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Ecosystem sensitivity and responses to change: understanding the links between geodiversity and biodiversity at the landscape scale

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Summary

Traditional approaches to nature conservation in the UK, and the legislative framework that supports it, have focused on the protection and enhancement of important species (i.e. rare, threatened or representative species) and key land areas of interest for their biological assemblages (habitats) or their physical assets (landscape and geodiversity).

The development of the ecosystem approach, which provides a new framework for action under the Convention on Biological Diversity, focuses on structure, processes, functions and interactions between natural resources and social and economic needs. It recognises that natural change is inevitable and that management should be conducted at appropriate spatial and temporal scales. An ecosystem approach integrating geodiversity and biodiversity is potentially applicable to a number of key issues, including the management of habitat and natural system responses and adaptations to climate change, catchment/river/floodplain restoration for sustainable flood management, coastal management and habitat/landform adaptation to projected sea-level rise, soils and habitat restoration, and multifunctional management of peatlands for habitat and carbon sequestration.

The aim of the study reported here was to gain a better understanding of the links between geodiversity and biodiversity at a landscape scale and their relevance for conservation management, as well as to promote awareness of such links among JNCC and country agency staff involved in advisory and policy development work. The study was based on a limited review of published and unpublished literature, as well as a consultation exercise among specialists in JNCC's Lead Co-ordination Networks. Two case studies from coastal and upland ecosystems emphasise the importance of understanding and working with natural processes.

From a conservation management perspective, spatially integrated approaches at the landscape/ecosystem scale are arguably most critical in a changing world. In the short-term, an appraisal is required of management principles and practical guidance on how existing understanding of physical processes might be better integrated and applied to meet the needs of adaptive management in a changing environment at the landscape/ecosystem scale. Crucially, there is a need for management advice for how to work with natural/physical processes in the context of climate change and sea-level rise.

Contents

1 Introduction

Traditional approaches to nature conservation in the UK have focused on important species and the protection of key areas, often without sufficient reference to wider ecosystem functions and ecosystem services. The diversity of our physical environment (geodiversity) and our living biota (biodiversity) have tended to be treated separately in conservation matters, and their spatial integration in conservation management, based on knowledge of geomorphological process systems (e.g. coastal zones, river catchments and ecosystems), has been lacking.

Rocks, landforms and soils form the foundation upon which plants, animals and human beings live and interact. The geomorphological processes that shape our mountains, rivers and coasts also maintain dynamic habitats, ecosystems and landscapes. Their diversity therefore has a fundamental role in supporting habitats, species and landscape character, and in providing ecosystem/environmental services (Gordon & Barron, 2011). For example, ecosystem resilience, sensitivity and responses to climate change and sea-level rise are conditioned by geomorphology and soils, including changes in the stability/instability of landforms, fluxes of sediment and water, substrate properties and soil properties. The importance of the continued operation of these natural processes and the value of more-integrated approaches in land and water management is now becoming more widely recognised for sustaining natural capital; for example, the Convention on Biodiversity and the European Landscape Convention both call for a more integrated approach to the conservation of living species, habitats and landscapes, both within and beyond protected areas. Such approaches recognise the connections between geodiversity and biodiversity. In particular, the ecosystem approach, which has been adopted as a primary framework for action under the Convention on Biological Diversity, focuses on structure, processes, functions and interactions between natural resources and social and economic needs. It recognises that natural change is inevitable and that management should be conducted at appropriate spatial and temporal scales. Increasingly, too, a multifunctional approach to soil conservation and sustainable management of soil resources is addressing habitat support and delivery of other ecosystem services.

The contribution of geodiversity to sustainable management of land and water at a landscape/ecosystem scale, including adaptations to climate change and sea-level rise, is now being recognised at a practical level in Integrated Coastal Zone Management, Integrated Catchment Management and Sustainable Flood Management. In particular, this involves understanding and working with natural processes, not against them, in a sustainable, spatially integrated manner. For example, this may include options for adapting to climate change through ‘soft-engineering’ techniques for flood management, including ‘creating room for rivers’ and ‘managed realignment’ at the coast. Knowledge of the geological record also provides detailed information about how past environments responded to climate changes. This information is important for the development of climate change impact scenarios for biodiversity and geodiversity.

Understanding geodiversity is therefore fundamental to sustainable management of land and water at a landscape and ecosystem scale. Geodiversity also provides many benefits for people, contributing significantly to the ecosystem services outlined in the Millennium Ecosystem Assessment (2005). It is a vital component of supporting services, but also contributes to the regulating, provisioning and cultural categories (Gordon & Barron 2011). However, there are real challenges ahead to achieve integration and the development of multidisciplinary approaches to nature conservation.

The present study formed part of JNCC’s Generic Framework for Lead Co-ordination Network (LCN) Work Programmes, ‘Priority project 4: Dealing with landscape-scale issues’.

It was set up as a first step to help gain a better understanding of the links between geodiversity and biodiversity at a landscape scale and their relevance for conservation management, as well as to promote awareness of such links among JNCC and country agency staff involved in advisory and policy development work. Physical processes underpin the structure and function of ecosystems and have a fundamental bearing on favourable conservation status (FCS), as highlighted in the conclusions from Article 17 reports[1] under the Habitats Directive (e.g. for Annex I habitats such as Atlantic salt meadows and Embryonic shifting dunes). However, most physical processes cannot be 'controlled' by human management in the medium to long term - we have to understand and work with them in a much more effective way than we have in the past. This is likely to be even more acute in the future as ecosystems respond to climate change and sea-level rise. This project therefore aims to provide a better awareness of the need for understanding the linkages between natural processes to help inform future management at a wider scale than has traditionally been the case, particularly to help attain FCS against a background of climate change and sea-level rise.

How future changes in geomorphological processes and soils will affect ecosystem processes, the resilience of habitats and their spatial distributions and responses, and the propagation of effects at the landscape scale, will be complex to describe and understand. However, as a starting point, there is already a high level of knowledge within individual LCNs that the project endeavoured to draw together. It was therefore scoped as an ad-hoc internal review based on current understanding of the issues, not as a research study *per se*. It was based on a limited review of published and unpublished literature, as well as a consultation exercise and discussions with members of the Soils, Coastal, Uplands, Freshwater and Woodlands LCNs. Two case studies from contrasting ecosystems (one coastal and one upland) helped to develop a common understanding of the importance of some key parameters and linkages, and to exemplify the benefits of linked working and how it might lead, for example, to better targeting of resources, fewer apparent conflicts between conservation objectives and more-realistic outcomes.

The report draws heavily on existing conservation agency material and sources, including:

- 'Scotland's geodiversity: development of the basis for a national framework' (Gordon & Barron, 2011);
- the unpublished outpu t from an internal SNH workshop in October 2007 on 'Ecosystem sensitivity and respon ses to climate change: understand ing the links between geodiversity and habitats';
- JNCC habitat web pages and unpublished information.

[1] http://www.jncc.defra.gov.uk/page-4064

2 Importance of understanding the links between geodiversity and biodiversity

2.1 Geodiversity - what is it?

In contrast to 'biodiversity', which has become a well-established concept amongst policy makers and land managers, awareness and understanding of geodiversity remain poor outside the specialist community. There are many definitions of 'geodiversity' in the scientific and stakeholder communities, but the majority are variations on similar wording (c.f. Gray, 2004, 2008). Broadly, in accordance with JNCC and the UK conservation agencies, we use here the following definition:

> *"Geodiversity is the variety of rocks, minerals, fossils, landforms, sediments and soils, together with the natural processes which form and alter them."*

Understanding the functional links between geodiversity and biodiversity is key to conservation management in dynamic environments, where natural processes (e.g. floods, erosion and deposition) maintain habitat diversity and ecological functions. Geodiversity also includes a cultural dimension. It links people, landscapes and their culture through the interactions of biodiversity, soils, minerals, rocks, fossils, active processes and the built environment, and therefore provides the framework for life on Earth (Stanley, 2004).

