Defining and Identifying Environmental Limits for Sustainable Development

A Scoping Study

Funded by

Final Overview Report

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Contents

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Executive Summary

If the goals of sustainable development are to be achieved then we need to understand environmental limits and thresholds. In this study we review current scientific thinking on these topics and trace the implications of recent work for policies related to the protection of natural resources and the promotion of sustainable patterns of consumption and production in the UK.

Natural resource systems can provide a range of benefits to people. These include clean and regular water supply, the production of food and fibre, and the protection of communities from hazards. External pressures, such as pollution or over-use, may impact upon natural resource systems and diminish the level or quality of the benefits that they provide. Eventually people may judge that a critical point has been reached, and that the reduction in benefit is no longer acceptable or tolerable. Such a critical level can best be described as an ***environmental limit***. An important goal of sustainable development is to maintain natural resource systems above such limits.

Natural resource system can respond to increasing external pressures in various ways. Some systems show a gradual decline in the level or quality or benefits they provide. Others show a more rapid change or even exhibit sudden collapse. Our review suggests when a natural resource system exhibit a rapid 'regime shift', then this may be evidence of the existence of an ***environmental threshold,*** marking the boundary between alternative stable states**.** Water quality in lake systems that are impacted by nutrient input, and marine fisheries suffering over-exploitation have all been found to show this type of behaviour. In these situations it is particularly important to define an environmental limit so we can prevent the pressures upon systems from triggering such a threshold response, because evidence suggests that when thresholds are crossed it may be difficult to restore systems to their former condition.

Although some natural resource systems can exhibit threshold types of response, the extent to which this is commonplace is uncertain. The concept of a limit is therefore more useful generally, since it focuses attention on the possibilities of system collapse and the possibly more widespread, chronic or progressive loss of integrity which natural resource systems may suffer with increasing environmental pressures.

Our review has considered the way in which ideas about limits and thresholds have been developed in relation to ideas about ecosystem health, resilience and ecosystem goods and services. We have also considered how the ideas fit in with contemporary approaches to the valuation of natural assets, and current debates about sustainable consumption and production. The ideas were developed and tested by a detailed review of current issues relating to biodiversity, land use and landscape, recreation, climate change, the marine environment, water supply and demand, pollution loads and soil.

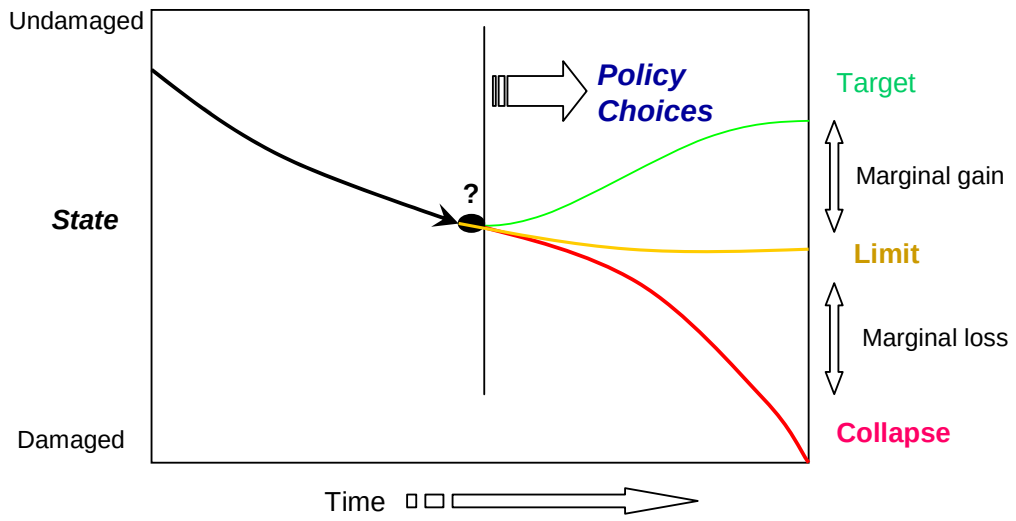
Several key conclusions emerge from the study:

- Although the terms 'limits' and 'thresholds' have been used in different ways in different areas of science, for future policy debates it is important to distinguish between them and to be consistent in the way they are used. We suggest that the notion of an environmental limit is relevant to all natural

resource systems, whether or not they show a threshold response under external pressure. **Limits are most usefully defined in terms of the point or range of conditions beyond which the benefits derived from a natural resource system are judged unacceptable or insufficient.**

- Given natural variability and the uncertainties that exist in our understanding of the behaviour of natural resource systems, it is wise to adopt a 'precautionary approach' to the definition of environmental limits. Thus while we may suggest some final limit beyond which significant harm to the system will occur, notions of wise management might suggest that we should be prepared to sustain the system at some level above this minimum. **Thus different types of environmental limit might be defined**. For example, in the fisheries literature, 'precautionary limits' or 'precautionary reference points' are set to ensure that irreversible harm does not occur to populations of economically or ecologically important species.
- While the identification of an environmental limit is important in terms of resolving questions about the sustainability of a natural resource system, it should not always be used to set management standards. Fundamentally the idea of a limit involves setting a maximum level of damage to a natural resource system that we are prepared to tolerate or accept. In management terms we might prefer to maintain the system in 'good' condition, and therefore specify management targets that are well above the agreed limit. **Thus our study suggests that discussions about environmental limits are part of wider debates about environmental targets**. Identification of an environmental limit can be useful in helping to justify where management targets should be set (See Box 1).

Box 1 Understanding Limits and Values



Faced with the progressive loss of benefit from a natural resource system, the choice of future policy options will depend on judgements about the maximum level of damage or loss that is tolerable. Justification for the limit will depend on the consequences of exceedence expressed in terms of the marginal losses in benefit from the natural resource system that might occur if the limit is passed. Justification for managing the system at some target level well above the limit of maximum acceptable damage, will depend on the marginal gains in benefit that can be achieved by adopting such a strategy.

The overall message from the study is that **while the definition of an environmental limit may be based on the biophysical properties of a natural resource system, its identification also depends on the way people value the outputs from it.** Thus if we view natural resource systems in terms of the benefits they can deliver, then judgments about where a particular limit is set can be based on changes in the marginal value of those benefits, or the assessment of those benefits relative to others that people identify. Additionally, depending on the circumstances, it can be based on the application of ecological or social values. As a result, it is argued that discussion of limits requires the development of deliberative forms of decision making.

Although the evidence base for environmental limits needs developing across all the thematic areas considered, in most cases there is a sufficiently understanding to begin a discussing what kinds of limits might apply for the protection of natural resources. We recommend that work should be initiated to develop guidelines for decision makers at national, regional and local scales to help ensure that development occurs within environmental limits. Thus future work on environmental limits should be directed at the scientific and institutional levels.

In relation to the promotion of sustainable patterns of consumption and production, the study also suggests that the general discussion of environmental limits would be helpful in making the case for broadening the suite of 'decoupling' indicators used in the UK, and in setting more precisely targets for policy in this area. We suggest that a scoping study is undertaken to determine the feasibility of extending the existing national environmental accounts as a framework for future work.

Part 1: Introduction

1.1. Context and Aims

Questions about environmental limits, and their implications for policies related to natural resource protection, have emerged as an important focus in discussions of how the goals of sustainable development might be achieved. The **aim of this study** is to collate and critically review recent developments across the range of discipline areas where these issues have been discussed, in order to:

- Outline how environmental limits are identified and defined;
- Assess the robustness of the evidence that underpins the identification of limits;
- Identify gaps in current understandings of environmental limits;
- Assess the need for, and feasibility of, collecting new evidence on environmental limits, including where knowledge of existing limits may be out of date;
- Look at how the evidence used to identify current limits might be collated;
- Identify current thinking on the application of environmental limits in policy-making; and
- Identify where further research may be needed to look at how limits could be used in policy making.

This study is part of a larger work programme initiated by the UK Department of Environment, Food and Rural Affairs (Defra), which is looking at how to develop the evidence base needed to support a strategic approach to conserving, enhancing and managing the natural environment at home and abroad[1]. The work covers issues related to making an inventory of natural resources, the way in which cumulative pressures upon them can be understood, the valuation of natural resources, the analysis of future trends and the examination of current policy frameworks (Figure 1).

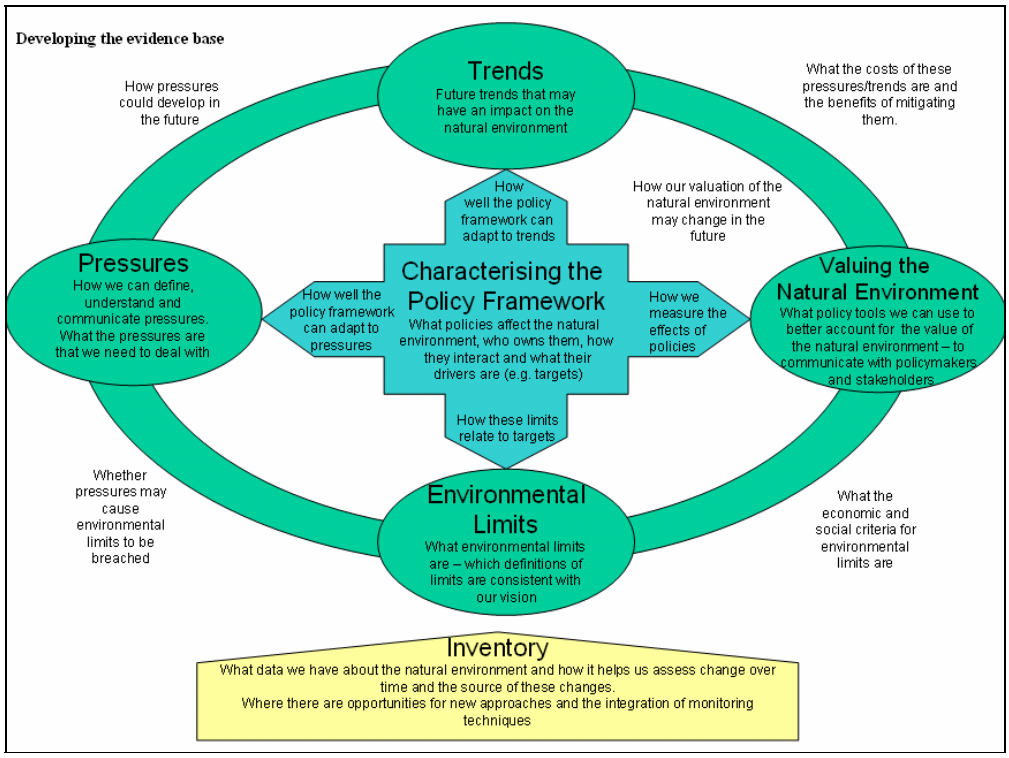
The need for this study arose from commitments made in the UK Sustainable Development Strategy to:

- Make a critical review on environmental limits;
- Collate existing research and to identify shortfalls in understanding about where environmental limits exist, and where they are being exceeded; and,
- Conduct a strategic assessment of future research needs in all policy areas.

The concerns of the UK Sustainable development Strategy for further work on environmental limits echo those made on a broader international front. The Convention on Biological Diversity, for example, specifically flags the need to develop a better understanding of biodiversity thresholds in relation to ecosystem functioning[2]. The FAO also emphasis the importance of identifying thresholds in their discussion of biodiversity and conservation[3]. The importance of thresholds as a research priority has been emphasised by the EU, through its 6th Framework Programme[4], which support several major integrated projects[5] that seek to develop the

[1] http://www.defra.gov.uk/wildlife-countryside/natres/evidence.htm
[2] http://www.biodiv.org/recommendations/?m=SBSTTA-06&id=7036&lg=0
[3] http://www.fao.org/documents/show_cdr.asp?url_file=/DOCREP/005/Y4586E/y4586e06.htm
[4] http://europa.eu.int/comm/research/environment/themes/article_1353_en.htm
[5] http://www.thresholds-eu.org/ and http://www.sensor-ip.org/

Figure 1: The Natural Environment Programme of D*efra*



concept as one of the tools for sustainability assessment, and the IGBP/IHDP in their recently announced Global Land Project[6].

1.2. Project Structure and Outline of Final Report

The study undertook two major tasks.

- The first was a review of relevant scientific literature describing environmental limits and thresholds. The aim was to clarify how the concepts are used, and to trace how the terms link to wider debates about ecosystem health, ecosystem resilience, ecosystem goods and services, sustainable consumption and production and the valuation of environmental assets.

- The second task involved using the literature review to develop recommendations about how the current ideas about limits and thresholds can assist in the development of policy frameworks related to the protection of natural resources in the UK. The aim here was to identify what gaps in present understandings exist and what research strategies might therefore be appropriate to build the kind of evidence base required.

The brief for the study was therefore very wide ranging, and so in order that it should focus on Defra's requirements the work looked specifically at the key thematic areas covered by the Department's responsibilities in the area of natural resource management, namely:

a. Biodiversity;
b. Water quality, supply and demand;

[6] http://www.glp.colostate.edu/report_53.pdf

c. The marine environment;
d. The soil environment;
e. Land use and landscapes;
f. Atmosphere, including air quality, green house gas emissions and rates of climate change;
g. Emissions and ozone depleting substances
h. Recreation and access to the natural environment; and,
i. Levels of dispersal of toxic substances and the disposal of solid waste.

This document is the Final Overview Report arising from this study. A more detailed account of the work undertaken can be found in the full Technical Report that accompanies it.

In this Overview Report, Part 2 explores the limits and threshold concepts in detail, and their place in wider scientific debates. This material describes how limits and thresholds are identified and defined, and thus contributes to the first objective of the study.

In Part 3, we consider the key issues arising from the reviews of each of the thematic areas. We explore how the limits and threshold concepts have been applied and what evidence there is for their identification in each area. The materials in this section will address objectives b through d. Finally, in Part 4, we make recommendations about how the concepts of limits and thresholds might be developed and applied in a policy context in the UK, and so focus on objectives f and g.

