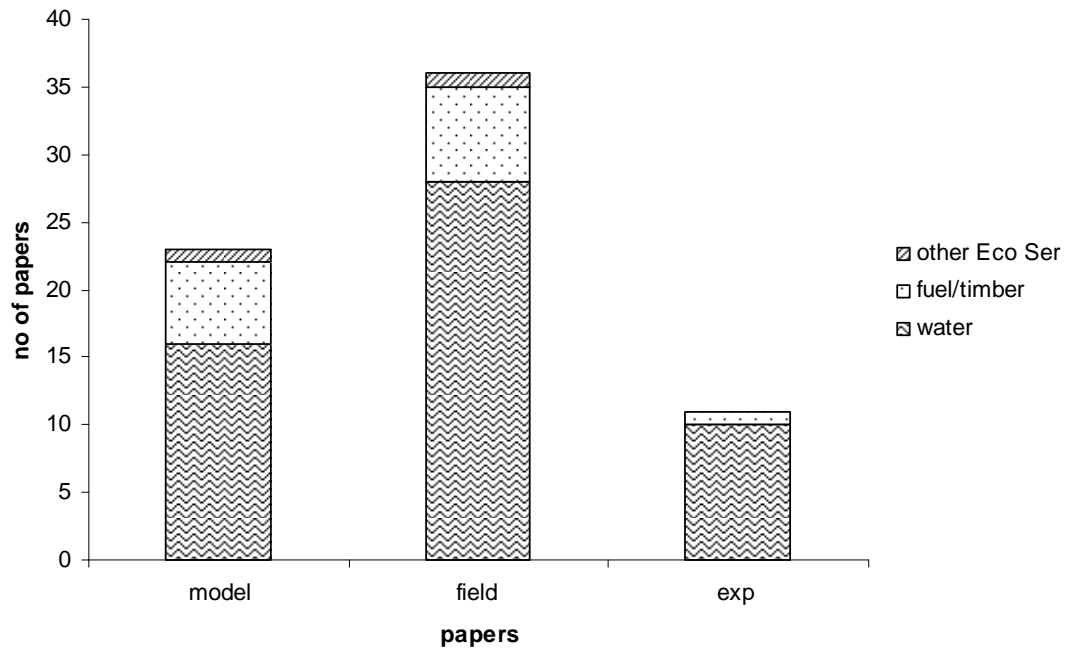


Figure 3.1.3.2: Forest Ecosystem services identified under various ecosystem states.

3.1.4 Final level

The papers based on experimental research were selected for assessment using the criteria in Table 2.2.4.1. While the number of papers assessed was small, marine and freshwater papers scored lower overall on the quality of evidence hierarchy than forest papers (Table 3.1.4.1).

Table 3.1.4.1: Critical assessment of high level papers reporting experimental results linked with both resilience and recovery time search terms. A – anthropogenic pressure (e.g. pollution), N – natural pressure (e.g. climate change, temperature change). Notes give an overview of the types of data available for meta-analysis (n = number of samples; sd – standard deviations; se – standard error).

Ecosystem class	Pressure	Main key word	Quality of evidence code	Notes	Endnote library code	Reference
	A	resilience	II-1	control; without randomisation; treatment; mesocosms, well designed; n, abundance mean (would have to request data).	112	Gallucci <i>et al.</i> (2008)
deep sea	A	recovery time	II-1/2	control; without randomisation; treatment; field-based study/mesocosms ; n, abundance, mean, sd (would have to request data).	119	Guerra-Garcia and Garcia-Gomez (2006)
shelf	A	resilience	II-2	control; without randomisation; field sampling based on existing conditions [distribution of fishing effort]; comparison of different sites; grouped data (would have to request data).	66	Pitcher <i>et al.</i> (2000)
	A	resilience	II-2	no control; without randomisation; field samples; treatment; n (small sample), mean.	417	Vinebrook <i>et al.</i> (2003)
	A	resilience	II-2	no control; without randomisation; field samples; treatment; n (small sample) mean.	539	Bicudo <i>et al.</i> (2007)
	A	resilience	II-1	control; without randomisation; treatment; mesocosms; n, mean, sd, biomass.	558	Morris <i>et al.</i> (2003)
lake	N	resilience	II-2	no control; with/without randomisation; field samples; treatment; n (small sample) mean (would have to request data).	505	Rae and Vincent (1998)
	A	resilience	I	control; randomised; treatment; field-based experiment; n (large sample), mean.	952	Katzensteiner <i>et al.</i> (1992)
	A	resilience	I	control; randomised; treatment; field-based experiment; n (small sample), mean, se.	953	Kosola <i>et al.</i> (2004)
	A	resilience	I	control; randomised; treatment; field-based experiment; n, mean (would have to request data).	954	Rydgren <i>et al.</i> , (1998)
	A	resilience	I	control; randomised; treatment; field-based experiment; n (small sample), mean, sd (would have to request data).	956	Strengbom and Nordin (2008)
	A	recovery time	II-1/2	control; without randomised; treatment; field-based experiment; n (small sample), mean	1004	Beaudet <i>et al.</i> (2004)
	A	recovery time	II-1	control; without randomised; treatment; lysimeters; n (small sample), mean, sd.	996	Roygard <i>et al.</i> (2001)
	N	recovery time	II-2	control; without randomisation; treatment; field based; comparison between sites; n (small) (only indirectly reports biotic effect).	1244	Cerda <i>et al.</i> (1995)
forest	N	recovery time	II-2	control; without randomisation; treatment; field based; comparison between sites; n (small) (only indirectly reports biotic effect).	1245	Cerda and Lasanta (2005)

4. Discussion

To quote Professor Sir John Lawton FRS in an essay presented at a seminar on the principles of ecosystem management, and in particular, the challenges to traditional ecological theory (Maltby *et al.*, 1999):

“...My brief asked me to discuss ‘resilience’ as something that conservation biologists ought to be concerned with. I cannot imagine anything less useful for conservation to waste time and money on.”