This cultural aspect reflects the important benefits that geodiversity provides for society by contributing to the delivery of many important ecosystem services, such as regulating flooding.

2.2 The links between geodiversity and biodiversity

Ecosystems are dynamic, functioning units of plant, animal and micro-organism communities interacting with their non-living environments. As such, they bring together biodiversity and geodiversity under a single framework. A fundamental feature of all ecosystems is that they are not fixed and stable but are continually adapting to change over centennial, millennial and longer timescales in response to a range of natural and human driving forces. To understand how ecosystems respond to change, it is crucial to think in terms of both space and time dimensions (c.f. Gordon & Barron, 2011).

An ecosystem approach linking geodiversity and biodiversity is timely and potentially applicable to a number of cross-cutting issues, including the management of habitat and natural system responses and adaptations to climate change, catchment/river/floodplain restoration for natural flood management, coastal management and habitat/landform adaptation to projected sea-level rise, soils and habitat restoration and multifunctional management of peatlands for habitat and carbon sequestration interests.

Changes in dynamic geomorphological processes and soil processes are likely to have fundamental implications for all terrestrial, coastal and water ecosystems. Hence, we have to understand and work with natural processes in a much more effective way than we have in the past. The importance of this was emphasised by Hopkins *et al* (2007) in *Conserving Biodiversity in a Changing Climate: Guidance on Building Capacity to Adapt*. They recommended that:

> "*………allowing natural processes to shape the ecology and structure of whole landscapes, will create the best possible chance for conserving the greatest amount of biodiversity* (p. 14)";

and in relation to site conservation:

> *"[t]here is a need to move from management largely focused on selected species and habitats towards much greater emphasis on the underlying physical processes that are essential to the maintenance of biodiversity on the site* (p. 22)."

Therefore, more joined-up working is required to develop better understanding of the linkages between geodiversity and biodiversity, particularly with regard to managing ecosystems in the context of climate change and sea-level rise, which are likely to have far-reaching effects on our landscapes if current projections are borne out.

2.3 Geodiversity and climate change

Climate change and sea-level rise are happening now. We are already locked into future changes as a result of past anthropogenic emissions of greenhouse gases. Recent increases in CO_2 and other greenhouse gas emissions have not yet been fully reflected in increases in atmospheric temperatures. The impacts of past sea level and climate changes are recorded in both the geological fabric and the imprint of geomorphological processes on the landscape. For example, geological records for the mid-Pliocene (~3-5 million years ago) (c.f. Dowsett *et al* 1994, Jansen *et al* 2007, Williams *et al* 2007) show CO_2 levels in the atmosphere then were ~360-400ppmv (compared with 389ppmv today and rising at ~2ppmv per year), global temperatures were ~3°C higher and sea level was up to 25m higher due to reduced polar ice sheet volumes and thermal expansion of the oceans. The earlier Palaeocene-Eocene thermal maximum (55 million years ago) also provides a salutary reminder of the effects of extreme global warming - some estimates of greenhouse gas release then are comparable to the estimated release from anthropogenic activities in the next few hundred years if present trends continue unabated.

Understanding of the past can significantly enhance our analyses of likely environmental responses to future scenarios where rapid changes in processes driven by human pressures on resource uses and increasing greenhouse gas emissions are superimposed on longer-term natural processes (e.g. isostatic rebound). Although there are unlikely to be any exact geological analogues for a future warmer world, we can nevertheless still learn from the past in terms of gaining a longer-term perspective on the status, trends, rates of change and future trajectories of ecosystems. Geological records can also provide the understanding and data for testing possible scenarios for change over different temporal and spatial scales.

The Kyoto Protocol has failed to deliver significant reductions in greenhouse gas emissions. This raises the issue of how realistic it is to anticipate that post-2012 policy will achieve the deep cuts needed to stabilise CO_2 below so-called 'dangerous' levels and whether we should therefore be planning now for risks and impacts arising from the higher Intergovernmental Panel on Climate Change (IPCC) emissions scenarios[2]. Also, IPCC projections of future sea-level rise are considered to be conservative in the light of observational data since the possible dynamic responses of ice sheets were not incorporated (e.g. Pfeffer *et al* 2008, Vermeer & Rahmstorf 2009). In terms of risk assessment, we need to consider a greater envelope of uncertainty and a wider range of possible futures (New *et al* 2011). Climate change is not short-term and will extend well beyond the AD 2100 timescale of current climate projections.

[2] Future climate projections for the UK are available from UKCIP09: http://ukclimateprojections.defra.gov.uk/content/view/12/689/

Climate change scenarios suggest that some landform processes that are also hazardous (such as coastal flooding and erosion, flash floods and landslides) are likely to occur more frequently. The response to hazards often results in expensive site-by-site geotechnical solutions. Many of these approaches are not sustainable, and may exacerbate or transfer the problem elsewhere in the catchment or along the coast, with consequent impacts on natural heritage interests and ecosystem functionality (Prosser *et al* 2010).

Climate change will lead to changes in land use and land management practices as a result of changes in land suitability for agriculture, forestry and renewable energy production and indirect pressure from population growth (e.g. food policy) and displacement (planning development away from flood-prone areas). The consequences for soil and geodiversity (and hence habitats and species) of such increased pressures on the land bank are unclear.

2.4 Ecosystem responses and landscape-scale issues

Geomorphological, hydrological and soil processes strongly influence the condition of many habitats and species and their abilities to adapt to the impacts of climate change and other anthropogenic pressures and land-use changes. Better understanding of the dynamic relationships between geodiversity and biodiversity will help to inform management and/or restoration options for mitigation and adaptation to such changes (e.g. through ‘opportunity mapping’ as in the Wetland Vision (2008)).

Interactions between geodiversity and biodiversity occur across a range of scales from the microscopic to the landscape scale. However, from a conservation management perspective, spatially integrated approaches at the landscape/ecosystem scale are arguably most critical in a changing world. For example, physical processes operate at wider scales than the boundaries of designated sites which only encompass very limited parts of functioning ecosystems. Consequently, changes in the wider landscape or catchment may significantly impact on the condition of designated features, while some features may be driven to shift their spatial locations outside existing designated areas. At the coast, sea-level rise will not only influence the tidal immersion of habitats, but also rates of erosion, sediment transport and accretion. These are real issues for some coastlines where there will be shifts in the locations of designated features (including geodiversity features). We need to be aware of the wider implications of climate change on habitats at the landscape scale, and perhaps not focus to such a great degree on individual protected species.

Ecosystems are not only affected by contemporary changes. They are also conditioned by changes in the past which are still causing a response today and will continue to impact into the future, although possibly in different ways and at different rates (e.g. most of the present coastal ecosystems of Scotland have been conditioned by isostatic uplift, but this is now being progressively overtaken by sea-level rise (Rennie & Hansom, 2011). The legacy of past human interventions (e.g. large-scale reclamation of estuaries affecting sediment processes), which have modified natural processes will also have an impact in the future (e.g. Defra, 2010). Such interventions may obstruct natural process responses and limit options for ecosystem management through working with natural processes. Awareness of past changes is therefore essential to understand future ecosystem changes.