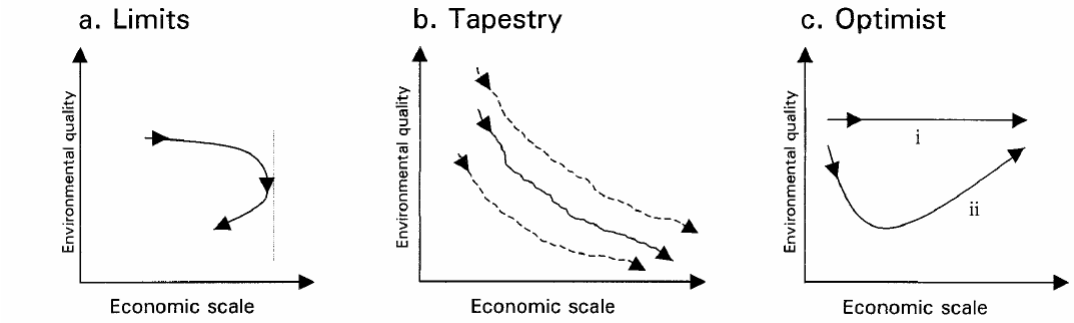
Part 2: Conceptual Frameworks

2.1. Limits and Thresholds: Definitions

2.1.1 What is an environmental threshold or limit?

The recent discussions about environmental limits and thresholds are part of a much longer and wide-ranging debate about the extent to which human development can be maintained in the light of environmental constraints. A number of different views can be identified (Figure 2). The more pessimistic commentators envisage futures ranging from those in which a critical point is reached at which environmental collapse might occur, through to ideas that environmental degradation is more gradual but nevertheless unacceptable. By contrast, more optimistic positions suggest that there is, in fact, either no relationship between increasing economic scale and loss of environmental quality, or that the initial losses of quality that we have experienced can be 'made good', as affluence levels or technological competence increases over the longer term.

Figure 2: Alternative paradigms describing the potential relationship between change in economic scale and environmental quality (after Davidson, 2000).



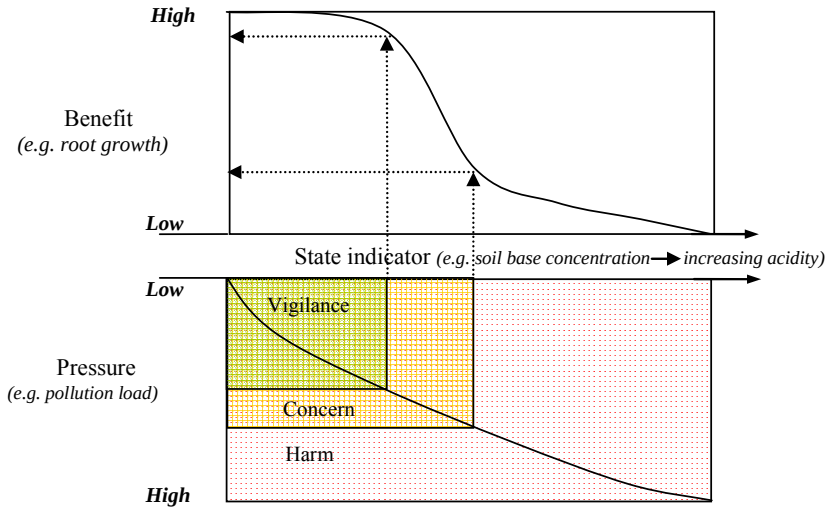
In undertaking our literature review our aim has not been to decide between these different positions, but rather to look at the way in which the concepts of 'limits' and 'thresholds' have been defined and applied, and so identify the role they play in current policy debates. **Our work suggests that, although the concepts have been discussed widely, the terms 'limits' and 'thresholds' have been applied inconsistently across the different fields.** In some areas, for example, the terms are used as synonyms, while in others they denote quite different sets of ideas. In order to take discussions forward it is therefore important to be clear about definitions.

2.1.2 Critical points and limits

A common idea across many of the fields reviewed by this study is that notion that when we look at the capacity of a natural resource system to deliver functions or benefits to people, there is a ***critical point or zone*** at which the benefits obtained may fall below some acceptable or tolerable level. That point may arise because:

- The pressures upon the natural resource system may damage its capacity or integrity, so that further benefits cannot be delivered; or

Figure 3: Relationships between pressure, state and the output of benefits in a natural resource system



- That while the system remains functioning, the level of benefit is judged to be unacceptable.

Depending upon the subject area being considered, that critical point or zone might be described as a 'critical load', when referring to the level of pollution by atmospheric deposition beyond which an ecosystem is damaged, or a 'limit reference point', when describing the level of fishing intensity that would damage the capacity of a stock to sustain itself. **In this study we suggest that all such critical points or levels are described as *limits*.** This position is consistent with the views expressed by the *Royal Commission on Environmental Pollution*[7] in relation to the different types of standard that may be identified.

Figure 3 describes how the notion of a limit can be represented and qualified by means of two linked graphs. It builds on the idea that we can represent the state of the natural resource system by an indicator (e.g. soil base concentration or acidity) which is causally related to some external pressures (e.g. pollution load). The impacts of these pressures are often judged by means of an indicator that describes the level of benefits that people derive from the resource (e.g. vitality of root growth, which may impact upon ecosystem productivity or structure).

There are several important features to note about the relationship shown in Figure 3:

- That the relationship between pressure and benefit can be 'non-linear', that is there is there is not necessarily a constant reduction in benefit as pressure increases. Over parts of the range the benefit may be quite insensitive to changes in pressure; in other parts more rapid changes in benefit might be detected.

[7] Royal Commission on Environmental Pollution, Environmental Standards and Public Values, A summary of the 21st report on *Setting Environmental Standards.*
http://www.rcep.org.uk/pdf/standardssummary.pdf

- That while both pressure and benefit limits can be defined, they are not independent of each other. Judgements about the level of allowable pressure are determined by resolving the question of what is an acceptable or tolerable level of benefit.
- That exceeding of a limit does not necessarily result in system collapse, but also conditions beyond which further damage to the resource is judged as unacceptable. Given the uncertainties involved in making such judgements, the limit might in fact be a range of conditions where concerns become significant, even though in practice we might identify or communicate this limit by setting a particular value.

Figure 3 also shows that we can recognise different types of limit in the context of uncertainty. For example, since we may feel that the information available to use is uncertain or incomplete, it might be appropriate to adopt a 'precautionary approach', and so build a safety margin into the considerations. Thus in Figure 3, zones of 'vigilance', 'concern' and 'harm' have been included. The boundaries of these zones might then be defined in terms of 'precautionary' and the 'environmental' limits.

The idea of a precautionary limit is widespread in the scientific and policy literatures. In areas it is referred to as the 'safe minimum standard'[8]. Above it, in the zone of vigilance it is wise to monitor integrity of the natural resource system, but exploitation is considered largely unproblematic. Although decisions about the position of the precautionary limit are often a matter of judgement, essentially it marks the point at which it is accepted that some action is needed. In the zone of concern, the urgency of the action is determined by how close the system is to the environmental limit. The latter marks the point at which tangible harm to the natural resource system, or to the benefits it generates, occurs.

2.1.3 Thresholds and regime shifts

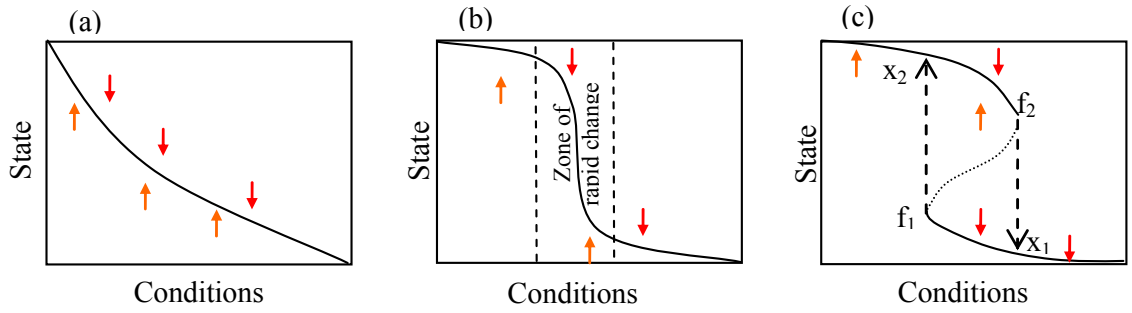
The discussion so far has avoided using the term 'threshold' because, while some writers used it as a synonym for 'limit', in some discipline areas it carries with it other ideas which are important in their own right. We will focus specifically on the problem of 'non-linear responses' and what they might entail.

The existence of non-linear responses has been mentioned in context of Figure 3. Simple non-linear responses of this kind are widespread, but other types of non-linear responses can also be found. It is with these that the concept of a threshold is often associated.

Figure 4 shows a range of different types of causal relationships that might exist between pressure and state. In each case the line represents the point of equilibrium between a given level of pressure and the resulting state of the system. If disturbed, the assumption is that the system will return to this equilibrium value. Systems can thus respond in a smooth or linear way to a change in external conditions or pressures (situation a) or show a more variable pattern of sensitivity (situation b). The important point to note in relation to the both models is that there is a 'one-to-one' relationship between pressure and state, so that when, for example, pressure is relaxed the system will move to the same state observed previously at the lower pressure level.

[8] Barrens, R. P., M. McKee and M. C. Farmer (1999): Incorporating distributional consideration in the safe minimum standard approach; endangered species and local impact. *Ecological Economics* **30**: 461-474.

Figure 4: Three contrasting system responses to changed external conditions



Each graph plots the way the equilibrium environmental state changes in relation to some controlling variable or environmental pressure. The ↑↓ indicate the direction in which the system would move if disturbed from the equilibrium line.

In contrast to situations (a) and (b), system (c) in Figure 4 illustrates a more complex type of dynamic, where 'catastrophic' change occurs. Thus:

- Starting at point x_1, a change in the pressure variable alters the state of the system gradually until point f_1 is reached, whereupon there is a sudden jump to the state represented by point x_2.
- Moving in the opposite direction from x_2, the system would flip at point f_2 back to the conditions represented in point x_1.

Systems exhibiting this type of behaviour are said to show 'hysteresis'. Points f_1 and f_2 are known as bifurcations, and the dotted line joining the marks the boundary or **threshold** between two different 'domains of attraction'. Systems exhibiting this type of behaviour are then said to show a '**threshold response**'.

There are a number of accounts in the scientific literature of environmental systems exhibiting threshold responses. The behaviour is particularly noteworthy in aquatic ecosystems. Such behaviour is significant because it has profound implications for the way that we manage systems that have thresholds associated with them compared to those that do not. Thus, with reference to Figure 4:

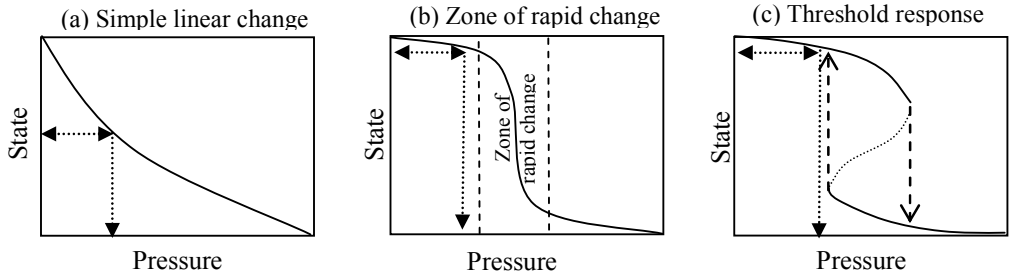
- In situations (a) and (b), assuming that the level of the pressure variable can be manipulated, then a desired target state can usually be achieved and any disturbances will re-establish the equilibrium state for that level of pressure.
- In situation (c), when the system is at a point close to one of the bifurcations then even a small disturbance may cause the system to flip to the alternate state, and it may be that much additional management input is required to restore it to the former condition. In some circumstances it could be that no 'reverse shift' can be engineered, even if pressure ameliorates. In this case, the bifurcation represents a 'point of no return'.

2.1.4 Defining Limits and Thresholds

Our discussion of thresholds shows that the term carries with it some important ideas about the potential dynamics that ecological systems can show. Thus, while it is often used in everyday language to refer to a critical point or line, it may be more appropriate to use it to refer to the specific situation that we have described above.

As Figure 5 shows, the existence of thresholds that separate alternative stable states may be significant for the way we approach the management of natural resource

Figure 5: Limit and Threshold Identification



In each case the dotted lines represent some kind of limit beyond which system is judged to be damaged or at risk.

systems, but it is clear that the idea of limits is not exclusively associated with systems showing these kinds of dynamic. For example in Figure 5 although system (a) does not exhibit a regime shift, and is therefore not formally associated with any kind of threshold, questions of whether changes in the environmental pressure variable lead eventually to an unacceptable level of benefit can result in a limit being defined.

Similarly, in Figure 5, situation (b), the 'zone of rapid transition' may mark the boundary between states that have fundamentally different implications for the people or organisms that are affected by them so that we would not want this zone of transition to be crossed. Once again a critical level or limit might be identified to ensure that the system does not move into the zone where rapid changes occur.

Finally, if we are aware that systems can exhibit threshold responses over certain ranges of the external driver or pressure variable, then we may chose, as in Figure 5 situation (c), to identify a limit beyond which the system should not be pushed.

On the basis of the discussion we suggest that it seems necessary to apply the terms 'limits' and 'thresholds' carefully, and certainly not without some qualification to convey precisely what is meant. It would also seem that while some commentators have done so, they should ***not*** be used as synonyms. Thus we suggest that:

- The term **limit** is used to refer to the level of some environmental pressure, indicator of environmental state or benefit derived from the natural resource system, beyond which conditions which are deemed to be unacceptable in some way, either because the system is judged to be damaged or because its integrity is at risk. The term can be applied irrespective of the type of dynamic exhibited by the system (linear response, simple non-linear response, threshold response).

- The term **threshold** is reserved to describe situations in which a distinct regime shift between alternative equilibrium states exists, which may or may not be reversible.

Furthermore, we suggest:

- The term **non-linear response** is used to describe any system in which the relationship between an environmental pressure and the resulting change in system state is not constant in its effect. A threshold, separating alternative stable states is merely one type of non-linear response. The term '**tipping point**' can be used to identify the boundary of the zone where a rapid change in state may occur.
- Different types of limit may be defined in order to cope with the risks associated with loss of ecosystem function or benefit, such as a '**safe minimum standard**', a '**precautionary limit**' or a '**precautionary reference point**'.