Lawton described this to be the case because he felt that the “*gap between theory and practice here is vast*” and that it would be wasteful to try and fill such a gap (Maltby *et al.*, 1999). Yet we live in an environment that is changing and with an ever-growing human population whom depend on the resilience of the ecosystems that we live within and the services they deliver. Surely we cannot ignore the need to further our understanding of the resistance and resilience of our ecosystems, and how this might change as both the environment and our demands on ecosystem services change?

As practising ecologists, we are aware of specific studies that have measured some aspect of resilience in a particular ecosystem, perhaps in response to a particular anthropogenic perturbation, or level of environmental change (e.g. lowland heath resilience under different management regimes, Mitchell *et al.*, 2000; shelf sea habitat resilience to anthropogenic disturbance, Hiddink *et al.*, 2007; Robinson *et al.*, *in revision*). To consider broad patterns in resilience responses, we need a more inclusive holistic approach that can account for the results from many such studies. Systematic Review (SR) is one such approach (Pullin & Knight, 2001) and here we have undertaken a pilot study to consider the potential for this approach to tackle some key questions on resilience of ecosystems and the services they deliver.

We believe it likely that we have only unearthed the tip of the iceberg in terms of the numbers of studies available to explore such issues (see discussions in Sections 4.1-4.4 below). Resilience is without doubt a complex issue, but given the potential wealth of studies measuring aspects of it, it is clear that there is now a real opportunity to bridge the gaps in our understanding by asking some specific answerable questions and using the available study data in a structured SR process to answer them. In order to do this, we will need to overcome the problems associated with the different uses of the terminology associated with resilience (Section 2.2, 4.2 & 4.4) and we will need to find common metrics (units of measurement) that can be used in analysing effect size and adapt the SR methodology to incorporate study types that are perhaps beyond its current scope. In the following text we describe these issues and provide some recommendations that will allow us to begin to bridge the gap between theory and practice that perhaps does not need to be quite as “vast” as Lawton (in Maltby *et al.*, 1999) describes it.

4.1 Overview of the project findings

The aim of this pilot review was to assess the relevant literature on ecosystem resilience with respect to the provisioning of ecosystem services; essentially, given the pressure that humans put on the earth’s ecosystems, can the ecosystems recover to continue to provide essential services. Here we managed to review the literature for four ecosystem types (Deep Sea, Shelf Sea, Lakes and Forests).

One of the important features of this pilot review was to develop a methodology for reviewing the literature of this potentially vast topic. The review started with six broad questions, which were tackled using a series of literature searches of Web of Science using Boolean search strings. Once the papers were identified they were assessed using a systematic protocol; all papers deemed irrelevant (off-topic, most were in this category) were discarded and the remainder were classified into the type of study being reported. These summary results were then assessed critically by both the project team and an expert group, the aim being to assess whether the results obtained were reasonable and how they could be improved. However, this short pilot review could only provide a snap shot of the data available; we were only able to make use of one search engine and were unable to make use of the likely wider availability of sources from grey literature, databanks etc. Pullin & Stewart (2006) describe the importance of searching the widest possible range of sources to capture information, and we acknowledge that in a full-scale SR the volume of sources returned could be far greater. Even so, based on this scoping exercise, we still found some results worth noting.

The first key result was that the quantity of information carried across ecosystem types, increased from Deep Sea through Shelf Sea and Lakes to Forest. This presumably reflects either the effort being put into studying resilience and ecosystem services in these different ecosystems, or differences in terminology between disciplines, but we do not believe that a wider searching strategy (as referred to above) would necessarily change the order of ecosystem classes in terms of volume of studies available. The potential impact of terminology was apparent at the start of the review (Section 2.1), and might be one of the reasons why certain searches appeared to have less information than might be expected (identified by both the review team and the expert panel). This is discussed further in Section 4.2 below.

Second, the types of study also varied widely between ecosystem types with observation field-based data being reported more widely than that of experimental data, with this being especially true in the aquatic sciences. This is due to the inherent difficulties in performing experiments in aquatic systems. There were more experimental studies in forest ecosystems. This has profound effects for Systematic Review as it moves the “Quality of Evidence” available for meta-analysis from Category I to the lower range of Category II (Table 2.2.4.1). Moreover, many of the questions identified in this pilot review will require time series data. For both these reasons, there may need to be development of meta-analysis methodologies beyond those used at present within SRs and time would need to be allocated for this in development of future approaches.

Third, based on the lower numbers of studies found in the Deep Sea, Shelf Sea and Lake classes, few of the studies explicitly linked ecosystem resilience, ecosystem services and environmental change. However, given the high numbers of references found in relation to certain ecosystem services (e.g. food provision (fisheries) and nutrient cycling) we are confident that with more detailed scoping of these studies using carefully honed search terms, we would find suitable data for the types of questions outlined as high priorities in Section 4.3 below. Within the Forest class, specific state-perturbation- ecosystem service linked research could be broadly identified and less specific (more sensitive) searches could be carried out on the Forest class to reveal even more references. We have no reason to believe that there would not be as high levels of return in the other terrestrial classes, which we did not have time to explore in this pilot review.

In this pilot study we have produced a preliminary assessment of the available literature on ecosystem resilience in relation to ecosystem services in four types of ecosystem. Part of the review process has been to identify:

1. Areas where there are obvious gaps (Section 4.2),
2. Questions that might be suitable for Systematic Review (Section 4.3), and
3. Improvements to the search methodology to accommodate at least some of the problems encountered in this study (Section 4.4).

These issues are further discussed below.

4.2 Gaps identified in this pilot review

Gaps could be differentiated into two major topic areas. We have tried to differentiate ‘real’ data or knowledge gaps (4.2.1) from those potentially due to terminology (4.2.2), and in each we have commented on improvements or refinements to the search strategy that could help to bridge gaps where this is possible (this is further developed in Section 4.4).