Habitats and species are fundamentally dependent on the availability of appropriate physical environments and natural processes, including relative stability or instability of landforms, substrate properties, soil physical, chemical and biological properties, and fluxes of sediment and water (Figure 1). Ecosystem resilience, sensitivity and responses to climate change and sea-level rise will therefore be conditioned by how the underlying geomorphological and soil processes respond. Changes in the magnitude, frequency and duration of processes, process rates and the nature and spatial distribution of processes are likely to have significant implications for the resilience and adaptability of most ecosystems. These may result in reductions in recovery time for habitats and species between extreme events, changes in the distributions of landforms in response to altered patterns and rates of both erosion and deposition and longer landform readjustment times to extreme events due to reactivation by subsequent events. Geomorphological processes and soils may become vulnerable to irreversible changes or changes in process regimes (e.g. Thomas 2001, Werritty & Leys 2001, Church 2002). In extreme cases, the frequency and speed of disruption may mean that habitat recovery is never fully established.

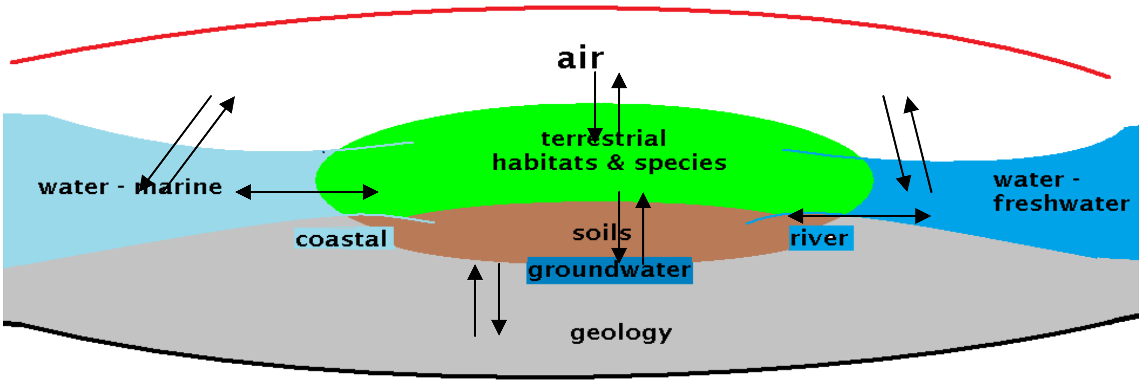

Figure 1. Schematic representation of the links between geodiversity and biodiversity. The arrows represent process linkages, including fluxes of sediment and water.

There are many uncertainties and questions about how changes in soils and geomorphological processes will affect ecosystem responses. For example:

- How adaptable and resilient are habitats or species if there is a change in the type of geomorphological and soil processes operating, or a change in the magnitude and frequency of activity? What are the implications for ecosystem adaptation or resilience, especially where the frequency and speed of disruption in some locations may mean that habitat recovery is never fully established?
- There may not be time for habitats and species to adjust *in situ* or suitable space for them to move to. Consequently, there is potential for major irreversible changes on human timescales if thresholds in dynamic systems are crossed.
- Do we know enough about species tolerances and thresholds in terms of habitat requirements (soils, hydrology, landform mosaics) for restoration or managed relocation?
- It may not be practical (or appropriate) to maintain species and habitats already at the edge of their European distributions, especially in increasingly dynamic environments.
- Ecosystems are continually adapting to change over different timescales in response to different levels of disturbance. However, palaeoenvironmental data can provide a detailed understanding of these changes and the range of potential options for management and/or restoration.

3 Assessment of the awareness of the links between geodiversity and biodiversity in UK inter-agency working

This section reports on the outcomes of an internal consultation conducted between 2008 and 2009 by the Soils and Coastal LCNs, targeting UK conservation agency staff engaged principally within the Soils, Coastal, Freshwater, Uplands, Lowland Wetland, Heathland and Woodland LCNs.

3.1 Methodology

The aim of the consultation was first to gain a better understanding of the past and present links between geodiversity and biodiversity at a landscape scale and to promote awareness of such links; and second, to examine the implications for the future conservation management of ecosystems and their responses to climate change and relative sea-level rise to help deliver favourable conservation status.

Two questionnaires were sent to specialists within the Soils, Coastal, Freshwater, Uplands and Wetlands LCNs. The first 'Project' questionnaire was intended to evaluate specialist awareness of geodiversity / soil issues; the second 'Expert' questionnaire, to provide a detailed expert assessment of the relationship between specific geodiversity processes and habitats and species listed under the EU Habitats Directive, Annex I habitats[3] and Annex II species[4] lists.

The questionnaires were aimed principally at fostering engagement between the Soils, Coastal, Freshwater, Uplands and Wetlands LCNs in cross-disciplinary working, but they were circulated to all the LCN chairs and officers. A wide range of responses were received even from those LCNs not directly targeted. This provided a good opportunity to assess how relevant the more 'terrestrial' habitat LCNs consider natural processes and geodiversity to be.

3.2 Project questionnaire

The Project questionnaire included eight questions to identify the general level of understanding of geodiversity issues and to assess requirements amongst habitat specialists (Table 1).

Questions 1 and 2 covered the scope and proposed outcomes of the project.

Question 3 addressed the relevance of the key issues described in section 2.4 in relation to the agencies' responsibilities and engagement in wider landscape and designated site activities.

Question 4 considered the appropriate scale of activities, in particular in relation to two linked priority themes, with a focus on improved demonstration of what 'working with natural processes' actually means:

- catchment management/floodplain restoration to facilitate habitat adaptation (including sustainable flood management and links to the Wetland Vision, for

[3] Information on the EU Habitats Directive Annex I habitats is available here: http://www.jncc.defra.gov.uk/Publications/JNCC312/UK_habitat_list.asp
[4] Information on the JNCC Species Red lists is available here: http://www.jncc.defra.gov.uk/page-1773

example), involving closer integration of upland, wetland and freshwater habitat interests from the perspective of a wider ecosystem that is linked by geomorphological and soil processes;

- coastal management/restoration involving closer integration of wetland, freshwater and coastal habitat interests from the perspective of a wider ecosystem that is linked by geomorphological and soil processes.

Questions 5 to 8 addressed current activities and future potential for interagency and interdisciplinary studies. In particular, they sought information for the development of case studies, with a focus on the identification of specific requirements and gaps from a nature conservation viewpoint.

Key points arising from the responses (Table 1) are summarised below. In particular, there is a need to:

- target a wider audience beyond the specialists and communicate the key messages about the value of more-integrated approaches linking geodiversity and biodiversity;

- integrate and apply existing understanding of geodiversity-biodiversity interactions to address actual management issues;

- consider the wider landscape and not only sites (i.e. the management of designated site features within a wider ecosystem context);

- focus on current conservation priorities; and

- develop case studies.