2.1.5 The consequences of exceeding a limit

How can the significance of exceeding a given limit be assessed? While the dynamics that a system shows once a limit has been crossed is important for assessing the importance of a limit, system dynamics is not the only factor that has to be considered. Of equal importance is an understanding the ***consequences of exceedence***, because these determine what type of management or policy actions are appropriate and therefore what priority should be attached to them.

Our review suggests that the consequences of exceeding an environmental limit can be varied, and do not depend on whether the system shows linear, non-linear or threshold types of response. Thus, for example, at one level exceedence of a limit might only trigger concern that critical situation is being approached so that additional safeguards to the natural resource system are necessary. An example of this type might be water protection measures at time of drought. By contrast, exceedence of a limit might lead to a series of actions to constrain or even prevent a given activity or practice, as in the case of pollution regulation.

The identification of a limit, and its significance, therefore depends on two sets of issue:

- On what types of relationship exist between environmental pressure, system state and the level of benefits that we derive from the natural resource system; and,
- The implications that exceedence of a limit has for ecosystem integrity or human well-being, and an understanding of what aspect of a natural resource system that we are seeking to protect by defining a particular limit.

2.2. Identifying Limits and Thresholds

In order to examine in detail the general issues surrounding the questions of how limits and thresholds have been identified, and how their significance has been judged, we have reviewed four conceptual frameworks that have been widely discussed in the scientific literature, namely those of 'ecosystem health', 'ecosystem

resilience', 'ecosystem goods and services' and 'sustainable consumption and production'. Each as been examined in terms of the types of evidence on which they are based, and the implications they have for policy development.

2.2.1 Ecosystem Health

The discussion of ecosystem health was identified as being potentially of interest to the present study because the concept embodies the idea that there is some limit beyond which the integrity or functioning of an ecological system can become so damaged that it cannot easily or quickly recover.

The conclusion that we have drawn from our review of the recent literature is that while the concept of 'ecosystem health' is an attractive idea, ***fundamentally it remains a metaphor***. It is widely acknowledged that the concept of ecosystem health is a broad and ill-defined one, and that no core set of indicators that can be used to assess it[9]. Since virtually any ecosystem parameter can be used to represent 'ecosystem health' it is therefore hard to see what we actually achieve by accepting the metaphor. The paradigm appears to provide few guidelines to suggest how limiting values for these indicators can be specified, or to explain what kinds of structures make some systems more resilient to disturbance than others.

We conclude from our review that, at present, the concept of ecosystem health had little to offer in terms of understanding where the environmental limits or thresholds might lie.

2.2.2 Thresholds, Resilience and Coupled Socio-Ecological Systems

The need to consider the 'coupling' of social and ecological systems has been identified as an urgent research priority by a number of organisations[10]. Much of the interest in the topic has been linked to discussions of resilience and ecosystem integrity[11].

Discussions of resilience are closely linked to the identification of threshold responses, because the former deals explicitly with the properties of systems that make them resistant to disturbance, while the latter is put forward as a consequence that the mechanisms which promote resilience have been overcome. Broadly, resilience is viewed as the capacity of a system to absorb shocks while maintaining function, and also includes ideas about the degree to systems are capable of self-organization have the capacity for learning and adaptation[12].

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[9] Raffaelli, D., White, Perrings, Smart and Renwick (2004): The Future of Healthy Ecosystems: D*efra* Horizon Scanning Report SD0306, D*efra*.

[10] http://www.glp.colostate.edu/report_53.pdf

[11] Folke, C., S. R. Carpenter, T. Elmqvist, L. Gunderson, C. S. Holling, B. Walker, J. Bengtsson, F. Berkes, J. Colding, K. Danell, M. Falkenmark, L. Gordon, R. Kasperson, N. Kautsky, A. Kinzig, S. Levin, K-G. Mäler, F. Moberg, L. Ohlsson, P. Olsson, E. Ostrom, W. Reid, J. Rockström, H. Savenije and U. Svedin (2002): *Resilience and sustainable development: building adaptive capacity in a world of transformations.* The Environment Advisory Council. Ministry of the Environment, Sweden

[12] Walker, B., C. S. Holling, S. R. Carpenter, and A. Kinzig (2004): Resilience, adaptability and transformability in social–ecological systems. Ecology and Society **9**(2): 5[Online], Folke et al (2002): see Footnote above

Although a number of examples of thresholds in coupled social ecological have been identified[13], the science community is still a long way from identifying any clear generalisations about what makes one system more resilient than another, or where the limits of resilience in a given system may lie. Specifically the literature review suggests:

- That neither thresholds nor resilience are constant properties, and that the extent to which resilience changes as thresholds appear is unknown;
- That although systems exhibiting both reversible and irreversible regime shifts have been examined, no system attributes could be identified that enable the type of threshold behaviour the exhibit to be predicted;
- Changes in scale appear to influence resilience and the positions of thresholds;
- As thresholds are crossed, different types of feedback are observed within the system, depending on which regime prevails;
- That regime shifts can be triggered by external shocks or by gradual change in a controlling variable;
- That management difficulties often arise because the possibility of threshold responses are unexpected or ignored; and,
- The consequences of crossing a threshold are context dependent, in that they are determined by what people judge the significance of crossing a given threshold to be in a particular situation at a particular time.

It is also acknowledged[14] that in practice it is difficult to identify a threshold before it is crossed.

We therefore conclude from our review that, despite its promise, the notion of resilience presently has little to offer in terms of any secure, practical, or general understanding about how environmental limits or thresholds might be identified, or what makes one system more resistant to disturbance than another. However, it is also apparent from this review that a sound conceptual framework for understanding the links between environmental and social systems is urgently required if we are to manage natural resources in a sustainable way.

2.2.3 The Millennium Assessment and the Concept of Ecosystem Goods and Services

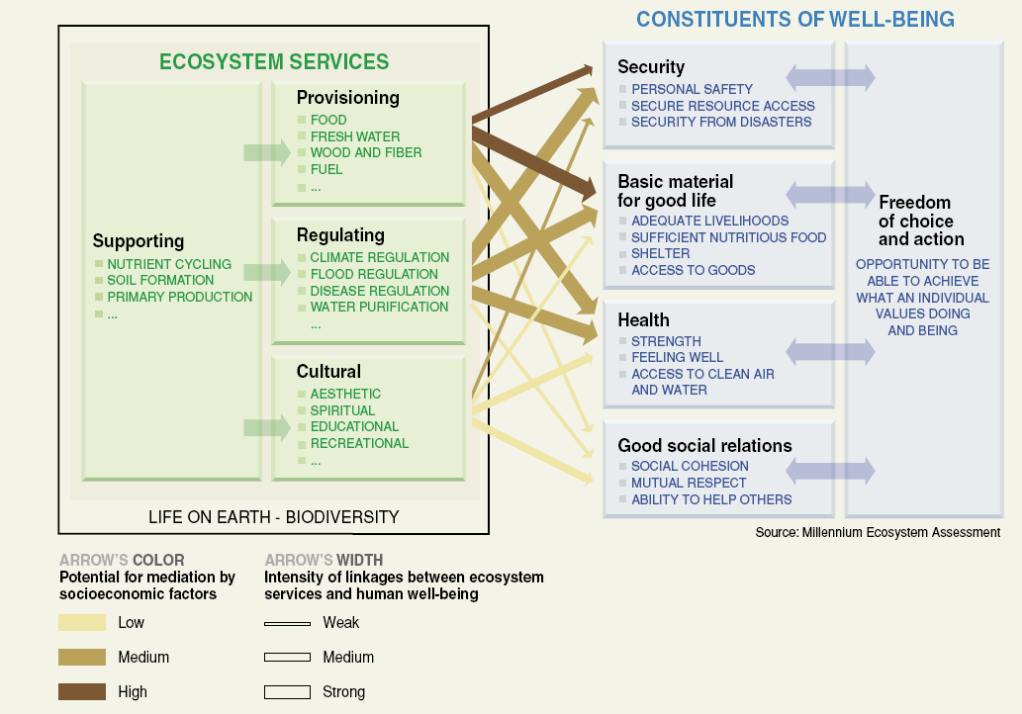
The idea ecosystems can generate goods and services grew out of the observation that ecological systems, and the biological diversity contained within them, can provide a number of important benefits to people (Figure 6). Recent interest in the idea has been stimulated by the 'Millennium Ecosystem Assessment'[15] (MA), which has sought to better conceptualise the relationship between ecosystems and the services they provide, to document the current status of ecosystem goods and services at the global scale, and to identify the future risks to which they might be subjected.

[13] Walker, B. and J. A. Meyers (2004): Thresholds in Ecological and Social–Ecological Systems: a Developing Database. *Ecology and Society* **9**(2): 3 [Online].

[14] Carpenter, S. R., F. Westley and M. G. Turner (2005): Surrogates for resilience of socio-ecological systems. *Ecosystems* **8**: 941-944.)

[15] http://www.millenniumassessment.org/en/index.aspx

Figure 6: Linkages between Ecosystem Services and Human Well-being (MA, 2005a)



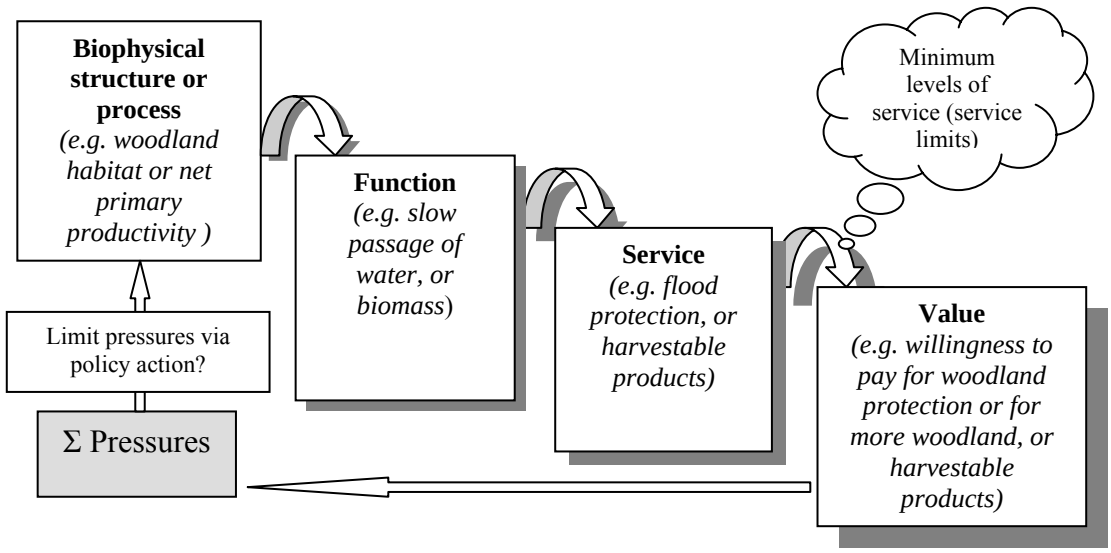
The structure of the MA, with its requirement that all evidence should be peer reviewed, together with the wide international support that the initiative received, means that both the conceptual approach and the results have considerable authority. While the Assessment has drawn upon concepts such as ecosystem health and resilience, it is also a much looser and simpler theoretical framework that places the analysis of the relationship between ecosystems and human well being at its centre. As a result, it is more pragmatic and empirical in its outlook compared to the other frameworks of 'ecosystem health' and 'resilience'. Its key ideas can also be more easily communicated and used by decision makers and policy advisors. The clear demonstration that the MA has given of the importance of ecosystem services for human well-being means that, potentially, a much stronger case for the environment can be made.

Our literature review suggested that the MA has both strengths and weaknesses, however. Its major shortcoming is that, as a result of lack of data, it is incomplete. Moreover, since it was directed at the global scale, its relevance for the UK is more to provide context for policies rather than a strong evidence base to underpin their detailed development.

The key strengths that the MA has are the consistency of its approach, its strong interdisciplinary character, and the template it offers for refining the analysis at, regional, national and local scales. Compared to the paradigms of ecosystem health and resilience, we consider it to be a more promising framework in which to refine thinking about limits and thresholds for policy.

The logic that underlies the idea that the biophysical structures or processes associated with ecosystems can give rise to sets of functions that may provide services that are valued by people is described in Figure 7. Thus a biophysical structure, such as

Figure 7: The relationship between biophysical systems, functions, services and values



woodland, may have the functional ability of slowing the passage of precipitation through a river basin, and this function may in turn give rise to the service of flood protection to which people might ascribe a value. Alternatively a process such as primary productivity may provide biomass that can harvested, and those products may also have a value to society. In both situations, depending on the values assigned, the minimum levels of service required, and perceptions of the risks that may threaten continued supply, society may take a view of how particular or cumulative pressures that impact on the biophysical system should be modified.

While we may accept that ecosystems are holistic, complex systems, the framework shown in Figure 7 focuses attention on the causal chain that gives rise to a specific service. It also emphasises that decisions about minimum levels of that service and the values placed upon it are fundamentally determined by people, and cannot be decided on 'scientific' grounds alone. The advantage of the framework is that creates a space in which resource managers and policy advisors can open a dialogue with people or groups who depend on a given service or whose activities might impact upon it to determine an appropriate strategy through which it might be sustained. Finally it advances the debate about the importance of engaging with the social and economic context of natural resource systems, by identifying tools and approaches that can be used to explore the issues that arise at the interface of people and the environment.

2.2.4 Sustainable Consumption and Production

As part of our review of the concept of environmental limits and thresholds, we though it valuable to explore the recent literature dealing with notions of sustainable consumption and production (SCP). Consideration of these materials is important because it brings out current debates about the levels and rates of consumption of physical resources (e.g. water, minerals, etc.) and the pressures that production might

have on the wider physical and biological environment through the generation of waste (e.g. carbon emissions on climate).

Our review suggests that a focus recent discussions of SCP is the assertion that wise environmental stewardship requires modern societies to 'achieve more with less'[16]. There is, of course, much disagreement about how this can be achieved, or how progress towards this goal can be measured[17]. However, common to all strategies is the notion that despite human development, we need to create some kind of 'ecological space' to ensure the integrity of the life support systems on which life depends. The identification of the limits that enclose this space is seen as a key, but unresolved research issue. Nevertheless, the imperative of changing consumption and production patterns is one of the overarching objectives of and essential requirements for sustainable development, as recognized by the Heads of State and Governments in the Johannesburg Declaration[18].