4.2.1 Real knowledge or data gaps

Types of data available

As described in 4.1 above, there is a paucity of experimental data from marine ecosystems, and in particular, low numbers of studies on resilience in deep sea ecosystems. It is unlikely that wider mining of sources will reveal more experimental data in these systems: it is simply too difficult to carry out controlled experiments in most marine systems although inclusion of intertidal studies would widen the scope somewhat. Meta-analyses of less rigorous study designs have been used before in marine systems (e.g. Kaiser *et al.*, 2006), and it is recommended that such approaches be considered for SR questions where marine data would be useful.

Resilience and resistance

Studies on resistance² (and to a lesser extent resilience) tend to use different units of measurement and this would complicate determining effect size in a SR meta-analysis. For example, the resistance of a marine ecosystem to the removal of fish biomass through food harvest may be measured in terms of the biomass removed before the ecosystem is shown to have changed state (e.g. where a significant difference in average fish length is seen). In an agro-ecosystem resistance to a particular natural perturbation may be measured in terms of frequency of crop failures. In order to carry out SRs at this stage some careful work will be required to recommend common units of measurement that could be taken from extant studies. At the same time, however, there is need for some dedicated research on ecosystem resilience and resistance to ecosystem service delivery in a range of ecosystem types where common units of measurement are used from the onset.

² Where resistance defined as ‘the ability of a system to maintain its structure and pattern of behaviour in the presence of stress’

Ecosystem services

One obvious discrepancy detected in the literature review was that most research on ecosystems' resilience in relation to ecosystem services is in the area of provisioning services; there is much less information on supporting services and considerably less on regulating services (but see discussion on terminology below). To some extent this manifests itself in whether there is a difference in ecosystem resilience where there is a clear, quantifiable harvesting of material from the ecosystem (offtake of material that would not normally be removed), and a situation where the service is provided without direct additional intervention by humans (carbon sequestration, water supply etc.). There is a need for studies to determine how ecosystems respond when subject to different types of use by humans (e.g. provisioning *versus* regulating services).

The response of any ecosystem, and by definition its ability to provide services, to any driver or drivers will depend on (a) the type of driver (pulse or press), and (b) interactions between drivers. Almost nothing is known about the differential responses of ecosystems to interacting drivers and especially when they might be a combination of pulse (one-off) and press (continuous) treatments. SR could be used to examine this where data is available on the response of ecosystems to pulse perturbations (e.g. a storm or fire), under known levels of press disturbance (e.g. different intensities of fishing pressure, pollution or forestry) over a known time-scale (see recommended questions in Section 4.3). There is still a need for dedicated experimental studies to determine how ecosystems respond to the effects of interacting drivers of change, and especially when they are combinations of pulse and press disturbances.

4.2.2 Terminology issues

In the limited time allowed for this pilot review, we could not fully explore the most appropriate search terms for every scenario, leading to unlikely low returns for some searches. The results of the limited searches we were able to complete did, however, reveal results that helped to identify the gaps due to terminology. Based on this, we were able to make suggestions for refinements to terminology that could be used in future full-scale SRs in this topic area. These are briefly discussed below.

Ecosystem classes

In the timescale of this pilot review we were only able to search on a very limited number of terms for our ecosystem classes (those in bold in Table 2.2.2.1). In a full-scale SR part of the scoping exercise would require careful consultation on the appropriate terms to be used for the relevant ecosystem class(es).

Resilience and resistance

In ecology generally there is confusion on the term resilience/resistance and stability and there are potentially other terms that might be used in their place (regeneration cycle, gap-phase dynamics, recovery, vulnerability etc). Resilience, if described in terms of the inverse of recovery time, is a relatively easy concept to measure, if we are clear to which point a system is described to be recovering to. We were, therefore, relatively confident that searches for studies of recovery time given different levels of perturbation and/or environmental change, would return results in most, if not all, ecosystem classes covered. We would then be able to frame suitable questions about resilience using any data on the inverse of recovery time.

We were much less confident that simply entering the search term ‘resistance’ would return many results containing measurable outcomes. Resistance ultimately would be measured as an amount of variable ‘x’ that would be endured before variable ‘y’ altered in a way that could be described as altering the state of the system. Thus in trying to find an evidence-base of studies that would provide data for meta-analysis questions related to resistance in a full systematic review, we recognised that the search terms would need to cover both types of perturbation (as a measurable variable of extent of perturbation) and measures of state variables (e.g. population size, species diversity) to return studies that could provide a measure of resistance. Also, there is the likelihood that some of our searches under ‘resilience’ could also bring back data that, based on our definitions, would actually relate better to resistance.

A full SR of key questions relating to resilience of ecosystem service delivery would have to take considerable time to investigate possible synonyms for resilience. In the expert workshop held during this pilot review we consulted on the terms most likely to be used by different groups of experts under our definitions for resistance, resilience and alternative stable state. The list generated will provide a useful starting point for a full SR (see Appendix 5).

Ecosystem services

Similarly for ecosystem services, papers will have been missed if the service was referred to using different terminology from the search terms used here (e.g. coastal defence instead of flood protection). Based on the results revealed from the pilot study, we consulted the expert workshop on search terms relevant to studies of ecosystem service delivery in their field and the list generated is given in Appendix 5. Again this would provide a useful starting point when planning a full-scale specific SR.

4.3 Proposals for full Systematic Review

Potential Systematic Reviews that could be undertaken with data available now were identified by:

- Reviewing the papers identified in the pilot scoping study to give some broad indications to the types and quality of data that would be available to tackle specific questions, and;
- Asking all experts consulted to write a series of possible questions following some particular criteria and then reviewing these as a group in light of known data availability and quality.

The criteria set for writing SR questions were that they should be answerable, relevant to resilience of ecosystems and/or ecosystem service delivery, and that there were known data with which they could answer them.

A large number of potential issues and questions were suggested and on further discussion with the expert group at the workshop, many were eventually deemed (sometimes only currently) unanswerable and/or better approached with new research rather than a Systematic Review. However, we felt the exercise was useful as it generated both a list of priority issues relevant to taking forward understanding in this subject area and a shorter list of questions that could be taken forward into the SR process (Appendix 6).