Table 1. Project questionnaire responses: linking geodiversity, biodiversity and processes in a landscape-scale approach**.**

Question	Lowland Wetland LCN	Freshwater LCN	Heathland LCN	Woodland LCN	Uplands LCN	Coastal LCN
1. Do you agree with the aims and target audience of the project?	Wider target audience needed. Terminology needs clarity. Should be more about integrating management with physical processes. More appreciation of abiotic processes needed.	Wider audience. Greater clarity on linkages needed - also which are the linkages being considered? Terminology needs more clarity.	Yes to audience. What about slow timescale for soil processes?	Yes to audience - but unconvinced of value of project to woodland.	Yes to aims. Audience group should be widened beyond staff working in advisory and policy development posts to include staff involved in conservation management, and also to other government policy staff.	Audience should include coastal geomorphologists. Aims need to make clear that the future of coastlines is dependent on conservation not preservation. The project should promote links across specialisms.
2. Are the proposed outcomes acceptable? Are there others to consider, bearing in mind the resources available?	Wider dissemination needed. More on abiotic processes as above. Management principles at a catchment scale need to be developed - use case studies.	Need to consider what outcomes will make a difference - should there be more on how abiotic processes and habitat conservation are linked? Management principles preferred over 'advice'.	OK but management seen as main influence.	Generally yes but see above.	Yes - but focus on quality and effectiveness of communication about these issues not volume. Note that blanket bogs may lie across watersheds, so process issues are not just at a catchment scale - get the topographic scale fit for purpose.	A key outcome should be to use the project to develop modifications to habitat management in the light of impacts of climate change on soil, water and sedimentary processes. There may also be issues with how this project could help with the WFD work on defining good ecological status - for example in sand dunes, the dune slack features are considered a groundwater dependent water body.
3. Have we identified the key issues? What are the consequences of not taking this approach forward? How should the project address the balance between wider landscapes and the designated site series?	Need to make clear that processes don't always occur in a linear way. Needs wider focus than designated sites. How are abiotic processes influenced/restored? What are the benefits to society from them? Can this work enable more co-ordination between JNCC and others?	Focus should be on 'abiotic catchment processes'. Wider landscape is important to emphasise. A project is needed in some form to ensure relevant linkages are made.	Processes of heathland soil development too slow to influence present condition. Management and weather thought to be more immediate concerns.	Need to be clear about current approach and where it needs improving. Spatial and temporal scales critical. Cultural impacts in a landscape must be considered.	The issue of managing designated site features within a wider ecosystem context is highly relevant and may prove essential as these respond to a changing climate. Linking policy and management with statutory requirements and safeguards will be essential. However, do not go too broad: focus on current conservation priorities and illustrate with examples. Also, may need to identify risks of not addressing processes adequately. Are there examples?	Greater awareness of the physical processes that support habitats and influence the options for management could help with stakeholder dialogue where significant changes to coastal landscapes are predicted. Cultural elements may have to take second place to processes if this is a more sustainable outcome. All coastal 'sites' have to be considered as part of the wider sediment cell.

Question	Lowland Wetland LCN	Freshwater LCN	Heathland LCN	Woodland LCN	Uplands LCN	Coastal LCN
4. Do you agree with the focus on catchment management/ flood plain restoration and coastal management/restoration? What specific issues would you like to see addressed from the perspective of your LCN?	More integration with current work is needed. Don't underestimate how difficult it is to achieve catchment-scale objectives!	Abiotic and biotic linkages are important in relation to these two areas - must be at the right scale. Integrate with landscape project led by Woodland LCN. Three specific issues identified: benefits to flood risk management; implications of climate change on static designated boundaries/features; vertical linkage between rivers and hyporheic zones.	It would be helpful to address soil nutrient and carbon storage issues.	Catchment management should integrate wet woodlands into floodplain restoration.	Note above on watersheds in uplands, but otherwise agree. Issues are grazing & burning management, planning development (mostly renewables) & balancing woodland expansion with open habitat interests. Ensure the project adds value to ongoing projects on floodplain/catchment management etc.	Yes - especially coastal adaptation to climate change and the role of saltmarshes in carbon sequestration. Must link to recent UKCP09.
5. There is already quite a bit of current work going on relevant to this project - can you provide key projects and particularly details of any significant gaps from a nature conservation viewpoint?	Several projects suggested e.g. Wetland Vision.	Several projects suggested - must be a link to flood risk management.	No answer	Forest Research contact given.	Several examples given - need to collate information on what's happening elsewhere and how these address the full range of physical processes.	A number of projects at country level are underway - this could provide an overarching theme.
6. What case studies would like to see included? How many should there be? Should we invite country agency landscape specialists to contribute to the work, and if so, at what point?	Important but no examples given - consider this is the next stage of the work.	Important but no examples given - consider this is the next stage of the work. Ensure one includes societal benefits.	Case	studies unlikely to focus much on woodland.	Better definition of 'case studies' needed. Upland blanket bog dominated catchments. Need to look at hydrological issues, linked to changes in rainfall, management (grip blocking) and restoration of blanket bogs - is that possible in the current and/or future predicted climate?	Case study could focus on a coastal protected landscape e.g. AONB.
7. Would you prefer the development of management principles and guidance to be	Internally - more cost-effective.	Internal lead with external input from other partners.		Internal	Contracted out. LCNs don't have time. There is concern that the approach is too demanding for LCN staff who won't have the time to do the	Internal steering of project - externally contracted work depends on resources available.

Question	Lowland Wetland LCN	Freshwater LCN	Heathland LCN	Woodland LCN	Uplands LCN	Coastal LCN
contracted out or undertaken by the LCNs?					spreadsheets, workshops, etc., particularly if this is only one of many joint LCN projects. Would it be better to have some focussed and relevant work they consider would be useful to improve links and information dissemination and then come back to LCNs for comments?	
8. What other work areas would scenario modelling support? Is there any similar work underway?	Evaluate models first. Preference for on-the-ground delivery.	Evaluate models first - may not give all the answers. Ongoing NERC project bid with SNH on 'Knowledge transfer - hydromorphological and ecological status of river systems' could be relevant.	No answer	Modelling is conceptual. Key areas are climate change and nitrogen pollution (covered by recent JNCC workshop).	Any work needs to be very targeted and relevant to future management and used to inform policy staff of the consequences of inaction. Check work on habitat networks.	There are studies such as the Defra 'Futurecoast' project which provides predictive information on future coastal alignments. Other modelling work on estuaries has happened as well as via individual Shoreline Management Plans - but these are only for England and Wales.

3.3 Expert questionnaire

The UK country agency LCN specialists were requested to complete an expert assessment of the interaction between habitats, species and geomorphological processes. The assessment was done by each LCN specialist team, based on a pre-determined list of key geomorphological processes and their potential changes in environmental impact that might arise as a result of climate change (Table 2). These were grouped into three geomorphological process-environment categories representing a crude downslope gradient, and a fourth category related to the impacts arising from human responses to adapt to or mitigate climate change that may impact on geodiversity, and hence indirectly on habitats:

a regolith: soils, slopes and summits;

b rivers;

c soft sediment coasts (including till-cliff sediment source areas);

d human responses.

The terminology used to describe the geomorphological processes and impacts is explained in Table 2.

For all relevant combinations of processes / impacts and habitats, each LCN was asked to compile a consensus view of the level and direction of the interactions between biodiversity and geodiversity features.

The expert assessment considered the degree of geodiversity-pressure, according to six levels coded as follows:

0 unable to provide an answer because there is a lack of evidence base;

a I don't know but I might get the information later;

1 positive interactions (beneficial to habitats);

2 negative interactions (detrimental to habitats);

3 negative and positive interactions;

4 no detectable change (from evidence-base data).

The default answer was set at 0 (unable to answer). However, when no interaction was expected (for example between upland processes and coastal habitats), the default was set at 4 (no detectable change).

The full responses provided by each LCN are presented in Appendix 1.