A number of normative frameworks have been proposed to achieve more sustainable patterns of consumption and production, including such concepts or metaphors as the 'ecological footprint'. We found that the approach of the UK Framework for Sustainable Consumption and Production[19] reflects a number of the themes identified in the literature and that the core objectives were well founded. The objectives are:

- Decoupling economic growth from environmental impacts,
- Identifying the key impacts associated with the use of particular resources; and,
- Increase in the efficiency of resource and energy use.

The question defining limits is particularly relevant in the context of the UK Framework, because it seems clear that one cannot judge whether an indicator shows decoupling unless we have some idea about what limits apply.[20].

Our review of the UK SCP Framework in the context of the wider SCP literature, led us to pose a series of questions that we felt might be explored once the other aspects of this and the associated parallel studies sponsored by Defra study were completed. The questions were:

- If we accept that progress towards more sustainable patterns of consumption and production can be measured by the extent of decoupling economic growth from environmental impacts and improving the efficiency of energy and resource use, then does the present approach capture all the important aspects that need to be considered?
- Through what causal chains are pressure indicators used by the SCP Framework linked to other systems or processes that deliver benefits to people, and how

[16] http://www.sustainable-development.gov.uk/documents/publications/strategy/Chap%203.pdf

[17] Cohen, M.J. (2005): Sustainable consumption in national context: an introduction to the symposium. *Sustainability: Science, Practice, & Policy* **1(1)**: 22-28. Published online February 8, 2005. http://ejournal.nbii.org/archives/vol1iss1/0410-008.cohen.html.

[18] http://www.un.org/esa/sustdev/documents/WSSD_POI_PD/English/POIChapter3.htm

[19] See for example, Defra (2003) Changing Patterns, The UK Framework for Sustainable Consumption and Production, http://www.defra.gov.uk/environment/business/scp/pdf/changing-patterns.pdf , and http://www.defra.gov.uk/environment/statistics/scp/download/scp_rpt200506.pdf

[20] Ekins, P. (2003): A draft response from the Sustainable Development Commission to The Joint DEFRA/DTI Consultation Paper Sustainable Consumption and Production Indicators. London, Policy Studies Institute)

might the integrity of those systems be threatened by present or increased levels of consumption or production?

- How can we use information about the pressures on systems that deliver benefits to people to specify limits for the basket of consumption and production indicators?
- Are pressure indicators the most appropriate tool for measuring trends in consumption and production patterns, or should the basket of measures also include state and impact indicators to measure the direct effect which those pressures have on key systems?
- Given that the environmental pressures arising from consumption and production may impact upon a number of systems that deliver benefits to people then, if we use information about those impacts to define sustainability, how and who should decide what priorities should prevail and what types of value are applied?
- How do we achieve an integrated view of the pressures resulting from patterns of consumption and production at different geographical scales, to ensure that unevenness of outcomes does not disadvantage particular groups?

In the final part of this report we will discuss what insights can be offered from a review of the topic areas that were asked to consider in our brief.

2.3 Values and the Problem of Limits and Thresholds

Although the problem of how environmental assets and natural resources are valued was not part of the brief for this study, our review of the conceptual frameworks dealing with ecosystem goods and services and sustainable consumption suggested that it needed to be considered. The review suggested that it is unlikely that environmental limits can be identified using only biophysical criteria. The significance people attach to both continuous changes in state and a catastrophic regime shifts depends on value they attach to the loss of outputs or benefits. Thus, before we went on to explore the evidence base about limits and thresholds in detail, felt it necessary to examine how thinking about them is also informed by recent debates concerning problem of valuing environmental assets.

The literature suggests that three types of value can be identified in relation to an environmental system:

- **Economic value,** which is expressed in terms of the monetary value people or societies are prepared or able to attach to the different functions.
- **Ecological value**, which is an expression of the importance of the ecosystem, determined by such criteria as the integrity of, for example, its regulatory functions, and by ecosystem properties such as diversity and resilience; and,
- **Socio-cultural value,** which is determined by considerations such as equity or justice, or conceptions of natural systems that are rooted in religious, cultural or philosophical beliefs.

It has been argued that these three dimensions of value need to be separated out because the balance between them may change as critical limits or thresholds are approached. A number of tools now exist to help calculate the Total Economic Value (TEV) of an environmental asset. TEV is not a measure of the absolute value, but rather the ***marginal*** worth that attaches to an additional unit of the service when all other factors are held constant. It is useful to try to calculate TEV because it allows us

to compare the marginal benefits that a consumer would derive from a given ecosystem good or service, against the benefits that might arise from some other type of expenditure.

It has been argued[21] that the calculation of marginal value is only possible when coupled social-ecological systems are far from unstable thresholds. In a 'marginal regime' there is high degree of certainty and so individuals are well placed to make decisions about trade-offs and substitutions. In such a regime, it is suggested that human preferences are best expressed in terms of such marginal values.

The same commentators go on to argue that close to an unstable threshold other valuation criteria appear to apply. When faced with collapse questions of trade-offs and substitution of benefits are no longer paramount. To cope with these situations 'risk avoidance' strategies are required, and these depend on criteria that equate more closely with ideas about ecological values, which emphasise properties such as resilience and ecosystem integrity, or environmental space than marginal value. Risk avoidance can also involve the types of ethical criteria emphasised by social valuation. Issues of rights, inter-generational equity and environmental justice may arise if the loss or collapse of ecosystem function impinges on human health or welfare.

We note from our review of the literature that there is considerable debate about whether or not economic valuation is helpful or relevant when environmental systems are unstable or near to collapse. Fortunately it is not necessary to resolve the issue here. What is important to note for this study is that we need to question what types of value are being applied when different types of limits and threshold are proposed. In making our review of the topic areas specified in the study brief, we have therefore attempted to identify what value frameworks are being used.

[21] Limburg, K. E., R.V.O'Neill, R. Costanza and S. Farber (2002): Complex systems and valuation. *Ecological Economics* **41**: 409-420.)

Part 3: Exploring the Evidence Base

3.1 Biodiversity

Our review of limits and thresholds confirms that the concepts are highly relevant to the development of management strategies and policies for biodiversity at the species and habitat level. Unfortunately in terms of developing guidelines for the identification of limits and thresholds, few theoretical generalisations can be made. Observed responses appear to be species and habitat specific, and may be crucially dependent upon the spatial and temporal scales considered. The uncertainties involved in defining limits or identifying thresholds arise from lack of basic information at species and habitat level, and in particular, from the lack of long term monitoring data.

Nevertheless, in the UK our review suggests that we are well placed to develop the evidence base that decision makers need, by exploiting information that is emerging from the *2005 Biodiversity Action Plan (BAP) Target Review*[22]. **The data presently being collated will allow gaps in the existing information base to be identified in relation to key limiting factors such as population size and range for BAP species, and the extent, quality and fragmentation of BAP priority habitats.** The work on BAP targets could provide a platform on which to build a similar body of information for the more common species and habitats associated with the wider countryside.

In the accompanying technical report, we make a number of detailed recommendations about how the materials being assembled during the BAP targets review can be exploited. They include taking steps to:

- Review the types of evidence used to determine whether the 2030 target is achievable, and what types of limit are thought to apply.
- Consider whether the revision of targets up or down has been based on the availability of addition scientific information about limiting factors, or is mainly based on practical experience gained from attempting to implement the original targets.
- Using the review to document evidence about pressures and threats to biodiversity, so that it can be linked to the other work being undertaken by Defra on environmental pressures;
- Examining the extent to which all species and habitat level targets are compatible and what types of criteria can be used to resolve potential conflicts.
- Document the magnitude and range of ecosystem goods as services associated with the BAP Broad and Priority Habitats so that the risks associated with them (e.g. climate change, alien species) can be assessed and their 'marginal' values more easily calculated.

3.2 Land Use and Landscape

The review of limits and threshold concepts in relation to land use and landscape was amongst the most challenging of all the areas we were asked to consider, because it overlaps with many of the other thematic areas covered in this study, such as biodiversity, water and soil. However, it was valuable to consider the theme because it

[22] http://www.ukbap.org.uk/GenPageText.aspx?id=98

is clear that the 'real world', natural resource issues often have to played out alongside each other, and it is useful to consider them in an integrated way through the 'prism' of land cover or landscape. In order to constrain the scope of the review we focused our work around the notion of 'multi-functionality' and posed the question - *in multifunctional land use mosaics or landscapes, what kind of limits and thresholds can be identified?*

As in the case of biodiversity, we found that the current literature contains a number of example, where the identification of limits in relation to land use and landscape structure have been identified, and where coupled social-ecological systems at the landscape scale show 'threshold dynamics' (i.e. alternative stable states)[23]. However, the literature lacks any secure theoretical insights that can be used to develop general guidelines for policy or management action. Rather, it seems that we need generic tools to help us explore the complexities of specific situations and issues.

3.2.1 Land Accounting

In terms of developing the evidence base needed for the identification of limits in this topic area, our work suggested that the concept of land cover accounting was a particularly useful one because it posed a series of challenging questions about the nature of the transformations taking place in land cover/use mosaics, and the 'critical points' might be crossed as change occurs. For example, in the context of the goal of sustainable development, we may look at the land cover/use changes over an 'accounting period' and ask:

- Do the gains in cover or use compensate for the losses?
- Is the quality of the stock carried over maintained, in the sense that retains its capacity to sustain or expand a given suite of uses or to provide a particular set of benefits?

Our review suggested that approaches to land accounting are now developing rapidly in Europe and that it would be valuable to broaden the information base available in the UK by exploring how the simple land cover accounts that are presently published by National Statistics[24] as part of our national environmental accounts can be extended. This could be done by:

- Drawing upon a wider range of available data to make a more detailed analysis of changes in both land cover and land use,
- Analysing the relationship of changes in land cover and use to activity levels across the key sectors of the economy; and,
- Tracing the implications for habitats and ecosystem services, particularly relation to the quality or levels of benefit.

3.2.2 Landscape Goods and Services

A discussion of the relationships between land cover and the multiple uses that it can support clearly has a close connection with ideas about ecosystem goods and services. Specific land uses may depend on particular ecosystem functions (e.g. forest products depend on woodland productivity) and be the means though which value of those

[23] Walker, B. and J. A. Meyers (2004): Thresholds in Ecological and Social–Ecological Systems: a Developing Database. *Ecology and Society* **9**(2): 3 [Online].

[24] http://www.statistics.gov.uk/statbase/Product.asp?vlnk=3698

functions are realised (e.g. forestry as a source of economic well-being). However, the relationship between land use and ecosystem goods and services is also problematic because there are some ecosystem functions that arise at scales beyond the individual land parcel. It is in this context that it is particularly useful to think about landscape. Landscapes, like individual land cover parcels, can have multiple uses; the difference is that the uses identified at the landscape scale are dependent not only on the properties of the parcels themselves, but on the mix and spatial relationships between all parcels in the overall mosaic.

Our review of the literature suggests that while the notion of ecosystem goods and services is widely discussed, only limited attention has been paid to the idea of goods and services at the landscape scale[25]. The concept is, however, a particularly important on in a countryside such as the UK, where landscapes provide not only a stream of benefits from nature, but also from our rich cultural and social heritage. Our review suggests that the landscape focus is not really a competitor to the notion of ecosystem goods and services, but as a way of operationalising it in the real world, where natural capital has to be considered alongside the other capitals[26] on which people depend.

The advantages of a landscape level approach are partly illustrated by the *Countryside Quality Counts* Project, which is using the spatial framework of the Joint Character Areas of England to resolve two key questions:

- Where is countryside change occurring?
- Do these changes matter?

The analysis uses information acquired by consultation with stakeholders to identify the limits of acceptable change in relation to maintaining patterns of local distinctiveness. **Given the goal of trying to ensure that development occurs within environmental limits[27], our review suggests that a landscape approach may be one way of defining the sustainability choice space, within which spatial planning decisions are made[28].**

3.3 Recreation and Access

3.3.1. Carrying capacity

In the literature relating to recreation and access to the natural environment, the term **carrying capacity**[29] has been widely used to express the notion that some limit to use might exist. In its simplest form, concept suggests that a particular place could sustain indefinitely a particular intensity of use providing it is at its capacity or use limit, but beyond this, additional pressure would produce undesirable resource degradation.

Unfortunately, despite various attempts to apply the concept in decision making, progress has been limited. Various commentators have claimed that there is either

[25] See for example De Groot, R. (2006): Function analysis and valuation as a tool to assess land use conflicts in planning for sustainable, multi-functional landscapes. *Landscape and Urban Planning* **75** (3-4): 175-186.

[26] http://www.forumforthefuture.org.uk

[27] ODPM (2004): Planning Policy Statement 11: Regional Spatial Strategies. Stationary Office, London

[28] Potschin, M. and R. Haines-Young (2006): Rio+10, sustainability science and Landscape Ecology. *Landscape and Urban Planning* **75** (3-4): 162-174.

[29] Sometimes 'recreational carrying capacity' or 'tourism carrying capacity'

little empirical evidence to support it, and that the concept is itself 'seriously flawed'[30]. A key issue that seemed to undermine the concept of carrying capacity was that its advocates assumed that it could be calculated objectively. Critics argue that from the outset the application of the approach involves value-based decisions about what the important qualities and functions of a site are, and how they should be used to define such limits. In response either other approaches, such as the assessment of the *Limits of Acceptable Change*[31] have been tried, or workers have confined themselves with the assessment of recreational impacts on specific site properties or characteristics (such as tranquillity).

3.3.2 Objectives rather than limits?

In turning away from notions that a general limit or carrying capacities for recreational pressure could be defined, resource managers have become more concerned with identifying resource management *objectives*, because these are more easily defined in a practical situation. Objective setting usually results in the specification of indicators and targets or standards, by which a site or an area can be managed, and only implicitly acknowledges that limits may exist. Examples of recent objective led approaches include the 'greenspace' targets suggested by English Nature[32].

The materials we have reviewed in the area of recreation and access suggest that notions of limits and thresholds are perhaps of restricted value in developing management strategies for recreation, and that objective or target-based approaches are more indeed appropriate. In fact, it could be argued that in the UK the objective- or target-led approach to managing recreational use of the countryside is well established, as is evidenced by the successful management plans that have been developed for our protected landscapes and the wider countryside. However, this is probably an over simplification.