The research on quantifiable, provisioning services (fishing, crops, timber *etc*) offers the most observational and experimental papers that would be suitable for the SR process. The benefit of performing these SRs is that there would be a clear increase in the knowledge base on the resilience of current ecosystem states (basins) that provide various food/fibre ecosystem services. These provision-based SRs may ultimately offer potential management options to manage human activities and understand the effects of environmental change to thus maintain productive states or manipulate states in ensure continuing or improved ecosystem service delivery.

As described by Pullin & Stewart (2006) a SR should start “*with a specific question, clearly defined with subject, intervention, and outcome elements*”. In the timescale of this pilot study it was not possible to fully formulate SR questions to the extent that they fitted the definitions set out by Pullin & Stewart (2006). However, in Appendix 6 the list of issues/questions is accompanied by comments on appropriate approaches to tackle them, including indications where SR may be possible and recommendations for actions required to do so.

4.4. Refinement of the search strategy for future reviews

Inevitably the exact question posed in any future Systematic Review will frame the specific search terms and search strategy. However, we have produced a tabulated list of terms identified during the pilot study by the review team augmented by discussions during the expert workshop. These term combinations (Appendix 5) will hopefully assist in improving the balance between sensitivity and specificity for any SR pursued.

The expert workshop attendees emphasised several recommendations to improve the capture of relevant research:

- The use of current grey material (e.g. unpublished governmental reports, academic or industry reports) would provide a rich resource of up-to-date research and relevant references of peer-reviewed journals for additional consideration;
- Evidence from historical ecosystems should be considered. Our understanding of ecosystem service resilience might be enhanced by studies on the physical response of environments over the long term. For example, using data from sediment cores to look at the resilience of lake ecology with respect to historic variation in the environment and its service delivery.
- Utilising pivotal, early-published papers and performing a forward, citation search, for example, a paper by Pimm (1984) on the complexity and stability of ecosystems has been cited 490 times, and
- Direct consultation with experts early in the Systematic Review process, and periodically throughout it.

These suggestions are not mutually exclusive and they largely agree with the recommendations of Pullin & Stewart (2006).

It is clear that any SR pursued on questions related to resilience and ecosystem service delivery will requires some dedicated effort at the start to define terminology and to find common metrics (units of measurement) that can be used in analysing effect size. This will add time to any SR on this issue, because the initial stages, where relevant sources are selected, will require not only quality control checking, but a high degree

of investment to locate comparable measures of effect size. This would require detailed searching of relevant sources (i.e. beyond abstracts) to actually decide on appropriate metrics and analyses. Before undertaking a specific SR it may even be necessary to complete an exercise whereby a group of experts examines studies from different fields to locate similar metrics suitable for particular SR questions. This may save time later by helping to further define questions and units of measurement before starting extensive searching.

For some of the SRs relevant to this topic, particularly those on the relationship between resilience and environmental change, time series data will be integral in describing effect. The use of meta-analyses using time series will require consideration of autocorrelation and pseudo replication. Myers and Mertz (1998) provide a potential meta-analysis methodology to enable this type of SR. In many cases, however, it may be possible to derive emergent metrics from time series that can then be used directly to measure effect size in a meta-analysis

5 Conclusions

Human well being can be linked practically to the delivery of ecosystem services. These services are dependant on ecosystem functioning. Management of the human activities that impact marine and terrestrial ecosystems necessitates improving understanding of ecosystem functioning in a changing world; a world that is changing in terms of its environment and the demands of the human population on it. Human activities can be managed; ecosystems cannot. Even so, the influence of the environment must be factored into the setting of levels of human activities that can be sustained. This requires quantitative understanding of how ecosystems respond to human perturbations against a background of environmental variability and change. This response is largely dependent on the ability of a system to maintain its structure and pattern of behaviour in the presence of stress (its resistance) and its ability to return to normal after a disturbance or stress (its resilience).

Management decisions are built on knowledge (of the ecosystem function, effects of various types of perturbations and the needs of humans) with the consideration of uncertainty. Ecological research is dominated by comparisons between different related ecosystems to determine resilience and resistance characteristics, where the baselines are (generally) unknown; this has uncertainty implications. A precautionary approach is required in the face of known uncertainty of thresholds (relating to ecological resistance and resilience characteristics) and what happens when we enter an alternate state when, by definition, ecological functioning (and therefore potentially also delivery of ecosystem services) changes.

Systematic Review (SR) is a tool that could be used whereby existing data can be used to explore patterns in effect size where change in some property of resilience or resistance is measured against known levels of environmental change or human perturbation (or both) (Pullin & Knight, 2001; Pullin & Stewart, 2006). Undoubtedly there will be future scenarios for which we will be unable to predict ecosystem response, but using existing data we can at least increase our understanding of variation in resilience/resistance known to date, and use historic scenarios of change to explore possible response trajectories.

In this pilot study, we reviewed the likely evidence base for SRs on issues related to the resilience (and resistance) of ecosystems and the services they deliver. It is likely

that we only unearthed the tip of the iceberg in terms of the numbers of studies available to explore such issues, because we were unable to explore all relevant search terms, nor utilise all likely sources to capture information in the time available. Of the sources we were able to access available research was better focussed on the effects of quantifiable, harvested provisioning services (e.g. fishing, agricultural crops, and timber) on ecosystems. There were fewer studies available on the physical-chemical processes which underpin supporting services, such as nutrient cycling, and regulating services, such as climate regulation. The volume of studies increased from the deep sea through shelf seas to lakes and forests. It is likely that other terrestrial ecosystem classes will also have high volumes of papers relative to aquatic systems, but that some aquatic ecosystems (e.g. intertidal) would yield higher returns than those explored in this pilot review. Observational, field data dominated the available, relevant material, especially in the marine and freshwater classes. Experimental studies were the least numerous.