Table 2. Key environmental geodiversity processes associated with climate change and their potential impacts by broad geodiversity category

Regolith: soils, slopes & summits	*Change in soil forming processes* * Biological processes (biological processes are impacted by temperature change, change in CO_2 concentration and affect soil organic matter accumulation - decomposition rate - primary productivity). * Chemical and biochemical processes (chemical and biological processes might affect substrate alteration, sediment and weathering patterns).
	Change in slope morphology - this may include local changes in slope steepness, shape and convexity, caused by river undercutting and impact on slope stability, water movement, accessibility.
	Increased erosion processes (by water and/or wind, and/or frost or snow) - this could result in, for example: loss of soil at local scale; rilling and gullying; sheet erosion; and / or soil creep, debris flows, hill slope slumps, soil or rock topples and falls.
	Changes in extent of snow cover and length of snow lie, changes in thaw patterns, seasonal length * Decrease of snow cover and length of snow lie. * Increase of snow cover and length of snow lie. * Changes in freeze/thaw patterns - reduction in number of degree days of frost. * Changes in freeze/thaw patterns - increase in number of degree days of frost. * Changes in freeze/thaw patterns - reduction in frequency of fluctuations about freezing point. * Changes in freeze/thaw patterns - increase in frequency of fluctuations about freezing point.
	Change in atmospheric deposition patterns * Increase in soil acidification and eutrophication from change in atmospheric deposition patterns. * Decrease in soil acidification and eutrophication from change in atmospheric deposition patterns.
	Variation in soil moisture status * Wetter (e.g. permanent or seasonal waterlogging) - e.g. leading to change in habitat and species distributions. * Drier (e.g. permanent or seasonal drought) - e.g. leading to change in habitat and species distributions.
	Drying up and oxidation of organic soil - leading to increased sensitivity to damage of peat with loss of topsoil, erosion of peat.
	Fertility and nutrient status change * Loss of soil fertility and nutrient depletion by processes other than physical loss of topsoil - this will include leaching from increased infiltration and changes in water chemistry. It can also relate to increased vegetation uptake from changes of land use and land management practices. * Nutrient enrichment - this will not include changes in land management practices and changes in on-site fertilisation, but may include off-site effects.
Rivers	*Upslope processes affecting river systems* * Increased hillslope erosion - change in surface sediment transport - impact from soil /sediment movement. * Increased runoff and changes in water quality arising from diffuse pollution - impact from water movement.
	Change in river sediment type and availability * Increasing trends. * Decreasing trends.
	Changes in catchment slope morphology and river margin morphology - not purpose-designed but resulting from natural processes
	Impacts on flooding * Increased flooding (duration and intensity of flooding) - link to changes in rainfall distribution. * Increased flooding (change in location and extent of flood-prone areas) - link to changes in rainfall distribution.
	Impacts on flood defence management * Increased river catchment flood defence (soft engineering) - purpose-designed.

	* Increased river catchment flood defence (hard engineering) - purpose-designed.
	Change in river sediment type and availability (through channel re-profiling / gravel and sand extraction) - purpose-designed.
Soft sediment coasts (including till cliff sediment source area)	*Change in coastal sediment type and availability* - not directly controlled by human actions (global / regional patterns) * Natural processes - increased supply. * Natural processes - decreased supply, leading to increased coastal erosion. * Change in beach profile and/or coastal landscape - this deals with modification rather than loss of habitat.
	Wave processes * Decrease in wave energy - amplitude not directly controlled by human actions (global / regional patterns). * Change in wave energy - amplitude - not directly controlled by human actions (global / regional patterns).
	General sea-level rise * Threat to and loss of habitat footprint - this deals with coastal squeeze and realignment changes. * Salinisation threats - this includes sea water seepage, salinity change, brackish water. * Coastal squeeze - this describes a situation where the coincidence of sea-level rise and coastal defence works threaten to reduce the area of inter-tidal environments, such as salt marshes.
	Increased flooding in coastal areas - this could be from storm surges (brackish water) or flooding (freshwater) from rivers.
	Coastal defence - purpose designed realignment activities * Coastal realignment - purpose designed realignment activities. * Soft engineering defence - purpose designed. * Hard engineering defence - purpose designed.
Other human responses to adapt or mitigate climate change	*Planning system* in so far as it impacts on geodiversity and has a direct impact on habitats * Planning developments (not related to energy needs). * Renewable energy (water) - small and large hydro-schemes. * Renewable energy (wind) - inland and offshore.
	Change in land use - in so far as it impacts on geodiversity and has a direct impact on habitats * Expansion of energy crops (arable + short rotation coppices). * Land use change (toward forestry). * Land use change (from arable to grass). * Land use change (towards semi-natural). * Increased recreational use of land - extension and change of tourism season and activities - increase in winter activities - increase in summer activities.
	Change in land practices and land management - in so far as it impacts on geodiversity and has a direct impact on habitats * Land practices change (grazing pressure increases). * Land practices change (extensification of marginal areas). * Land practices change (intensification of farming on more productive land).
	Perpetuation of current practices - under current management and land use practices may lead to compaction - poaching exacerbating erosion, and leading to soil and habitat change * Impact of variation in soil moisture (wetter and more waterlogging). * Impact of variation in soil moisture (more permanent or seasonal drought).

The distribution of the responses to the questionnaire, normalised to account for differences in numbers of habitat types and species diversity/ density assessed by the specialist teams, indicates that most experts have a strong perception of how geodiversity drivers affect their particular features of interest. Most responses indicate twice as many negative interactions or effects of geodiversity processes on habitats and species as positive ones (Figure 2).

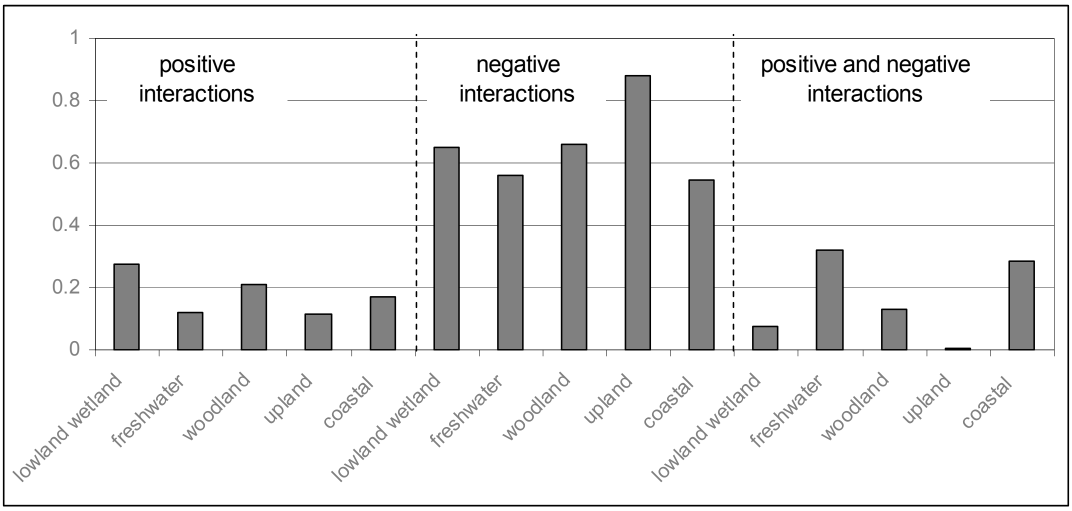

Figure 2. Perception of the impact on habitats and species of geodiversity processes (see Table 2 for the full list) by LCNs - Normalised data for positive interactions, negative interactions and both positive and negative interactions.