Our review suggests that consideration of limits and capacities will re-emerge in this topic area to inform objective- and target-led management strategies, not by trying to develop better direct measures the physical or social capacities of a place, but through the analysis of the factors that constrain that social, cultural and economic values imply for its use. Such work on the value of the natural environment for recreation and access is likely to be informed by current work involving the valuation of environmental resources based on people's willingness to pay and willingness to travel, and by the marginal values they place on changes in the outputs of ecosystem goods and services associated with the places they visit.

Our review suggests that an additional way in which the evidence base could be developed in this topic area, particularly in relation to issues concerning sustainable consumption and production, would be to build an environmental account around the recreational issue. A prototype approach has been developed by the European Environment Agency. Such an account would help identify the pressures associated with recreation and the linkages they have with other sectors of the economy and the natural environment.

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[30] Price, D. (1999): Carrying capacity reconsidered. *Population and Environment* **21** (1): 5–26.

[31] Krumpe, E. E. (2000): The Role of Science in Wilderness Planning — A State-of-Knowledge Review. *USDA Forest Service Proceedings* **4** (RMRS-P-15): 5-12.

[32] http://www.english-nature.org.uk/special/greenspace/

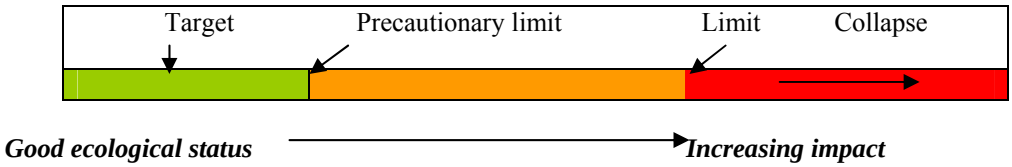
3.4 The Marine Environment[33]

3.4.1 Reference points and targets

The UK Marine Stewardship Report, *Safeguarding our Seas* (Defra, 2002) sets out the Government's vision for the marine environment, which is broadly for a 'clean, healthy, safe, productive and biologically diverse oceans and seas, and to have made a real difference in one generation'. The ecosystem approach is at the heart of the strategy; it seeks to promote understanding of the current ecological status, the identification of ecosystem properties that are structurally and functionally important, and the threats to which they are subject.

The goal of achieving a healthy marine ecosystem means that issues need to be resolved across a range of sectors and policy areas[34]. For example, it might focus on water quality issues and relate to nutrient loadings, or it might be defined from a fisheries perspective and involve considerations of the maximum sustainable level of benefits that can be achieved from a fishery. Common to all, however, is the fact that in setting objectives, it is accepted that there should be some understanding of the ***limits*** beyond which pressures will cause unacceptable harm to the marine environment, and that ***targets*** need to be met if the overall quality of the marine environment is to be achieved or the risks to which it may be exposed are to be minimised.

Figure 8: Relationship between target, precautionary and limit reference points (EC, 2004)



Discussions of limits, particularly in relation to the need to protect systems from crossing thresholds between alternative stable states, or where complete collapse occurs, are frequent in the literature, especially in relation to the maintenance of commercial fishing stocks. As a result sophisticated systems limits have been defined, involving identification of indicators of the health of the system, and the specification of limits, or 'reference points', that might trigger different levels of policy or management response (Figure 8). Precautionary reference points are generally set to ensure that irreversible harm does not occur. Thus, in the context of an individual fish stock, where data on actual limits of viability are unavailable, the precautionary limit may be set using the lowest biomass observed from historical records.

[33] Chapter 3.4 draws heavily on the position paper by Agnew, D. (2006): Marine Environment. Unpublished Position Paper for Scoping Study on "Defining and Identifying Environmental Limits for Sustainable Development, funded by D*efra*.

[34] Rogers, S.I.; Tasker, M. and D. Whitmee (2005): A draft technical paper to support the development of marine ecosystem objectives for the UK. Ecosystem Objectives background paper (unpublished).

The literature describing approaches to setting limits for fisheries is of interest in the context of the present study because it illustrates the situation where even though a limit has been agreed, this critical value is not taken to mean that the systems should be managed at this level. Rather, for fisheries and marine systems more generally, it is argued that on grounds of caution, it is more appropriate to aim to manage at some higher target condition, where the status of the system is judged to be favourable or good. In fact, the European Marine Strategy has proposed that meeting the objectives for good ecological status will only be achieved by achieving targets, rather than avoiding limits. **The literature from marine systems is therefore of interest because it suggests that more extensive consideration should be given over to the relationship between limits and targets than has been apparent in the topic areas described to this point. It is certainly an issue that we will return to in the final part of this Report.**

3.4.2 Reference points for marine ecosystems

Although the theory and application of reference points for single species fisheries is well established, our review suggests that the development of reference points for other ecosystem components is much less well advanced. This poses a particular challenge in terms of implementing an integrated ecosystems approach to the management and protection of the marine environment, where it is generally accepted that a suite of indicators are required to describe the integrity of the system. Such a suite could include[35]:

- Indictors relating to the condition of populations in relation to disease and contaminant loads;
- Indicators relating to the population status of individual species;
- Indicators based on the status of community properties, such as richness, diversity; and,
- Indicators of ecosystem function, such as tropic structure and dynamics.

Given that many marine systems are, in fact, 'coupled socio-ecological systems' it is possible that this list should be extended to include elements from the social and economic realms.

In terms of the robustness of the evidence base available to policy customers and managers, there appears to be scant information or understanding about the kinds of reference points that might be constructed around these wider indicators of ecosystem structure and function, and how these limits vary over time and space. **Our review suggests that further work is required:**

- **To understand how the limits and targets identified across each of the ecosystem dimensions should be compared or combined, since objectives may not always mutually consistent.** This is particularly important in the context of developing a more representative set of sustainable consumption and production indicators for the marine sector.
- **To understand how those limits and targets might need to be adjusted over time in the light of changes in external drivers such as patterns of human development or climate change.**

[35] Rogers, S.I.; Tasker, M. and D. Whitmee (2005): A draft technical paper to support the development of marine ecosystem objectives for the UK. Ecosystem Objectives background paper (unpublished).

3.4.3 The need for deliberative approaches to management

The identification of limits is often proposed as one way of guarding against the risk of collapse in marine systems. However, the need to develop integrated approaches to ecosystem management poses a considerable difficulty, because society will need to decide what limits or reference points should apply, how they should be prioritised and how trade-offs between different targets might be achieved. Our review suggests that it is widely accepted that it is unlikely that challenges will be resolved simply by more scientific research, but rather by using the evidence in the context of deliberative approaches to resource management. Such a conclusion is consistent with the view developed in the Millennium Assessment, and in the recent report of the Royal Commission on Environmental Pollution, *Turing the Tide*[36].

3.5. Water Supply and Demand[37]

3.5.1 Introduction

Our review identified three pressure points with implications for environmental limits, that are likely to emerge at global scales at different times in the future in relation to water quality, supply and demand[38]:

- in the short (20 year) term, human impact on the 1% of freshwater that is readily available in rivers and lakes is likely to increase, and so needs to be very carefully managed;
- in the mid (20-50 year) term, improving and protecting groundwater quality will be essential for the sustainable management of the freshwater environment; and,
- in the long (50 year +) term, climate change impacts on water bound in snow and ice will have far reaching but unpredictable impacts on the water environment.

Since issues of climate change and pollution loads to aquatic systems has been discussed elsewhere in our study, this section deals with only the first two sets of pressures.

The recent debates surrounding the ideas about integrated water management and the sustainable use of water have emphasised the importance of thinking about limits and thresholds in a wider ecosystem context. Policies relating to water supply have in fact begun to move away from simply seeking to ensure maximum extraction of available water for Society, to perspectives that emphasise the wider benefits that river and lake systems have to people. The concept of 'environmental flows' is now one actively

[36] Royal Commisson on Envronmental Pollution (2004) *Turing the Tide,* http://www.rcep.org.uk/fisheries/englishsummary.pdf

[37] Chapter 3.5. draws heavily on the position paper by Heathwaite, A.L. (2006): Water Quality, Supply and Demand. Unpublished Position Paper for Scoping Study on "Defining and Identifying Environmental Limits for Sustainable Development, funded by D*efra*.

[38] Gleik, P. H. (2000) The World's Water 2000-2001. Washington DC, Island Press.

being promoted, for example, by the IUCN (see Dyson et al., 2003) and other international bodies[39].

The importance of the environmental flow concept is that it sets up a framework in which the delivery of ecosystem-related goods and services can be considered, and the relative values that people associate with them brought into sharper focus. They are therefore particularly relevant in the context of debates about sustainable consumption and production, because they show how notions of sustainability might need to be redrawn once the wide consequences of maintaining particular levels of consumption are considered. With the scenario approaches that discussions of environmental flows foster, the marginal costs and benefits of different management options can potentially be considered and communicated more effectively.

With the exception of lakes, freshwater systems do not generally exhibit threshold type dynamics, with rapid regime shifts. Rather, changes are thought to be a gradual process[40]. The limited evidence for regime shifts in the freshwater environment may be a consequence of the large bulk of the freshwater stock – groundwater – being subterraneous and consequently difficult to monitor. This does not mean that thresholds are not crossed; just that they are much more difficult to detect.

3.5.2 *Diffuse Pollution: land use pressures, sediment transport and aquatic ecosystem health*

In the short term, human impact on the freshwater that is readily available for exploitation in rivers and lakes requires careful management if the quality and quantity of the resource is to be sustained. Human activities have increased the availability of nutrients such as nitrogen and phosphorus in freshwater and coastal environments. Although it is known that changes to nutrient loadings to ecosystems affect carbon and nutrient transformations, the literature suggest that predicting the responses of ecosystems to nutrient loading is difficult because multiple factors regulate biogeochemical transformations in freshwater and coastal ecosystems. The sources of elevated nutrient loadings are relatively well-understood, and much work has focused on how they might be limited through regulation.

Reduction in point source nutrient loadings from, for example, sewage treatment works, has shifted the emphasis to agricultural diffuse pollution as a significant threat to the long term sustainability of freshwater ecosystems. Diffuse pollution is a critical issue because the cost of tackling only the tangible aspects of diffuses pollution from agriculture in the UK has been estimated by be around £300 million per year (Pretty et al., 2003). However, approaches to policy have largely been target-led rather than driven by the identification of limits. Reducing diffuse pollution is, for example, a central aim of the UK Government's Sustainable Food and Farming Strategy (Defra 2002) and is critical if Public Service Agreement targets to bring 95% of SSSIs into 'favourable' condition by 2010 are to be met.

The environmental consequences of land management decisions include the degradation of freshwater ecosystems, increased water treatment costs and reduced aesthetic value. The main physical drivers of these processes have been identified (*e.g.* for water quality degradation they include sediment-associated contaminants,

[39] Dyson, M., Bergkamp, G. and J. Scanlon (Eds.) (2003): Flow. T*he Essentials of Environmental Flows*. IUCN, Gland/Switzerland and Cambridge/UK. Xiv + 118 pp. http://iucn.org/themes/wani/pub/FLOW.pdf

[40] www.apis.ac.uk

livestock waste disposal, and pesticide and veterinary medicines). However, from a social and economic perspective, the impacts of these drivers are largely *external* to the agricultural system and are not factored into decisions. Consequently, limits for freshwater ecosystems are not linked to the land management decisions that may be causing their deterioration. Only recently has this *status quo* started to change towards more risk-based evaluation of land-water causality. The source of this change is primarily legislative in the form of the WFD but also in terms of the reform of the Common Agricultural Policy (CAP) away from headage payments and towards environmental stewardship via the Entry Level Scheme (ELS) and Higher Level Scheme, and such initiatives in the water industry as the Asset Management Planning Round Four (AMP 4). The latter is the process by which the Office of Water Services (Ofwat), determines the level of water charges required to fund future improvements in water infrastructure and environmental performance[41]. Risk-based management is a relatively new science involving uncertain decisions and thresholds are as yet difficult to discern. Much risk-based science follows the DPSIR (drivers, pressures, states, impacts, and responses) modelling framework for risk forecasting[42] .

While the control of diffuse pollution is a major theme in the literature, issues arising out of sediment transport are also important. Sediment plays a major role in the transport and fate of pollutants and is of critical concern in water quality management. Toxic chemicals can become attached, or adsorbed, to sediment particles and then transported to and deposited in receiving waters. Unlike water, sediments can be long-term or permanent sinks for contaminants in rivers and lakes, posing a risk to ecosystem function, water resources and human health. River beds are transitional environments between groundwater and surface water, and are known to be both a sink and source of fine organic and inorganic sediment and associated pollutants, including phosphorus. Stream borne sediment directly affects fish populations through reduced light penetration and increases susceptibility to disease through irritation of the gills, scales and mucous covering the eyes.

Our review suggests that, traditionally, environmental research has been compartmentalised in different sectors (e.g. air, land, water) and has been integrated across the different compartments[43]. The holistic approach to river basin management required under the Water Framework Directive has recently pinpointed the strategic importance of understanding sediment sources, pathways and sinks as a controlling 'switch' on aquatic ecosystem health.

[41] http://www.publications.parliament.uk/pa/cm200304/cmselect/cmenvfru/121/121we13.htm
[42] www.org.eea.eu.int
[43] Harris, G. P. and Heathwaite, A. L. (2005) Inadmissible evidence: knowledge and prediction in land and riverscapes. Journal of Hydrology. February 2005.