In terms of SR questions identified as high priority (because they were relevant and possible to tackle with extant studies), they largely build on one over arching question: given anthropogenic and natural perturbations which will persist, how much pressure can we put on a system without compromising resilience or the ecosystem services that the system delivers? This over arching question can be also considered as how pristine does an ecosystem need to be to deliver ecosystem services? Alternatively, how degraded does it need to be to continue to deliver the level of ecosystem services required by the human population?

The resilience (and resistance) of ecosystems and the services they deliver is without doubt a complex issue, but given the potential wealth of studies measuring aspects of it, it is clear that there is now a real opportunity to bridge the gaps in our understanding by asking some specific answerable questions and using the available study data in a structured SR process to answer them. In order to do this, we will need to overcome the problems associated with the different uses of the terminology associated with resilience and we will need to find common metrics (units of measurement) that can be used in analysing effect size and adapt the SR methodology to incorporate study types that are perhaps beyond its current scope. We have provided starting points in terms of recommendations for a refined search strategy, expanded lists of recommended search terms, and a list of questions that could be pursued.

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7 Appendices

Appendix 1: Summary of the volume of papers returned for initial searches on some key state terms

Primarily, the use of resistance and resilience was shown, as suspected, to require constraining to return pertinent results. Secondly, the general issue that the English language has a large lexicon and is a very precise, heavily nuanced language complicates the choice of search terms to enable specific, relevant returns when a broad topic is being explored.

Table A1. Summary of the volume of papers returned for initial searches on some key state terms

Term searched	Search engine returns (references)
<i>Key words from the derived from the six</i>	
Resistance	c.f. 100 000 *
Resilience	c.f. 11220 *
Persistence	77321*
Anthropogenic perturbation	240
Natural perturbation	2890*
Resistance and Natural perturbation	1
Resistance and anthropogenic perturbation	1
Resilience and natural perturbation	1
Resilience and anthropogenic perturbation	2
Persistence and natural perturbation	19
Persistence and anthropogenic perturbation	5
<i>Metrics at the ecosystem level.</i>	
mean trophic level	60
connectance index	6
System Omnivory Index	5
Primary Production Required	21
Fishing in Balance index	4
Production/Respiration	218
Finn Cycling Index	17
Predatory Cycling Index	0
Mean Path Length of cycles	0
Total System Throughput	86
Biomass/Throughput	6
The Transfer Efficiency	3, 964*
Emergy	318
Exergy	2779
Fisher information index	6
Ascendency	99
Overhead	27487*
Mean Path Length	83
Mixed Trophic Impact	10
Ecosystem stability	316

Appendix 1 continued.

<i>Metrics at the community level.</i>	
<i>Species composition</i>	
Species abundance	6864
Index of rare species	0
Index of declining species	0
Index of increasing species	0
Proportion of sensitive of threatened species	0
Species turnover	719
Species loss rates	5
Abundance Biomass Comparison (Curves)	38
Life history composition	0
Elasmobranch/teleost ratio	0
Biodiversity	33547
k-Dominance (Curves)	83
Hill's NO N1 N2;	
Hill and NO	3
Hill and N1	35
Hill and N2	52
Species-effort (index)	6
Species richness	18 956*
Margalef* and "Species Richness"	61
Pielou* and "Evenness Index"	34
Taxonomic Diversity	997*
<i>Habitat size and quality</i>	
Biotic integrity	730
Benthic habitat quality	12
Habitat Affinity	34
Habitat Quality	2552*

* Search terms which have to be constrained – cross discipline term (cdt).

Appendix 2: Endnote library

This database is attached [LWEC_libraryCopy.enl]



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Table A.2. Endnote Coding

Endnote library code	level	Data type	Content
A	ecosystem level consideration	experimental study; data field study; data	correlative; designed study - reports on perturbative response correlative; sampling -- reports on perturbative response
M1	ecosystem level consideration	model data; [could be very useful]	reports on perturbative response
M		model results/study	reports on perturbative response
M meta		existing meta analysis	
R1d	community, population or species level response	experimental data field data	these identified papers may have experimental or field data; but, for example, may only report on one species on growth related information
R1m	community, population or species level response	modelling;	"METRIC STATE" information
R			not relevant; off topic; review; project report; methodological; management advice
X			A code could not be assigned due to issues (e.g. lack of details) in the abstract. Additionally, the paper could not be acquired within the time constraints of the scoping study.

Appendix 3: Excel LWEC overview worksheet

This file is attached. The excel overview sheet accompanies the LWEC ENDNOTE library and is a summary of the ENDNOTE database.



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Appendix 4: LWEC Workshop agenda

LWEC workshop on ‘Assessing the resilience of ecosystem service delivery: Can the Earth bounce back?’

AGENDA – Tuesday 12th May, 10am – 4pm

Venue: Thornton Room, Foresight Centre, University of Liverpool, 1 Brownlow Street, Liverpool, L69 3GL (see map attached)

Arrival reception: 9.30am-10am (tea and coffee served)

10.00 – 10.30 Welcome, aims of workshop and introduction (LWEC Obj. B, broad questions, systematic review process)
10.30 – 11.15 Discussion 1: Initial exploration of key questions and priorities for systematic review on the resilience of ecosystem service delivery

11.15-11.30: Coffee break

11.30 - 12.30 Discussion 2: Delivery of ecosystem services – what are they? Which are delivered by which ecosystem(s)? What kinds of studies might provide evidence?

12.30 – 13.15: Lunch

13.15 – 14.30 Discussion 3: Measuring change in resilience of ecosystems – how is it done? How is this linked to ecosystem service delivery? What kinds of studies might provide evidence?

14.30 -14.45: Coffee break

14.45 – 15.30: Revisit and refine key questions

15.30 – 16.00: Finalise recommendations of workshop

16:00: Close

19:30: Dinner - venue to be confirmed.

Appendix 5: Potential search terms to improve the SR strategy

These terms might be used to improve the identification of suitable references to answer specific Systematic Review questions on ecosystem resilience in relation to ecosystem state and ecosystem services.