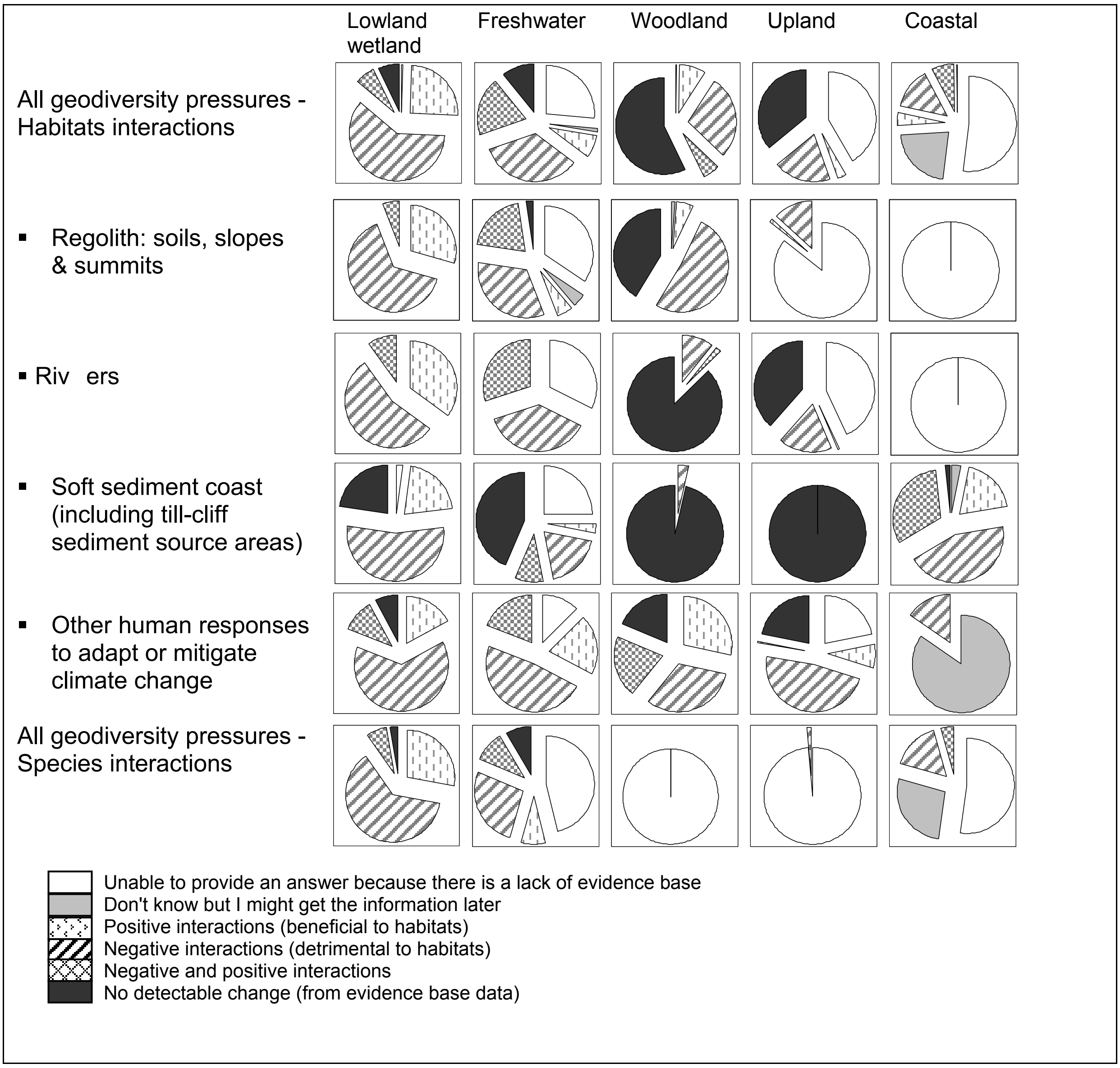

Figure 3. Normalised responses to the questionnaire, as also depicted in Figure 2, but here shown as a breakdown by geomorphological-process specialist topic and LCNs, with the pie charts showing the proportion of the six geodiversity-pressure scoring categories. Also, summary pie charts are provided for habitats and species (top and bottom).

The breakdown by broad geodiversity pressure categories (Figure 3) shows clearly that the quality and extent of evidence on geodiversity processes are more limited for assessing interactions with individual species than interactions with habitat types.

- Experts not involved with coastal habitats considered that the soft sediment and coastal processes appeared to show weaker links (based on available evidence) compared to other processes.

- There is more uncertainty about the impacts of human-driven activities on geodiversity processes. Half of the impacts are perceived as negative, the remainder are split evenly between positive and mixed (positive / negative) impacts.

- Apart from wetland, few of the geodiversity impacts associated with regolith / soil and rivers are seen as positive.

4 Development of evidence-based examples

A more substantial body of evidence on the interaction between individual abiotic and biotic processes is required to ensure that our understanding and use of an ecosystem approach accounts for geodiversity processes. A range of anecdotal evidence collected from experts on those interactions provides an initial basis to understand where to focus our attention.

However, in order to demonstrate the practical options for sustainable management in response to drivers of change and threats to our environment, a more systematic approach is needed to cover not only individual issues, but also to consider compound effects of multiple drivers and outcomes.

The development of case studies was therefore considered essential to promote a common understanding of the key issues and linkages and to identify where the gaps are. The case studies should help identify where management guidance is needed (e.g. in relation to adaptation to climate change) and how it may be informed by better understanding of geodiversity-biodiversity links. This should lead, for example, to better targeting of resources, less apparent conflicts between conservation objectives and more-realistic outcomes. Proposals included:

- selected regional studies (e.g. the Cairngorms, the Jurassic Coast of Dorset and East Devon, or the Holderness Coast); and/or
- a focus on selected habitat types (e.g. sand dunes) that cover a range of issues across the UK.

Helpfully, the Project questionnaire also identified several existing projects that might provide relevant examples for case study development (Table 3).

Land-use change is driven by a range of factors such as demographic change, economic market pressures, policy change, recreational patterns, and adaptations /responses to climate change. These factors exert pressures on the natural environment that in turn lead to a range of responses in biota and physical processes. The impacts are more noticeable for upland and coastal systems where the movement of species and options for adaptation are constrained by geographical factors or the low range of tolerable bio-climatic conditions for the species and habitats. As a first step, therefore, it was decided to focus on these environments and to examine two case studies through an internal review based on existing information and expertise immediately available to the LCNs.

4.1 Connectivity and natural processes at the coast: sand dunes and sediment processes

Sand dunes form above the tide line as a result of aeolian (wind) processes on sand particles interacting with the vegetation that stabilises the wind-blown sand into dunes, which can then provide habitat for other plants and animals. Coastal sand dunes are not only unique habitats but also highly dynamic systems that play an essential role in coastal risk management. A sand-dune system is variable over space and time, reflecting the degree of stability, sand particle grain-size and origin, water availability, storm frequency and wind predominance, degree of leaching and historical/present-day management. Dunes are therefore the product of complex interactions between geodiversity and biodiversity and prevailing climate, with vegetation able to respond to, or instigate, physical changes. The ability for vegetation to re-start successional stages after disturbance helps to promote vegetation diversity. Dunes are of international importance for biodiversity, with several types of dune habitat listed in Annex I of the Habitats Directive.

Table 3. Current and proposed activities with demonstrable geodiversity / biodiversity linkages identified during the survey.