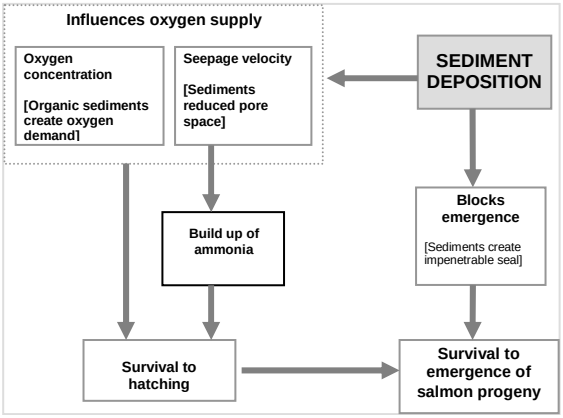
Figure 9 illustrates the controls and potential limits for the impacts of fine sediments in rivers[44]. It shows the complexity of the links from sediment deposition to ecological impacts and begs the question as to whether ecologically acceptable levels of fine sediments can be set in rivers for e.g. salmon. Current research[45] suggests that limits cannot be defined at the river reach scale, and probably not at river scale, because salmon spawning depends on a combination of factors and these factors vary in time and space. The causes of low pre-emergent survival of salmon appear to be river-specific, which means that it is difficult to set ecologically acceptable levels of fine sediments in rivers. Preliminary research suggests, however, that oxygen flux is a critical factor in spawning success. Elevated nutrient loads generate increased organic matter detritus which in turn increases the sediment oxygen demand; the latter appears to be an important control on spawning success but to date there is no research to indicate appropriate levels for fine sediments in rivers. The evidence base needs to be better developed in this area.

3.5.3 Sustaining Groundwater Quality

In the mid term, improving and protecting groundwater quality will be essential for the sustainable management of the freshwater environment. The challenges are already been felt in the context of water abstraction, saltwater intrusion into groundwater bodies, wetland sustainability, and water treatment to maintain the quality of water supplies.

The quality of groundwater in UK aquifers has deteriorated significantly over the last few decades. The UK Groundwater forum[46] estimate that around 2450 Ml per day, almost 50% of the groundwater used for public supply is affected by quality problems. Research funded by UK Water Industry Research Limited (UKWIR) and the Environment Agency found that deteriorating groundwater quality in the UK has cost the water industry c. £754 million since 1975 – over 60% was spent on treatment schemes, 17% on blending, and 24% on replacement water to compensate for source closures. The costs reflect a combination of deterioration in groundwater quality and more stringent regulatory standards for drinking water. The capital and operating costs of groundwater treatment

Figure 9: Controls and potential limits for the impacts of fine sediments in rivers (modified from Sear et al, 2003)[43] .



44 Sear, D., Greig, S., Carling, P. and Whitcombe, L (2003) The impact of fine sediment on Salmon: Implications for the management of fine sediment in UK rivers and catchments. Defra Phosphorus Coordination meeting, 8 May 2003.

45 Greig, S.M., Sear, D.A. and Carling, P.A. (2005) The impact of fine sediment accumulation on the survival of incubating salmon progeny: Implications for sediment management. Science of The Total Environment, 344: 241-258

46 (www.nwl.ac.uk/gwf)

for the water utilities are passed on to the consumer through water charges. Groundwater contaminants come from two categories of sources: point sources and diffuse sources. Landfills, leaking gasoline storage tanks, leaking septic tanks, and accidental spills are examples of point sources. Infiltration from farm land treated with pesticides and fertilizers is an example of diffuse sources. Clearly there are links here between diffuse pollution of rivers and lakes as described in the section above and the contamination of groundwater resources. To date, much of the concern has focussed on nitrate contamination. However, recent evidence suggests that phosphorus in groundwater may be a potential future problem. Phosphorus contamination of groundwater may occur were there are high densities of septic systems. Problems with septic systems worsen when communities that rely on subsurface disposal systems also depend on private wells for drinking water.

3.5.4 Developing the evidence base

The use of environmental indicators or thresholds for freshwater systems has been developed to describe the state of the ecosystem, and to indicate the risks that it might move to a less-favourable status. Such systems have only recently been incorporated into land management schemes, largely in response to the Water Framework Directive (WFD) that is requiring an holistic approach to the management of aquatic ecosystems. The concept of environmental flows (Dyson et al., 2003) illustrates particularly well, how a more integrated approach to the management of water supply might be developed. Such ideas could clearly be applied to other topic areas where decisions are needed about what levels of resource consumption are consistent with the broader goals of sustainability.

Most uncertainties relate to the quality of the available data and the scale at which is it collected. Integrated treatment of water quality and water supply and demand issues require data from many disciplines to be brought together. Often such data and conceptual models are built around research that spans large spatial and temporal scales. Future research is needed to identify limits in the context of new approaches to integrated catchment management, sediment transport and fate, groundwater quality evaluation and measures, and diffuse pollution modelling. The AMP4 Process, involving the identification of pollution control measures required to ensure good water status of SSSIs, illustrates how to achieve this, despite uncertainties.

It should also be noted that many of the approaches for river basin management and sustainable water management in use today were not designed to deal with indeterminacy in decision making, particularly about new investments to meet the requirements of, for example, legislation like the Water Framework Directive (WFD). Thus as in the other topic areas covered by this study, the recent literature suggests that deliberative styles of decision making are likely to become increasingly important in the context of managing issues related to water quality, supply and demand.

3.6 Climate Change[47]

The issue of climate change and the implications that it may have for the integrity of natural resource systems and human societies dominates current research and policy agendas. The topic area is a vast and complex one, and so in our study we focused only on the position that the concepts of limits and thresholds have in current debates.

3.6.1 Gradual vs. Abrupt Change

The work of the IPCC[48] has resulted in a broad consensus across the science and policy communities, that there is a high probability that, as a result of human action, climate is changing. In the context of this study a particularly interesting question that arises is what type of change is likely to occur. Are we faced with the situation that while rates of change are higher than in the pre-industrial period, change is essentially gradual and continuous, or do we face discontinuities and the potential of catastrophic collapse? Our literature review suggests that in recent years the position taken by the science community of the issue of gradualism vs. discontinuity has changed.

While early work was built on the assumption of gradual change, it has been increasingly recognised that the Earth's climate system is highly nonlinear. Climatic records suggest that large, widespread abrupt climate changes have occurred repeatedly throughout the geological period and it is suggested that such dynamics may apply in the future. But what constitutes an abrupt change?

The scientific literature suggests that definitions of what constitutes an abrupt climate change can be developed using:

- ***Mechanistic*** criteria that focus on transitions of the climate system into a different state (of temperature, rainfall etc.) on a time scale faster than that of the drivers of change.
- ***Impacts-based*** criteria that focus on changes in the climate system that are faster than the adaptation of social and ecological systems.

Despite an increasing awareness of non-linear features of the climate system, the scientific community are only beginning of formulate and test hypothesis using climate models and proxy data. Moreover, the extent to which the changes in climate will involve non-linearities, points of no return, or thresholds defining alternative stable states with hysterisis effects, is also largely unknown. These issues are particular important because they affect judgements about the significance of climate change.

[47] Chapter 3.6. draws heavily on the position paper by Olsson, L. and J. Stripple (2006): Environmental thresholds, the case of climate change. Unpublished Position Paper for Scoping Study on "Defining and Identifying Environmental Limits for Sustainable Development, funded by D*efra*.

[48] http://www.unep.ch/ipcc/

Table 1: Potential Events that could be initiated by climate change and associated trigger thresholds

Vulnerability	Critical limits for Initiation	References
Shutdown of thermohaline ciculation	3°C in 100 yr 700ppm CO_2	O'Neill and Oppenheimer (2002) Keller et al. (2004)
Weakening of thermohaline circulation	Very low	Higgins and Vellinga (2004) Gregory et al (2005)
Disintegration of West Antarctica Ice Sheet	2°C, 450ppm CO_2 2-4° C, <550ppm CO_2	O'Neill and Oppenheimer (2002) Oppenheimer and Alley (2004, 2005)
Disintegration of Greenland Ice Sheet	1-1.5°C	Hansen (2004) Gregory et al. (2004)
Complete melting of the Greenland Ice Sheet, starting at:	3°C	Johannessen, Khvorostovsky et al. (2005)
Widespread bleaching of coral reefs	>1°C	Smith et al. (2001) O'Neill and Oppenheimer (2002)
Broad ecosystem impacts with limited adaptive capacity	1-2°C	Leemans and Eickhout (2004), Hare (2003), Smith et al. (2001)
Large increase of persons-at risk of water shortage in vulnerable regions	450-650ppm CO_2	Parry et al. (2001)
Increasingly adverse impacts, most economic sectors	>3-4°C	Hitz and Smith (2004)
El-Nino Southern Oscillation Changes	Deeply uncertain	Philander and Fedorov (2003) Timmerman et al (2004)
The table builds on Schneider and Lane (2005) and Keller et al. (2005) but modified and extended by the Olsson and Stripple (2006).		

3.6.2 Understanding the significance of change

A review of the literature on the significance of climate change was found to be of interest in the context of this study, because it showed that judgements about the issue of what changes constitute a 'danger' are usually made by reference to some threshold or limit being crossed. Table 1 summarises the main types of event that the scientific literature suggest could be triggered by climate change. There is much discussion about the probability of such events and their likely consequences. The debate illustrates the context in which scientific work about climate change now has to be set, and value-judgements that have to be made when deciding what constitutes a 'danger'.

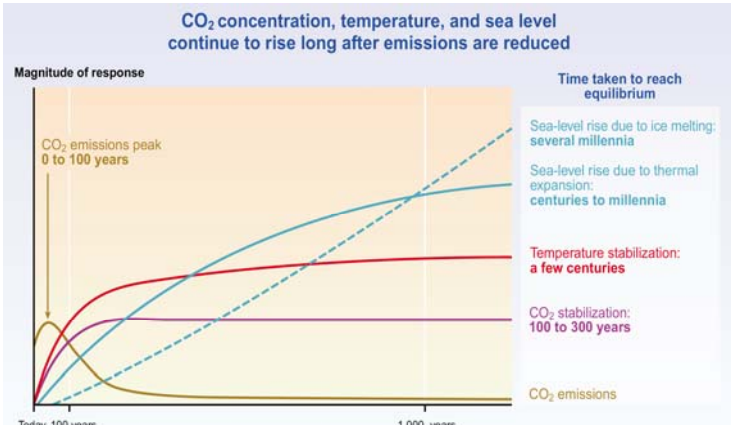
The *rate of climate change* is, for example, only 'dangerous' when the speed of response in society (i.e. the capacity for adaptation) or other ecological systems, is insufficient to avoid harmful consequences. Many commentators suggest that science is only partly capable of documenting the sensitivities of human and ecological systems to changes in climate, and so it cannot fully assess what 'dangerou's rates of change are for different activities or systems. Moreover, even if all the social impacts of climate change were known, some commentators assert that we still would not be able to decide what constituted a 'danger' simply on biophysical grounds. The question of whether or not a given impact is significant or not is, they suggest, a value-based judgement, which ultimately can only be resolved in the political arena. The same arguments apply whether we are dealing with dangers associated with

possibilities of gradual or abrupt change, although clearly with non-linear responses, systems are less likely to be able to accommodate those changes.

Our review of recent debates within the climate change literature suggests that thinking about limits and non-linearity is a fundamental part of the discussion, particularly in terms of how we might assess the significant implications of future changes. It is especially interesting to note, however, that in thinking about such limits the focus rapidly shifts from the discussion of biophysical factors to the evaluation of social and economic consequences. **As a result, if we consider how the evidence base that is needed to support decisions about climate change must be developed, it is clear that while we need to improve the general circulation and Earth system models, we also need to be able understand what those changes will mean for human societies.** Indeed, some have argued[49] that 'radical new methods of participatory research are necessary to truly elicit what level of climate change might be regarded as dangerous by different cultures, communities and constituencies'.

The difficulties of framing both research and policy agendas can be highlighted by reference to the conceptual model suggested by the IPCC for the coupled climate - ocean - land system (Figure 10). The key point this model illustrates is the fact that

Figure 10: Conceptual model showing the inertia of the coupled atmosphere – ocean – land system (source IPCC, 2001)



the time lags between mitigation actions and a system response in the biophysical systems are likely to be very long and varied.

Even if the stabilisation of CO_2 concentrations in the atmosphere is achieved, this will only result in a gradual levelling off of the temperature increase (red curve), with a stabilisation after an additional time lag of 50 – 100 years. The temperature increase before this levelling off will cause a rise of sea levels by thermal expansion of water that will continue for many centuries after the stabilisation of GHG and temperature (blue solid curve). If we also consider the effect on the polar ice caps of the temperature increase, the sea level rise is likely to continue over millennia (blue dashed curve).

Thus decisions about limits and targets to mitigate GHG emissions and to slow the rate of temperature increase are only part of the problem that we have to resolve. The

[49] Dessai, S., W. N. Adger, M. Hulme, J. Turnpenny, J. Khler and R. Warren (2004): Defining and Experiencing Dangerous Climate Change. *Climatic Change* **64**(1-2): 11-25.

consequences of the changes that have been initiated go much wider. Since they will have different effects in different places, the judgements societies will try to make about them are likely to be contentious.

For example, the EU has adopted a temperature target for its climate policy of maximum 2°C above the pre-industrial level. This threshold, however, does not represent a level below which no severe climate impacts are believed to occur, but rather a pragmatic level that might be realistic to achieve from both a technological and a political point of view. The countries that make up the Alliance of Small Island States (AOSIS) have a completely different perception of what might be a dangerous interference compared with an industrial European country. **An important aspect of current research agendas is to explore the fairness and social justice issues related climate change, the mitigation measures proposed, and strategies for adaptation.** In the UK, further work along these lines is also required to develop the evidence base at national and regional scales.

3.7 Pollution Loads [50] [51]

Our review of pollution loads on environmental systems considered two principle areas, namely the literature relating to the definition and use of the critical loads concept for soils and ecosystems more generally, and current developments in the literature relating to environmental quality standards for soils in relation to levels of potentially toxic substances.

3.7.1 Critical Loads

The literature on critical loads is of particular interest because it demonstrates the development of an extensive evidence base on which to base discussions of limits. A critical load is a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge.[52] Definitions of critical loads have now been developed for a range of pollutants, including sulphur, nitrogen, ozone, volatile organic compounds, and the heavy metals lead, cadmium and mercury. Techniques for mapping these critical loads and identifying where actual pollution loads exceed them are not well established.

The review shows that in terms of developing the evidence base, a pragmatic approach is possible, with initial decisions being based on the best available data, and progressive refinement as further work is completed. The work also shows that despite the fact that the calculation of critical loads and their exceedance is

[50] Chapter 3.7 draws heavily on the following unpublished Position Paper for Scoping Study on "Defining and Identifying Environmental Limits for Sustainable Development, funded by D*efra*.

Emberson, L. (2006): Environmental thresholds and their application for ground level ozone air quality management in relation to vegetation.