Table A5.1: Search terms related to the state of an ecosystem and the delivery of ecosystem services

Resistance	Resilience	Changing state
Resistance	Resilience	Alternat* stable state
Ecological resilience	Recovery time	Alternate state
Tolerance (stress tolerance)	Engineering resilience	Regime shift
Stability	Regeneration (cycle/time)	Basin of attraction
Sensitivity	Gap-phase dynamics	Hysteresis
Vulnerability	Stability	Quasi-equilibrium
	Sensitivity	
	Vulnerability	

Table A 5.2. Ecosystem service terms

Ecosystem services (MEA list)		Ecosystem class	Actual term(s) used in relevant research	Other related service terms
1. Supporting services	Nutrient cycling	Generic	Stoichiometry, microbial loop, nitrogen/phosphate, decompensation, eutrophication. carbon sequestration, carbon turnover, uptake, turnover, depletion	Nutrient flux Environmental change
		Marine and fresh water: Deep sea Shelf sea Lake system	Nutrient dynamics nitrogen, phosphorus, bioturbation, runoff	
		Terrestrial: Forest Agro Semi natural cultural landscape.	De/nitrification, Eutrophication	
	Oxygen production	Generic	Photosynthesis, anoxia, oxygenation, hypoxia, oxygen tension	Air-sea gas exchange
		Marine and fresh water: Deep sea Shelf sea Lake systems		
		Terrestrial: Forest Agro Semi natural cultural landscape.	Photosynthesis, oxygen	
	Soil formation	Ggeneric	Sediment flux, erosion,	
		Marine and fresh water: Deep sea Shelf sea Lake systems	Sediment, resuspension	
		Terrestrial: Forest Agro Semi natural cultural landscape.	Pedogenesis, Decomposition, litter, chronosequence, soil erosion	

Table A 5.2. Ecosystem service terms continued

Ecosystem services (MEA list)		Ecosystem class	Actual term(s) used in relevant research	Other related service terms
2. Provisioning services	Food	Generic	Productivity, harvesting, biomass	Environmental change
		Deep sea	Fisheries, secondary production, trawling, demersal, aquaculture, whaling	
		Shelf sea	Spawning grounds, nurseries, aquaculture	
		Lake		
		Forest	Fruit, nut, pollinator, bushmeat, game	
		Agro	Crop, crop yield, production	
		Semi natural cultural landscape.	Crop yield	
		Fibre	Generic	
		Deep sea		
		Shelf sea		
		Lake	Wetlands, peat, reeds, swamp	
		Forest	Crop yield, yield class	
		Agro	Crop yield	
		Semi natural cultural landscape.	Crop yield	
	Fuel	Generic	Mining, oil extraction, natural gas, timber, peat, coal, renewable energy (wind farm, tidal and waves)	
		Deep sea	Tidal, wave, offshore wind, renewable energy, oil, gas	
		Shelf sea		
		Lake		
		Forest	Fire, vegetation change, wood	
		Agro		
		Semi natural cultural landscape		
	Water	Generic	Water yield, water resource, water cycle, rainfall, evaporation, Atmospheric dynamics	
		Deep sea		
		Shelf sea	Sea level rise	
		Lake		
		Forest		
		Agro		
		Semi natural cultural landscape		
	Aggregates			Dredging, aggregates, building materials Restoration

Table A 5.2. Ecosystem service terms continued

Ecosystem services (MEA list)	Ecosystem class	Actual term(s) used in relevant research	Other related service terms		
3. Regulating services	Climate regulation	Generic	Carbon budget, greenhouse gases, REDD, DMS/DMSP, ocean temperature, gas exchange, cloud formation, air/sea exchange, primary production, thermohaline circulation, carbon sequestration	Ocean acidification, sequestration Environmental change	
		Deep sea	Sea level rise, carbon		
		Shelf sea	cycling, carbon dioxide, sequestration		
		Lake			
		Forest	Vegetation, climate, feedback, deforestation, rainfall, fire, vegetation change, forest-atmosphere		
		Agro			
		Semi natural cultural landscape.			
		Water purification	Generic	water quality	
			Deep sea		
			Shelf sea	sea level rise	
Lake					
Forest					
Agro					
Flood protection	Generic	Flooding; flood hydrography, sustainable flood management; flood plain			
	Marine:	Tidal levels, sea level			
	Deep sea	change, coastal			
	Shelf sea	defence, managed retreat, coastal squeeze, salt marsh, sewage, erosion, groynes, sea walls, break water Sea level rise, storms, Holocene coastal change			
	Lake	Riverine, water storage capacity			
	Forest				
	Agro				
	Semi natural cultural landscape.				

Table A 5.2. Ecosystem service terms

Ecosystem services (MEA list)	Ecosystem class	Actual term(s) used in relevant research	Other related service terms		
4. Cultural services	Education	Generic	Knowledge, school study, university degree, conservation	Environmental change	
		Deep sea			
		Shelf sea			
		Lake			
		Forest			
		Agro			
		Semi natural cultural landscape.			
	Recreation	Generic			
		Marine and fresh water:	Angling, sport fishing, rod- fishing, spear fishing, whale watching, bird watching,		
		Deep sea	charismatic species, SCUBA, green space, birdsong, well-being, urban biodiversity.		
		Shelf sea	Hiking, water sports, nature tourism, sailing, diving, protected area, SSSI/SAC, visitor numbers		
		Lake system			
		Forest	bird watching, walking, skiing, biking, game		
		Agro	Game		
		Semi natural cultural landscape			
		Aesthetic value	Generic	Nature tourism, visitor numbers, non-use, landscape value	
			Deep sea		
			Shelf sea		
			Lake		
			Forest		
Agro					
Semi natural cultural landscape					
Conservation	Generic	Ecosystem approach, ecosystem-based management			

Appendix 6: Issues/questions highlighted by the expert workshop

The content of Table A6 is largely unaltered from the discussions at the workshop, containing a list of issues/questions and where relevant some comment on appropriate approaches to tackle them.