Project	**Lead**
'Peat erosion and the management of peatland habitats'.	SNH
'Managing upland heaths for carbon sequestration' - PhD study.	SNH
'Peatlands and climate change: an analysis of current evidence-base to inform policy development in peatland conservation and restoration in the context of climate change'.	SNH Partnership Project
'Scaling in interdisciplinary upland research: from plots to catchments to regions': Travis, J.M.J., Palmer, S.C.F., Pitchford, J.W. & Redpath, S.M. This is a UK Population Biology Network project, that is undertaking experimental research at a catchment scale.	UK Population Biology Network project
Climate Change and Uplands Working Group. http://quest.bris.ac.uk/research/wkg-gps/soil.html	NERC - EA QUEST
Moors for the Future - undertaking a wide range of relevant research in the Peak District. http://www.moorsforthefuture.org.uk/mftf/main/AboutTheProject.htm	Moors for the Future
Tees Water Colour Project - aims to develop, demonstrate and promote a more holistic approach, linking upland catchment management with water treatment. http://www.nwl.co.uk/Teeswatercolourproject.aspx	Tees Water Colour Project
Langholm Moor Demonstration Project - the project is not really set up to consider geomorphology processes but there might be potential to do so.	Partnership project
Wild Ennerdale - a National Trust/Forestry Commission/United Utilities partnership aimed at minimal management intervention. As for Langholm, this is not looking at geomorphological processes, but it would provide a potential catchment study area. http://www.wildennerdale.co.uk/	Partnership project
European Life project: 'Wise use of floodplains'. http://www.floodplains.org/	EU
European project: FLOBAR (FLOodplain Biodiversity And Restoration). http://www.geog.cam.ac.uk/research/projects/flobar2/	EU
EA/Defra project: 'Broad scale ecosystem impact modelling'.	EA/Defra
RSPB/United Utilities 'SCAMP' initiative - Sustainable Catchment Management Programme. http://www.rspb.org.uk/ourwork/conservation/projects/scamp.asp.	RSPB / United Utilities
The Wetland Vision is currently providing a good basis for finding appropriate locations for large-scale conservation wetland projects in England.	Six Partners including RSPB, NE, EA
Wise Use of Floodplains.	EU LIFE Environment Programme
Biological and Environmental Evaluation Tools for Landscape Ecology (BEETLE) project - targeting policy makers.	Forestry Commission

The sustainable management of sand dunes needs to address the value of their full range of ecosystem services, particularly for flood risk regulation, and be based on a better understanding of the geomorphological processes. In many cases, this can mean changes in management practice away from hard engineering to develop more-dynamic systems to enable sand dune systems to adapt to the impacts from climate change, sea-level rise and coastal squeeze.

Many dune systems, especially in England, have been affected by human actions, including over-stabilisation of dune surfaces and prevention of the exchange of sand between the dunes and the beach. Impacts on hydrology and soil development make systems more vulnerable to pollution and drying out and less able to adapt to climate change impacts (Rees *et al* 2010). Other impacts, such as beach-cleaning, can remove any potential new embryo dunes and invertebrate habitat. Remedial measures may include fencing and replanting of large areas to combat dune erosion. However, the long-term sustainability of these measures can be comprised by changes in climate factors. For example at Dawlish Warren NNR, rocks and matting were installed several years ago and were subsequently buried by sand. They later became exposed after a storm (Figure 4). The exchange of sand between the dune and the beach is now limited and may exacerbate beach lowering. If this continues it will result in more wave energy reaching the dune and an increase in flood and erosion risk (c.f. Taylor *et al* 2004). This may also prevent the dune from building up again. It also means that embryo dunes are not forming.

Figure 4. Dune stabilisation, Dawlish Warren NNR. Originally covered by sand, the matting and rocks has subsequently been exposed after erosion by a storm, and may actually now inhibit dune re-establishment. (© Phil Chambers).

Beach managers are increasingly integrating the functions that dunes may provide into flood and erosion risk management measures (Pye *et al* 2007, Davy *et al* 2010, Rogers *et al* 2010). However, the legacy of defence structures and a slow approach to implementing adaptation measures means that some systems are currently managed inappropriately, ultimately leading to future problems, such as beach lowering and loss of sediment offshore.

The key pressures on sand dune habitats are listed by JNCC[5] as:

- **Erosion and progradation** - Unless artificially constrained, the seaward edge of sand dunes can be a highly mobile feature, though there is a natural trend to greater stability further inland as vegetation and soils develop. Very few dune systems are in overall equilibrium, and a majority of those in the UK demonstrate net erosion rather than net progradation; insufficient sand supply is frequently the underlying cause, which is exacerbated by rising relative sea levels.

- **Sea defences and stabilisation** - Many dune systems are affected by sea defence works or artificial stabilisation measures such as fencing and marram grass planting. These engineered defence systems usually reduce the biodiversity inherent in the natural dynamism of dune systems, and may cause sediment starvation down-drift or beach lowering. UK dunes as a whole suffer from over-stabilisation and poor representation of the mobile phases.

[5] http://jncc.defra.gov.uk/page-1429

- **Recreation** is a major land use on sand dunes. Moderate pressure by pedestrians may cause little damage, and may even help to counteract the effects of abandonment of grazing. However, excessive use, and vehicular use in particular, have caused unacceptable erosion on many dune sites.

- **Grazing** is normally necessary to maintain the typical fixed-dune vegetation communities, but over-grazing, particularly when combined with the provision of imported feedstuffs, can have damaging effects. A more widespread problem is under-grazing, leading to invasion by coarse grasses and scrub, though rabbits are locally effective in maintaining a short turf.

- **Afforestation** of dunes is not as prevalent in Britain as it is in parts of continental Europe, but in a few locations it has had a major effect on large areas of dune landscape. Some sites hold large conifer plantations that have contributed to suppressing the dune vegetation communities and affected the water table.

- **Beach management** - On some heavily used beaches the formation of embryo dunes is inhibited by beach cleaning using mechanical methods that impede the seaward accretion of dune systems. The removal of natural beach litter by such methods also removes organic material which promotes stability directly (increases the critical entrainment velocity), and via increased microbial activity. This often results in ‘mechanically cleaned beaches’ experiencing greater instability.

- **Air pollution** - There is a range of evidence and research that considers atmospheric nutrient deposition as a factor adversely affecting sand dunes. It is also likely that nutrient deposition on many sand dunes is already above the critical threshold for impacts on vegetation. For dune slacks, this could lead to an accelerated succession away from dune slack vegetation. For more stable systems, increased nutrients lead to changes in vegetation communities and an increase in the development of soils (sand dunes typically have thin, nutrient-poor soils that support less competitive vegetation).

- **Falling water tables -** Dune slacks support characteristic communities dependent on a seasonally high water table, including the formation of temporary or even permanent ponds. In some dune systems with important slacks, a long-term fall in the water table has led to loss of the specialist slack flora and invasion by coarse vegetation and scrub. The causes are believed to be local extraction of water, afforestation and/or drainage of adjacent land used for agriculture or housing.

- **Infestation by *Phomopsis juniperovora*** - Dunes with Juniper are a habitat of European importance found only on two sites in Scotland. Juniper is vulnerable to infestation by pathogenic fungi, especially juniper blight (*Phomopsis juniperovora*) which infects new growth, leading to death and ultimately to the loss of the habitat.

Examples of coastal processes responsible for coastal erosion / accretion which may impact on the formation sand dunes include:

- **Changes in sediment supply** resulting from:
  - changes in the angle of approach of dominant waves;
  - changes in supply from the adjacent sea bed (e.g. because the supply has run out);
  - migration of beach lobes or forelands under longshore drift, causing cycles of shoreline advance and retreat;
  - changes in supply from eroding cliffs and foreshore outcrops (e.g. due to construction of coastal defences);
  - interception of longshore drift (e.g. because of breakwater construction).

- **Interaction of wave fields**
  - increased wave attack upon the coast due to a relative rise in sea level;
  - increased wave attack upon the shore due to more frequent, long-lasting or severe storms as a possible consequence of climate change.

- **Vegetation feedback**
  - increased loss of sand inland due to total destabilisation and dune drifting landwards, often then removed artificially from the system;
  - reduction of sand supply to the shore from seaward drifting dunes (e.g. due to over-stabilisation).