Shaw, G. (2006): Levels of dispersal of toxic substances and the disposal of solid waste

Sverdrup, H. et al. (2006): Critical loads for acidity to ecosystems. How environmental limits came to set the policy.

[51] For ozone it has communally been discussed with reference to critical levels (since it refers to a critical concentration in ambient air rather than a deposited pollutant (e.g. via wet deposition).

[52] Nilsson, J. and Grennfelt, P. (ed.). 1988. Critical loads for sulphur and nitrogen. Report 1988:15. Nordic Council of Ministers, Copenhagen, Denmark.

scientifically sound, decisions about what actual limits should be upheld for particular systems is a matter of judgement, the science can only inform the wider discussions that society must have, and not replace them. The discussion of critical loads also throws in to sharp focus the issue of whether we should aim to sustain systems at the level of 'maximum allowable damage' or adopt higher targets related to favourable ecological status.

Our review summarises some suggested limit values for a range of soil and ecosystem parameters that have been proposed in the literature. We also consider critical loads in relation to ozone, which provide an interesting case study to illustrate the advantages of an effect-based approach to the definition to limits over one based mainly on consideration of ambient concentrations.

We suggest that in terms of developing the evidence base the current work concerned with mapping and monitoring exceedance to be more strongly linked to issues covered in the sustainable consumption and production framework, to make the link between economy and the environment more transparent. The marginal values associated with managing pollution loads so that ecological targets are achieved, rather than that minimum standards are met, needs to be better understood. A important *caveat* which should be applied to the interpretation of critical loads is that exceedance does not imply sudden and catastrophic ecological collapse. In truth, the exact response of an ecosystem exposed to chronic accumulation of any pollutant or contaminant is difficult to predict, which is why ongoing monitoring and research into pollutant effects are essential.

3.7.2 Environmental Quality Standards for Soils

The review of Environmental Quality Standards (EQS) for soils provided an interesting contrast to the materials on critical loads, because while the latter tended to emphasise criteria such as 'maximum allowable damage', EQS is more precautionary in its outlook. Here the goal is setting limits to ensure that no harm to human health occurs; thus limits are set above the level where any damage might occur.

Despite this contrast between the two approaches, this topic area, like that relating to critical loads, is of general interest because it demonstrates once again how a robust evidence base has been built up to inform the discussion of limits. Our review traces the development of Soil Quality Standards (SQS) through the ICRCL system, with its definition of limits as 'trigger' and 'action' points at which different responses to a potential hazard might be initiated, though to the introduction of Quantitative Risk Assessment (QRA) in the 1990s.

QRA is a formalised, quantitative and defensible methodology in the assessment of chronic risks associated with many environmental hazards and liabilities. The basis of QRA is the use of predictive models which are capable of forecasting risk(s) in the form of probability distributions. In the case of contaminated land assessments, such forecasts are focussed on the probability of adverse outcomes associated with individual contaminated sites, such as exposure of individuals to harmful doses of substances at the site, or the impact the site may have on a sensitive 'receptor' such as a controlled water body (surface or groundwater) or ecosystem. Our review also looked at the way the approach can be used to assess risk associated with radioactive materials in soils, waters and other environmental media.

Implicit in the construction of models for QRA is the 'Source → Pathway → Receptor' linkage, which can be traced to the 'pollution pathway' concept. This is one that is also emphasised in the critical loads literature, although the probabilistic modelling of exposures is not one that has been developed here so strongly.

Our review emphasised that despite the progress that has been made with QRA, much uncertainty applies to our understanding of the effects on human health of 'undesirable' levels of potentially toxic contaminants in the environment. This is addressed by ensuring that Generalised Derived Limits (GDLs) and Soil Guidance values (SGVs) are calculated using deliberately pessimistic assumptions. The nature of threshold values for potentially toxic environmental contaminants is, in general, precautionary, so that the monitoring of outcomes is essential.

A major area of uncertainty that should be considered in future efforts to develop the evidence base concerns to possibility of the 'chemical time bomb'[53]. This envisages a situation in which a trigger mechanism may suddenly render potentially toxic contaminants already present in an environmental system to become suddenly more harmful, either because their physical location is altered or because their chemical state is altered. Trigger mechanisms may involve natural physio-chemical changes or human induced land-use changes. **Current threshold values such as SGVs, GDLs and CLs may be adequate under steady state conditions, but may be irrelevant under conditions in which rapid environmental change occurs.**

[53] Stigliani, W.M., Doelman, P., Salomons, W., Schulin, R., Smidt, G.R.B. and S.E.A.T.M Van der Zee (1991): Chemical time-bombs. *Environment* **33**, 26 – 30.

Part 4: Conclusions and Recommendations

4.1 Respecting Environmental Limits

In its paper *Think Twice,* English Nature[54] argue that, from a nature conservation perspective, consideration of environmental limits is an important principle. Our review suggests that it is important for sustainable development more generally.

There is a broad consensus in the scientific literature that the goals of sustainable development will not be achieved unless we are better able to identify and define what environmental limits are. Thus the aims set by Defra for this study are particularly relevant to current debates. In this final part of the overview report is now appropriate to review what can be concluded from our study.

4.1.1 How are environmental limits identified and defined?

Our review suggests that while at times the terms 'limit' and 'threshold' have been used interchangeably, it is useful to distinguish between them because they highlight important features of natural resource systems that must be considered in policy and management.

Natural resource systems are important to people because of the benefits they actually or potentially deliver to people and the contribution they make to human well being. However, external pressures may progressively undermine the capacity of natural resource systems to continue to deliver these benefits at the level required. As a result, society may judge that a 'critical point' has been reached, beyond which further change is unacceptable. **This critical point is a limit.**

Our review suggests that despite the diversity of materials in the different subject areas, and the different scientific methodologies used to identify these critical points, the notion of a limit is a useful one which can be applied across most fields. Limits can be identified for all types of system, whether they exhibit a progressive linear decline in the face of external pressures, whether that change is progressive but non-linear, or whether there may ultimately be some collapse if the system experiences a regime shift.

In terms of the relative importance that limits and thresholds have, it seems clear that while threshold responses with alternative stable states can be found in some natural resource systems, the extent to which such dynamics are widespread is unclear. Thus, the notion of a limit is generally considered to be more useful. In addition to highlighting the dangers of collapse, thinking about limits also focuses attention on the consequences of the chronic or gradual loss of the functionality of natural resource systems that results from increasing environmental pressures.

Although our definition of a limit seems straightforward there is, however, a hidden complexity which must be discussed. The identification of a limit hinges on the judgment made by individuals or groups 'that a critical point has been reached'. How is that judgment made and justified? Our review suggests that it is mainly in terms of the consequences or implications of exceeding a given limit that those judgments are made.

[54] Burney, J. (2004): "Think twice": respecting environmental limits in our sustainable development strategy. Unpublished draft paper. English Nature.

It is interesting to note that across all of the science areas considered, once the advantages of the different ways of characterizing the system response was resolved, the need to apply that knowledge took us into realms where questions of value had to be resolved. For example, in the area of critical loads, we saw that while the scientific rationale for their calculation was sound, judgments ultimately had to be made about what ecosystem function was to be protected, and what level of protection it was to be afforded. Should the critical load be calculated to protect forest productivity or biodiversity? Is there a maximum level of damage that can be accepted or should the limit be before any damage could be detected? Similarly, in the area of climate change, the question of what constituted a 'dangerous' or 'abrupt' change depended on the how people valued the losses resulting from the event.

Our review suggests that while the definition of a limit may be grounded on biophysical criteria it also depends fundamentally on the value systems being applied. If we view natural resource systems in terms of the stream of benefits they deliver, then judgments about the where a particular limit is set can be based on changes in the marginal value of those benefits, or the assessment of those benefits relative to others that people identify. Additionally, depending on the circumstances, it can be based on the application of ecological or social values. For example, if the underlying science suggests that the relationship between the pressure and system output is non-linear, or may involve threshold dynamics with regime shifts and possible points of no-return, then we may choose to justify a limit using criteria based on social justice and equity, rather than on economic grounds alone.

In other words, in a policy or management context, decisions about limits cannot hide behind the science. Not only are we forced to make value-based judgments about how limits associated with particular systems are identified, but in the real 'multi-functional' world we have to deal with the problem of potentially conflicting limits and therefore the trade-offs that might need to be considered. Such issues are particularly acute where cumulative impacts might occur. Since the problem of valuation cannot be avoided, the implication is that we have to find ways of ensuring that such issues are properly included in discussions of limits. The recognition that judgments ultimately had to be set in some kind of 'deliberative' decision-making framework was apparent in a number of the topic areas considered, and is consistent with the view taken by the Royal Commission on Environmental Pollution in their work on environmental standards and pubic values[55].

The problem of how to assess and prioritize the different types of limit that can be identified when the range of benefits provide that natural resource systems are considered alongside each other, is one that urgently needs to be resolved. **We suggest that Defra could make a significant contribution in this area by initiating future work to look at the way people value the benefits associated with natural resource systems for a set of contrasting 'multifunctional landscapes' or regions in England, and how future decision making can best be supported by the provision of information about the status natural resource systems at different geographical scales**. Such work would also help to clarify the way in which the concept of ecosystem goods and services can be implemented in situations where landscapes also have significant cultural, social and economic value.

[55] Royal Commission on Environmental Pollution, Environmental Standards and Public Values, A summary of the 21st report on *Setting Environmental Standards.* http://www.rcep.org.uk/pdf/standardssummary.pdf

4.1.2 How robust is the evidence base that underpins the identification of limits, what gaps exist in our current understandings, and how can the evidence base be developed?

Any discussion of limits has to be grounded on a good understanding of the relationship between the functioning of the natural resource system, the way it supports the stream of outputs that benefit people, and the way it is impacted by external drivers. Much of the material we covered in our review of the different thematic area covers just these topics. As we have seen progress in the different fields has been variable. It is, for example, fairly well developed in the area of critical loads and the setting of environmental quality limits for toxic substances in soils. Thinking is much less well advanced in areas such as recreation and access.

However, it is probable that no simple answer can be given to the question *how robust is the evidence base*? In fact, there is a sense that this is probably the wrong question to be asking. As the development of the critical loads approach has illustrated, decisions and judgments have to be made on the basis of the best evidence available at the time. We cannot wait for science to deliver some 'final answer'. The act of making *and testing* those judgments in the public arena is the only sure way of assessing the robustness of the evidence base, and understanding how it should be developed. The review of BAP Species and Habitat Targets illustrates the type of work that is necessary. The evidence base is best developed by using it. Such a proposition is central to the notion of adaptive ecosystem management.

On the basis of our review we therefore suggest that, while the evidence base probably needs developing in all areas, in most there is a sufficiently well articulated body of materials that would allow a start to be made, in terms of discussing what kinds of limits might apply. Therefore, future work in the area of environmental limits should focus on both scientific issues related to the structure and dynamics of natural resource systems, and the institutional frameworks in which judgements about the consequences of exceeding environmental limits are made.

There are two key areas where it would be particularly useful to direct resources if work in this area is taken forward at the institutional level:

- In developing a better understanding of the ways in which the goods and services associated with ecosystems and landscapes are linked to biophysical processes at local, regional and national scales. This kind of information would provide a useful body of evidence for regional and local planning bodies. Thus Defra should consider initiating a 'Millennium Assessment' for the UK that can serve as a strategic framework for discussion about environmental limits and as a stimulus to developing the evidence base that underpins policy.
- We need a much better understanding of the economic, social and ecological values of our ecosystem and landscape goods and services. This kind of information would be useful to help us understand how their values are potentially affected by external pressures, and what positive benefits arise through their protection and enhancement. Thus Defra should consider initiating a series of pilot studies which demonstrate how questions of the value can be resolved in relation to assessing the consequences of exceeding an environmental limit.

4.1.3 How can the evidence base used to identify limits be better collated?

Given our suggestion that there is a sufficiently well developed body of materials in the topic areas covered by this study to initiate a discussion about limits, the question arises about how this material is best collated and communicated. A number of approaches can be identified.

We are aware, for example, of the preliminary findings from the parallel study sponsored by Defra on environmental pressures, and the suggestion that 'topic maps' and 'causal chains' be constructed for the different natural resource systems that fall within the Department's remit. **In the short-term, the work on topic maps could be developed to include identification of limits, both with respect to the pressures themselves and the outputs from the natural resource systems themselves.** Such an approach could provide a framework in which questions of the marginal value of benefits and potential costs of protection and management might also be explored. These causal chains might also be a way of identifying potential thresholds, where the integrity of systems might be jeopardised.

Topic maps are useful as a framework for discussion, but they are limited in that they do not yet deal with issues of geographical scale and temporal scale, nor do they take spatial heterogeneity of the resources systems into account. Thus other ways of collating information and communicating it also need to be considered.

If the goal of ensuring that development occurs within environmental limits is to be achieved, then in the short to medium term Defra needs to give clear guidance on how this might be accomplished. Thus the Department's website could provide:

- Examples of 'best practice' and reviews of the current thinking about limits in the main topic areas; and
- A checklist describing the types of question that need to be asked so that thinking about limits is included in decisions affecting natural resource systems at regional and local levels. These materials should also set out how discussions about limits can be built into the existing approaches to Strategic Environmental Assessment and Sustainability Impact Assessment, and how it can be included in cost-benefit studies.

Finally, in the medium term, Defra should make a much stronger link between the issues covered in the areas of sustainable consumption and production (SCP) and natural resource protection. For example, while it is recognised that the decoupling indicators need to have limits associated with them, so that the effects of decoupling can be judged (see section 2.2.4), the range of issue covered in the existing SCP framework is narrow. Moreover, the casual connections between the themes that are included and the natural resources that Defra seeks to protect are also unclear. The decoupling of air quality and the economy is judged by the emission of sulphur dioxide, nitrogen oxides, ammonia and particulates, and not, for example, by the extent to which resulting pollution levels exceed the critical loads for key habitats and soils. Similarly, the only aspect of land use considered is the proportion of new housing on previously developed land, and not the effects which land use patterns have on resource consumption and quality more generally.

Clearly the development of the suite of SCP indicators to include a wider range of natural resource protection issues many be hindered by lack of easily accessible information. **In order to overcome this problem we suggest that a scoping study is**

initiated to determine the feasibility of extending the existing national environmental accounts (section 3.2.1) to resolve some of these deficiencies.