Table A6. Issues and/or questions highlighted by the expert workshop that are relevant to furthering our understanding of the resilience of ecosystems and ecosystem service delivery. SR = Systematic Review

Issue/Question	Comment
1. Does the length of human perturbation (disturbance history) in an ecosystem affect its current resistance to climate change?	<ul style="list-style-type: none"> - Possible to tackle in SR if can determine ‘length’ of human perturbation in a known ecosystem, and measure ‘resistance to climate change’. - Some concern that it would be difficult to find the information to quantify ‘length’ of perturbation (disturbance history) although more likely in terrestrial systems. - Unlikely to generate clear results because length alone may not be important (see next question).
2. Does the amount of harvest (food/fibre) from an ecosystem over a given time period affect its resilience to a short term (pulse) anthropogenic or natural disturbance (e.g. fire, hurricane, oil, spill)?	<ul style="list-style-type: none"> - Possible to tackle in SR if common metrics to measure the ‘amount’ of provision from a known ecosystem can be agreed, where there is also a described pulse disturbance and data on recovery time of a common ecosystem state variable after this. - It would be important to outline the potential factors that could cause bias or error in interpretation (such as area of the ecosystems being used, how comparable the systems are etc.)
3. How is the provision of food (or another provisioning service) from an ecosystem altered by environmental and climatic variability?	<ul style="list-style-type: none"> - Possible to tackle in SR if common metrics to measure the ‘the provision of X’ and the effect of environmental/climatic variability could be described. - If this were possible there should be plenty of relevant available data from long-term climatic/environmental datasets and long-term datasets collected on particular types of provision (e.g. in the aquatic ecosystems, landings of commercial stocks (fish, shellfish); in the terrestrial ecosystems, crop yield etc.). - Has obvious relevance to the issue of resistance and is a “hot topic” in terms of thinking about the implications of climate change.
4. a. Are there comparable points beyond which the sustainability of populations, communities or ecosystems is at risk of serious decline? b. Can we identify thresholds for ecosystem resilience, or ecosystem service delivery resilience? c. What could be the safest assumptions on risks and uncertainties whiles extracting ecosystem services for human appropriation?	<ul style="list-style-type: none"> - These questions were identified as having a common theme, and the terminology ‘tipping points’ and “safe minimum standards” was thought to be relevant. - There was discussion on whether indicators could be set for different ecosystem components and these then analysed in a SR to look for thresholds or tipping points (e.g. equivalent thresholds are set for fish stocks based o spawning stock biomass)

Table A6 continued. Issues and/or questions highlighted by the expert workshop that are relevant to furthering our understanding of the resilience of ecosystems and ecosystem service delivery. SR = Systematic Review

Issue/Question	Comment
<p>5. a. What is an 'optimal state' in terms of ecosystem service provision given different levels of resilience, measured in terms of human welfare provision?</p> <p>b. What is the change in welfare provision associated with shifting from <i>status quo</i> to a safe minimum standard (see 4) in terms of the resilience in each ecosystem class?</p>	<ul style="list-style-type: none"> - From a fisheries perspective this can be addressed by considering MSY and Bpa in fish stocks with tipping points. - How do we define human welfare provision; what does this really mean? - If these questions could be further clarified <u>a SR may be feasible</u> using information from datasets on provisioning services and known measures of resilience of the ecosystems defined.
<p>6. a. Does an improvement in ecosystem health always improve human wellbeing in the area?</p> <p>b. Does an improvement in ecosystem resilience always improve human wellbeing in the area?</p> <p>c. Does an improvement in ecosystem resistance always improve human wellbeing in the area?</p>	<ul style="list-style-type: none"> - Is a 'healthy' ecosystem always a resilient one? - What is a 'healthy' ecosystem? - This question itself not so relevant to the topic, but phrased differently (as 6b or c) it is. - 6b or c <u>could be tackled with a SR</u> if measures of improvement in ecosystem resilience (e.g. increase in recovery potential) or resistance (e.g. tolerance measures) could be determined and metrics for human well being also be determined and available from the same systems over the same time scales.
<p>7. What is the difference in the balance of provisioning and regulating services from different ecosystem classes (e.g. forests versus agro-ecosystems versus lakes)?</p>	<ul style="list-style-type: none"> - An interesting question that may provide some insight into overall distribution of service provision. - Not necessarily a topic for SR but would provide context. Would need further development to then link to issues on resilience and environmental change.
<p>8. What are the metrics/measures of ecosystem resilience and resistance in the different ecosystem classes?</p>	<ul style="list-style-type: none"> - A broad question related back to the overall issue of terminology and definitions. Important if we are to successfully carry out SRs on this topic. - Might require a dedicated workshop using studies from different ecosystem types to look for metrics and commonality.
<p>9. Is it possible to use the same metrics and approaches to determine effect size for different ecosystem services, even within the same broad category (e.g. provisioning services)?</p>	<ul style="list-style-type: none"> - Again, as with 7, may need a dedicated workshop to develop this before setting a specific SR.
<p>10. What is the balance in the importance of drivers controlling ecosystem service/resilience, i.e. physico-chemical factors versus biotic?</p>	<ul style="list-style-type: none"> - E.g. sediment flux/sea level impacts on sensitivity (true for some ecosystems e.g. marine habitats, not so much for ecosystems where top predators have significant top down control) - e.g. Does coastal defence reduce estuary function (waste assimilation, carbon cycle) re regulating services

Table A6 continued. Issues and/or questions highlighted by the expert workshop that are relevant to furthering our understanding of the resilience of ecosystems and ecosystem service delivery. SR = Systematic Review

Issue/Question	Comment
11. How does ecosystem resilience/service provision change in an ecosystem along an intervention gradient?	<ul style="list-style-type: none"> - <u>Possible to tackle in SR</u> if we can determine a common measure of ecosystem resilience or service provision, and classify 'intervention' so that comparable points along a gradient can be identified. - Known case studies with data for terrestrial ecosystems were suggested (e.g. the lowland heath experiments are one example)
12. a. What management interventions produce improvements in human wellbeing? b. What management interventions alter ecosystem service delivery?	<ul style="list-style-type: none"> - Neither of these questions are that relevant to the topic of interest on their own. - <u>Could do a SR</u> to look at situations where management has been shown to have an effect on an ecosystem, to see if it has any relationship with a defined measure of human wellbeing (a), or changes in ecosystem service delivery (b).
13. Do interventions clash, compete or interact?	<ul style="list-style-type: none"> - There is much less data on the interactions of different interventions. - Not clear how this related to the overall topic specifically; however, this is an important issue in terms of understanding the results of SRs on systems where there may be multiple types of human interventions occurring at the same time. - New research required in this areas; some ongoing?
14. Can ecosystem resilience be characterised as a community of ecosystem services?	<ul style="list-style-type: none"> - As with multivariate analysis of species or ecosystem functions, would it be possible to study the relationship between the composition of ecosystem services delivered from different ecosystems (through multivariate analysis) and properties of their resilience? - Probably not a question for SR but interesting for further research options.
15. Does resilience/resistance differ between ecosystem services within an ecosystem (e.g. is water quality more sensitive than crop yield)?	<ul style="list-style-type: none"> - <u>This could be broken down into a number of SRs</u> about resistance and resilience of ecosystem services. - In terms of resistance we would need a common measure that determined the sensitivity of the services to different disturbances (natural and/or anthropogenic) or levels of demand. Sensitivity may be defined as the point beyond which the service fails (e.g. below safe standards for water quality, or failures of crops).

Table A6 cont. Issues and/or questions highlighted by the expert workshop that are relevant to furthering our understanding of the resilience of ecosystems and ecosystem service delivery. SR = Systematic Review

Issue/Question	Comment
16. Can an understanding of ecosystem service resilience be gained from information on the physical response of environments over the long term?	<ul style="list-style-type: none"> - Historic data (e.g. from sediment cores) could be used in conjunction with long-term climatic/ environmental data to examine the return times (recovery) of particular systems subject to different perturbations or levels of climatic variability. This could be measured in terms of ecosystem service delivery (e.g. nutrient cycling potential). - <u>Possible for a SR</u> although would need investment to determine metrics of effect size that ‘convert’ the recovery/return time of services (e.g. nutrient cycling potential) from measured quantities from sediment core data.
17. Can human perturbation be distinguished from natural background change (e.g. climate change, successional change, edaphic factors) using long term data?	<ul style="list-style-type: none"> - Not necessarily a relevant question on its own, but important in terms of answering any questions about long-term change and causality. - Some of the same issues as 16 in terms of ‘conversion’ of measured quantities in historic data to meaningful metrics.
18. What have been the historical trends in ecosystem service provision? In the absence of data what proxies can be used (e.g. historical land cover maps)?	<ul style="list-style-type: none"> - An interesting question in terms of setting the context (see 19). - Not an SR itself, but a research job that may be necessary to then take forward other SRs (e.g. 19). - Proxy data types could include: Farm record. Historical land cover. Aerial photography. Vegetation maps. Core records.
19. Building on (18) what has been the historical relationship between ecosystem service supply and demand, and is the relationship between the two related to, e.g. ecosystem collapse, phase shift?	<ul style="list-style-type: none"> - <u>Possible to undertake a SR</u> on at least the latter part of the question, but will it be possible to untangle from other drivers (see 17)?
20. Is (or could it be) resistance actually defined in terms of the continuation of ecosystem service provision against a background of environmental change?	<ul style="list-style-type: none"> - In other words, if an ecosystem continues to supply particular services at a given level does this equate to the system maintaining its resistance against environmental change? - The question itself is not an SR question, but an interesting issue that could be examined through research and would then provide a useful metric for other SRs on ecosystem resistance.
21. Is there a relationship between estimated resilience (eigenvalue) of a linearised model of biomass and the percentage of primary production captured by humans?	<ul style="list-style-type: none"> - Good specific question that <u>could be captured in a SR</u> if we can measure ‘primary production captured by humans’ and biomass for particular systems.

Table A6 cont. Issues and/or questions highlighted by the expert workshop that are relevant to furthering our understanding of the resilience of ecosystems and ecosystem service delivery. SR = Systematic Review

Issue/Question	Comment
<p>22. How important is the extent of habitat fragmentation (cultivated/non cultivated; spatial/temporal dynamics) to the intrinsic (natural) regulation of pests (insects, fungi, weeds)?</p>	<ul style="list-style-type: none"> - Important in terms of 'set aside' issues and provisioning services. - Phrased differently this <u>could be tackled in a SR</u> and there are good data sets available for terrestrial systems at least.
<p>23. Does the removal of a size specific/mass specific portion of a population or community affect the population or community dynamics in subsequent generations, and subsequently decrease provisioning ecosystem services e.g. food to humans?</p>	<ul style="list-style-type: none"> - Sustainable harvesting question in relation to off take and also service provisions. - <u>Possible in a SR</u> with extant research into fisheries from several different ecosystem classes.
<p>24. When a regime shift/shift-in-state occurs and results in a new stable, alternate state, do humans adapt to exploit the 'new' resources?</p>	<ul style="list-style-type: none"> - There are various case studies. - Definitions of regime shifts within the question would be paramount as would clear measures for human exploitation.
<p>25. Inevitably, climate change will force dependency for food security in many global areas, e.g. on rain fed agro-ecosystems or pelagic fish stocks where spawning stock-recruitment dynamics are tightly linked to environmental condition.</p> <p>Question related to this: How will environmental change alter dynamics of soil properties (C, NO₂, CH₄ etc) in relation to productivity (provisioning services)?</p>	<ul style="list-style-type: none"> - Important issue that could be examined using extant data where soil properties (or other similar properties for different ecosystem service types) can be measured against patterns of environmental change. - We may not have data that would cover the types/magnitude of environmental change likely given all future climate change scenarios.