The extended accounts could include more detailed information about the consumption, quality and protection of natural resources and their changes over time. They could also include national and regional ecosystem accounts linked through a refined land cover/land use account to key economic sectors. Such an accounting framework would underpin the development of indicators with a secure evidence base, and provide a model on which issues of limits and the costs of environmental protection and incentives could be calculated. **Such work would also provide a coherent framework for maintaining an inventory of our natural resources.** In order to retain flexibility during development, these accounts should be treated as a set of 'satellite' accounts that supplement the national accounts, rather than being fully integrated with them.

4.1.4 How can current thinking on environmental limits be used in policy-making and what further research is necessary?

The major implication of our study is that the identification and definition of limits can only be achieved through deliberative decision-making processes, so that the value-based judgements on which decisions depend can be made clear. Thus further research is needed into the concepts, tools and institutional arrangements that are needed to support these more inclusive styles of decision making.

The advice of the Millennium Assessment on how to evaluate ecosystem assessments is particularly useful in understanding what has to be achieved by any socially robust process which tries to identify and define an environmental limit. For example, we might ask of judgement about a given limit:

- Did it bring the best available information to bear?
- Did the decision function transparently, use locally grounded knowledge, and involve all those with an interest in a decision?
- Did it pay special attention to equity and to the most vulnerable populations?
- Did it use decision analytical frameworks that take account of the strengths and limits of individual, group, and organizational information processing and action?
- Did it consider whether an intervention or its outcome is irreversible and incorporate procedures to evaluate the outcomes of actions and learn from them?
- Did it ensure that those making the decisions are accountable?
- Did it strive for efficiency in choosing among interventions?

To these we might add – did the judgment take account of the consequences for natural resource systems and human well-being that might arise if a given limit is exceeded?

Our review of the current literature suggests that there are examples of the types of concept and tool that are needed already available. For example, the *Quality of Life Capital Approach (QoLC)*[56] could be adapted to providing guidelines for people to

[56] http://www.environment-agency.gov.uk/aboutus/512398/830672/831980/832252/?lang=_e

develop their thinking about environmental limits when faced with some new development or policy. They might, for example be encouraged to ask[57]:

- What are the factors likely to limit the benefits obtained from the natural resource systems associated with the area affected?
- How important are these benefits, to whom, and for what reasons?
- What, if anything, could replace or substitute for these benefits?
- Do we expect to have enough of each of these benefits natural resource services in the future?
- What kinds of management actions are needed to protect or enhance the benefits?

These questions provide a framework around which the evidence base relating a particular issue can be assembled, and thus the basis for making judgements about limits. They also provide an approach to decision making whose robustness could be tested using the criteria proposed by the Millennium Assessment (section 2.2.3). We suggest that by addressing such questions the consequences of exceeding a given limit might better be identified, alongside the implications of potential conflicts between different types of limit that might arise in relation to a multi-functional ecosystem or landscape.

The Millennium Assessment has attempted to identify the types of deliberative tools that are currently available for assessing the status of ecosystem goods and services; they include cost benefit analysis, multi-criteria and vulnerability analysis. By using such tools it is suggested assessments will be based on public participation, gather appropriate information, and evaluate different planning options in a transparent way. We suggest that Defra could usefully take such work forward, by building on the recommendations of this study and the parallel work combining environmental values, to develop a set of best-practice guidelines that show how these deliberative approaches can most effectively be used to identify and assess limits at a range of different spatial and temporal scales.

4.2 Joined-up thinking

Our review of environmental limits and thresholds suggests that while they are valuable concepts, identification of such 'critical points' is not by itself going to solve all natural resource protection problems. The ideas have to be used in the context of the other tools that we currently have.

For example, our review of the way in which limits have been defined and used suggests that there are clear dangers in using them to set management parameters. As the literature review for the marine environment illustrated, identification of limits is useful in understanding the way pressures impact upon systems, but the goals of managing the system should be that it is sustained in 'good' or 'favourable' condition, not in a state where a level of damage is judged 'acceptable'. Discussions of environmental limits therefore have to be seen as part of target- or objective-led approaches to environmental policy and management. Although the thinking about limits in relation to recreation is much less sophisticated than in many of the other topic areas considered, the importance of setting objectives, rather than limits also emerged as a key message from current debates.

[57] We have freely adapted the 'core' questions that make up the QoLC framework for present purposes.

It is wise in management terms to know the limits to which any system can be pushed. However, quite apart from the dangers of managing to the minimum, the attempt to enforce those safe minimum standards can be contentious and difficult. Given the history of debates, such as those surrounding *Limits to Growth*, it often seems to people that talking about limits is a way of suggesting that all development should be halted. Our literature review suggests that this is clearly not the case. In fact, the recognition of limits can be a positive and constructive step if they are used to demonstrate, not just the losses in benefit that might occur of they are crossed, but what additional marginal value is of managing at a higher target level. If we are to take the calls for more 'deliberative' approaches to policy seriously, then these discussions need to be informed by an understanding of the consequences of different actions and decisions. A clear articulation of the costs and benefits of sustaining the system at the limits or in 'favourable condition' would greatly assist in such matters. In taking such work forward, the notion of ecosystem goods and services is clearly a very helpful one, since it places discussion of human well-being at the centre. If sustainable development is about ensuring that future development is qualitatively different from the forms it has taken in the past, then an understanding of environmental limits, and the consequences of exceeding them, is a vital part of the scientific and institutional framework that needs to be put in place for such goals to be achieved.

The problem with deliberative approaches to the formulation of environmental management and policy is that even though they may achieve transparent and fair outcomes no decision can be final, because constraints are always changing. Climate change, the development of new technologies and the emergence of new values and aspirations will mean that any assessment of limits and targets will probably have to be revised. Such a requirement means that the acquisition of long-term monitoring data is essential.

Efficient monitoring systems require an understanding of what indicators are needed to track the status of a given resource system, the ability to collecting the appropriate information and the commitment to maintain the collection of those data. It is in this context that approaches represented by the sustainable consumption and production framework in the UK are so important. The challenge that we now face is to ensure that they include the range of issues that have to be considered if the sustainability of our natural resource base is to be assured, and that we are able to use this information to make a case for managing societal impacts above the minimum level that is acceptable.

In section 2.2.4 of this report we posed a number of questions about the SCP framework. To resolve them all would go far beyond the remit of this study. **However, from the materials we have presented here, it does seem clear that a closer linkage between the consumption and production issues covered and the costs and benefits of better protection of natural resources and the ecosystem goods and services associated with them, would be an appropriate way forward.** Better integration into systems of environmental accounting would also ensure that the work is underpinned by a clear body of evidence.

The discussion of environmental limits seems to have taken us to the boundaries of what traditional science has been expected to provide. In many of the areas reviewed, for example, scientists acknowledge that, while their work can map out what consequences might follow if certain limits are crossed, the significance of limits has

to be determined by society at large. These tensions between science and values are not confined to the discussions of environmental limits. They are part of much larger set of issues concerning the way we view traditional science in the context of sustainability. The discussion of limits can, nevertheless, make a very real contribution to such debates, because it requires us to think about their implications in ways that transcend traditional disciplinary boundaries.

In order to help chart the next steps, an overview of the key recommendations arising from this study are provided in Table 2. These material are cross referenced ot the material contained in the Full Technical Report.

Table 2: Overview of Key Findings and Recommendations

Key Findings and Recommendations	Reference (Full Technical Report)
Overall • *Although the evidence base for environmental limits needs developing across all the thematic areas considered, in most cases there is sufficient understanding to begin discussing of what kinds of limits might apply for the protection of natural resources. We recommend that work should be initiated to develop guidelines for decision makers at national, regional and local scales to help ensure that development occurs within environmental limits.*	Executive summary
Definitions • *The term limit is used to refer to the level of some environmental pressure, or level of benefit derived from the natural resource system, beyond which conditions which are deemed to be unacceptable in some way. The term can be applied irrespective of the type of dynamic exhibited by the system (linear response, simple non-linear response, threshold response).* • *The term threshold is reserved to describe situations in which a distinct regime shift between alternative equilibrium states exists, which may or may not be reversible.*	Para 2.22
Key findings from review of concepts: • *We conclude that presently the concept of ecosystem health has little to offer in terms of understanding where the environmental limits or thresholds might lie.* • *The literature suggest that we are still a long way from any clear generalisations about what makes one system more resilient than another, or where the limits of resilience in a given system may lie.* • *The logic of ecosystem goods and services that underlies the Millennium Assessment has much to recommend it in terms of communicating to people what is important in the context of natural resource protection and ultimately what environmental limits might exist.*	Para 3.9 Para 3.25 Para 3.27

Key Findings and Recommendations	Reference (Full Technical Report)
Exploring the Evidence Base: Biodiversity	
• *When published the materials of the UK BAP Targets review should be used to identify the robustness of the evidence base about the targets, and to identify what knowledge gaps are apparent in terms of the factors that limit species or habitat abundance and distribution. This work could provide a platform for developing a similar body of information for the more common species and habitats found in the wider countryside.*	Paras 5.9.a, and 5.21
• *As part of the reporting process, Defra should ensure that the information on limiting factors for species and habitat viability that are contained in the target descriptions, are summarised, and linked to the types of information contained in the species and habitat action plans which document the pressure upon them.*	Para 5.9.b
• *Given the nature of the BAP Process, information about limits will mainly be determined using ecological criteria. Thus it would be valuable to initiate a study to identify what the contribution individual species or species groups make to the generation of ecosystem goods and services, so that the benefits of achieving and exceeding the targets identified can be communicated. The costs of recovery can also to be looked at in relation to the benefits that might be realised.*	Para 5.9.d
Exploring the Evidence Base: Land Use and Landscape	
• *In the UK we are well placed to explore issues relating to limits further through the development of such approaches as land and ecosystem accounting. We recommend that further work is undertaken in this area. The land and ecosystem accounts potentially provides both a framework in which issues of multifunctionality can be explored, and means by which information about the status of natural resources system can systematically be assembled and communicated to decision makers.*	Para 6.24
• *The extension of land cover accounting methods is likely to complement other mass-balance studies being addressed under the umbrella of the UK Sustainable Consumption and Production Strategy, and would facilitate better analysis and modelling of long term trends.*	Para 6.10
Exploring the Evidence Base: Recreation and Access	
• *The literature suggest that notions of limits and thresholds are perhaps of restricted value in developing management strategies for recreation, and that objective or target-based approaches are probably more appropriate.*	Para 7.15
• *We recommend that the evidence base can best be developed by better understanding the relationship between recreation and the elements of our natural capital that support it. Such work on the value of the natural environment for recreation and access is likely to be informed by current work involving the valuation of environmental resources based on people's willingness to pay and willingness to travel, and by the marginal values they place on changes in the outputs of ecosystem goods and services associated with the places they visit.*	Para 7.19

Key Findings and Recommendations	Reference (Full Technical Report)
Exploring the Evidence Base: The Marine Environment	
• *There is currently scant information or understanding about the kinds of reference points that might be constructed around the wider indicators of marine ecosystem structure and function, and how these limits vary over time and space. Our review suggests that further work is required to understand how the limits and targets identified across each of the ecosystem dimensions should be compared or combined, since objectives may not always mutually consistent..*	Para 8.10
• *Deliberative styles of decision making are likely to become increasingly important in the context of managing issues related to water quality, supply and demand*	Para 9.17
Exploring the Evidence Base: Climate Change	
• *More work is required to develop the evidence base, particularly in terms of making a judgement about the consequences of the abrupt changes for ecological and social systems more generally*	Para 10.15
• *While we need to improve the general circulation and Earth system models, we also need to be able understand what those changes will mean for human societies*	Para 10.18
• *Further work is required at global, European and national scales on the issues of equity and fairness arising out of the implementation of climate change mitigation and adaptation measures*	Para 10.24
Exploring the Evidence Base: Pollution Loads	
• *In terms of developing the evidence base, the current work concerned with mapping and monitoring exceedance should be more strongly linked to issues covered in the sustainable consumption and production framework, to make the link between economy and the environment more transparent.*	Para 11.17
• *Current threshold values (i.e. Soil Guideline Values, Generalised Derived Limits, and Critical Loads) may be adequate under steady state conditions, but may be irrelevant under conditions in which rapid environmental change occurs.*	Para 11.23
Respecting Environmental Limits	
• *Our review suggests that despite the diversity of materials in the different subject areas, and the different scientific methodologies used the notion of a limit is a useful one which can be applied across most fields.*	Para 12.5
• *In terms of the relative importance that limits and thresholds have, it seems clear that while threshold responses with alternative stable states can be found in some natural resource systems, the extent to which such dynamics are widespread is unclear. Thus, the notion of a limit is generally considered to be more useful*	Para 12.6
• *Our review suggests that while the definition of a limit may be grounded on biophysical criteria it also depends fundamentally on the value systems being applied to assess the consequences of a limit being crossed*	Para 12.9
• *The problem of how to assess and prioritize the different types of limit that can be identified when the range of benefits provide that natural resource systems are considered alongside each other, is one that urgently needs to be resolved.*	Para 12.11

Key Findings and Recommendations	Reference (Full Technical Report)
Next Steps • Defra *should consider initiating a 'Millennium Assessment' for the UK that can serve as a strategic framework for discussion about environmental limits and as a stimulus to developing the evidence base that underpins policy.*	Para 12.15
• Defra *should consider initiating a series of pilot studies which demonstrate how questions of the value can be resolved in relation to assessing the consequences of exceeding an environmental limit.*	Para 12.15
• Defra *needs to give clear guidance on how development within limits might be accomplished. Thus the Department's website could provide:* o *Examples of 'best practice' and reviews of the current thinking about limits in the main natural resource protection areas.* o *A checklist describing the types of question that need to be asked so that thinking about limits is included in decisions affecting natural resource systems at regional and local levels. These materials should also set out how discussions about limits can be built into the existing approaches to Strategic Environmental Assessment and Sustainability Impact Assessment, and how it can be included in cost-benefit studies.*	Paras 12.19-12.20
• *In the medium term,* Defra *should make a much stronger link between the issues covered in the areas of sustainable consumption and production (SCP) and natural resource protection. Closer linkage between the consumption and production issues covered and the costs and benefits of better protection of natural resources and the ecosystem goods and services associated with them, would be an appropriate way forward*	Para 12.33