- **Human impacts on coastal processes - development planning**
  - construction of sea walls or other hard engineered structures (rock armour), causing reflection of storm waves and consequent beach lowering; intensification of wave attack due to beach lowering on an adjacent shore;
  - removal of sand and shingle from the beach by quarrying or ad-hoc extraction;
  - increased wave attack upon the shore due to deepening of the nearshore seabed (e.g. due to unregulated inshore dredging or removal of intertidal sand).

- **Changes in dune water table,** caused by
  - increased rainfall;
  - local drainage modification;
  - low rainfall rendering the sand more erodible by wind;
  - interception of rainfall by tree or shrub cover.

Impacts on sand dunes and their geodiversity are therefore related to a range of drivers (e.g. sea-level changes, sediment supply reorganisation, change in wave fields, hydrology, vegetation feedback and human activities, including those originating at a distance from the location, such as air pollution). The pressures exerted on the dune geodiversity processes influence not only the coastal landforms, but also the biodiversity they support, and vice-versa.

A number of these issues and interactions are illustrated at Morrich More.

Case study 1: Morrich More

Morrich More, in the Dornoch Firth in North East Scotland, is an outstanding coastal site that comprises an extensive, low-level sandy plain (Figure 5). The site is protected under national (Site of Special Scientific Interest) and international (Special Area of Conservation) legislation and includes a range of coastal habitats - machair, intertidal flats, saltmarsh, dune, brackish pools and heath. These areas are species-rich and together support a wide range of plants and animals[6]. The geomorphological interest of Morrich More is exceptional both for the variety and scale of its coastal landforms, including fixed parabolic dunes, stabilised grey dunes and developing foredune succession, saltmarshes and sandflat, and especially for the complete morphological and stratigraphical record it contains of shoreline changes over the last 7000 years (Hansom, 2003).

Extensive, grazed saltmarsh grades into dune and other coastal habitats, thus enabling an extensive range of habitat mosaics to develop, especially on the north side of Inver Bay. The saltmarsh supports a variety of creeks and brackish pools. Most of the site, however, is dominated by sand dunes that support heath and grassland habitats according to the water table and nutrient conditions. The youngest and most dynamic parts of the site have mobile dunes with Lyme grass (*Leymus arenarius*) and Marram grass (*Ammophila arenaria*), as well as strandline species such as Sea holly (*Eryngium maritimum*). More stable (and older) dunes have extensive heath or grassland communities. The heath supports heather, cross-leaved heath and crowberry. Juniper is abundant and is more extensive than at any other British dune system. There is a wide range of mosaics between all these habitats.

Figure 5. Aerial view of Morrich More. (© P&A Macdonald / SNH).

The diversity of habitat results in a wide range of vascular plants, including species such as seaside centaury (*Centaurium littorale*) which is growing close to its the northernmost limit in Britain. In contrast, Eyebright (*Euphrasia foulaensis*) is growing close to its southern limit in Britain on the east coast. Other nationally scarce species include variegated horsetail (*Equisetum variegatum*), slender-leaved pondweed (*Potamogeton filiformis*), Baltic rush (*Juncus balticus*), narrow-leaved eelgrass (*Zostera marina var. angustifolia*) and dwarf eelgrass (*Zostera noltii*). The populations of eelgrass, Baltic rush and seaside centaury are especially large and extensive.

The range of habitats within the site is also reflected in a rich invertebrate community. Populations of the Grayling butterfly (*Hipparchia semele*) and Galium carpet moth (*Epirrhoe galiata*) are close to their northern limits. The wide range of other nationally rare and scarce invertebrate species includes the fungus gnat (*Mycomya lambi*), a species of cranefly (*Tipula nodicornis*), several water beetles and the water flea (*Eurycyrus glacialis*) in its only Scottish location.

[6] SNH SSSI information portal - http://www.snh.gov.uk/protecting-scotlands-nature/protected-areas/national-designations/sssis/

A number of observations support the hypothesis that changes in sea level lead to geomorphological and ecological responses within the coastal zone. Erosion and frontal recession have replaced long-term accretion along the north-east-facing frontal edge of the dune system (Figure 6). This appears to be the most extensive erosion in the last 7,000 years and the reworked sediment is being moved towards the dune interior via the low-lying saltmarsh troughs. Ecological adjustments include numerous examples of pioneer saltmarsh species invading the lower edges of mature sand dune habitats (Figure 7).

Morrich More provides a clear example of the influence of sea-level change on habitat development. Sea levels have been falling for the last 7,000 years (Figure 8), but recent records show a rise for at least the last 15 years. Understanding of how a range of factors contributed to changes in geodiversity processes and their interactions with biodiversity in the past will help in the assessment of future changes. The impact of geomorphological changes on ecosystems is often a function of several factors related to the ecological condition of the system and its inherent resistance and resilience to change. Coastal ecosystems with good physical and ecological function, including uninterrupted links to the wider sediment system, are most likely to have the greatest potential for adaptive management in the face of rising sea levels and climate change.

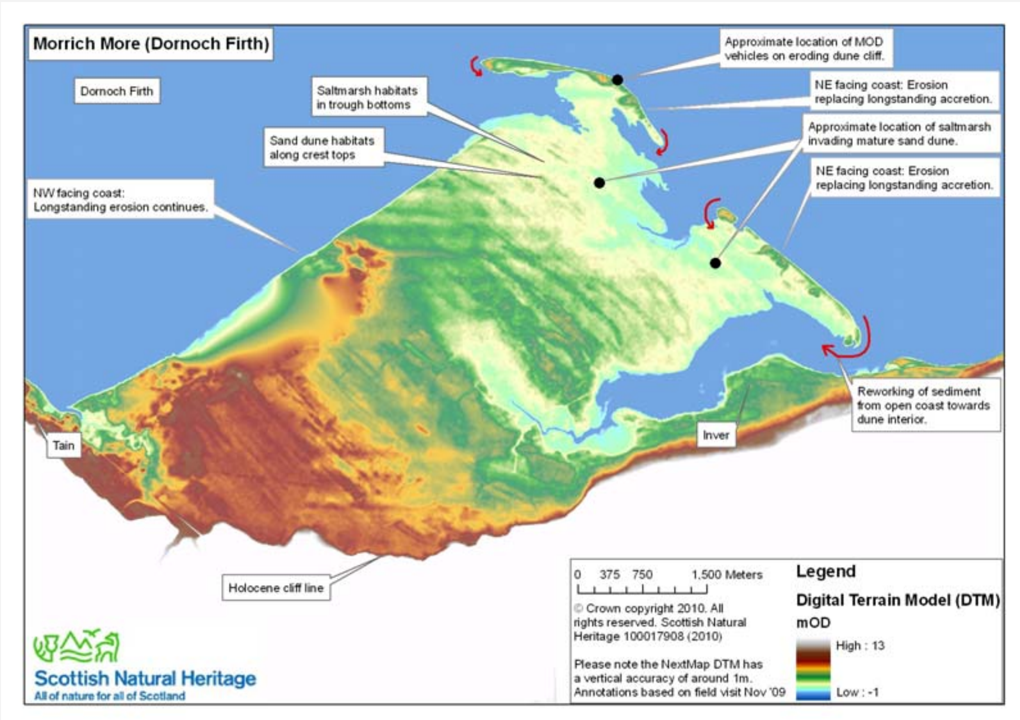

Figure 6. Topographic map of Morrich More SSSI, identifying key locations and processes. (Illustration supplied by A. Rennie / SNH).

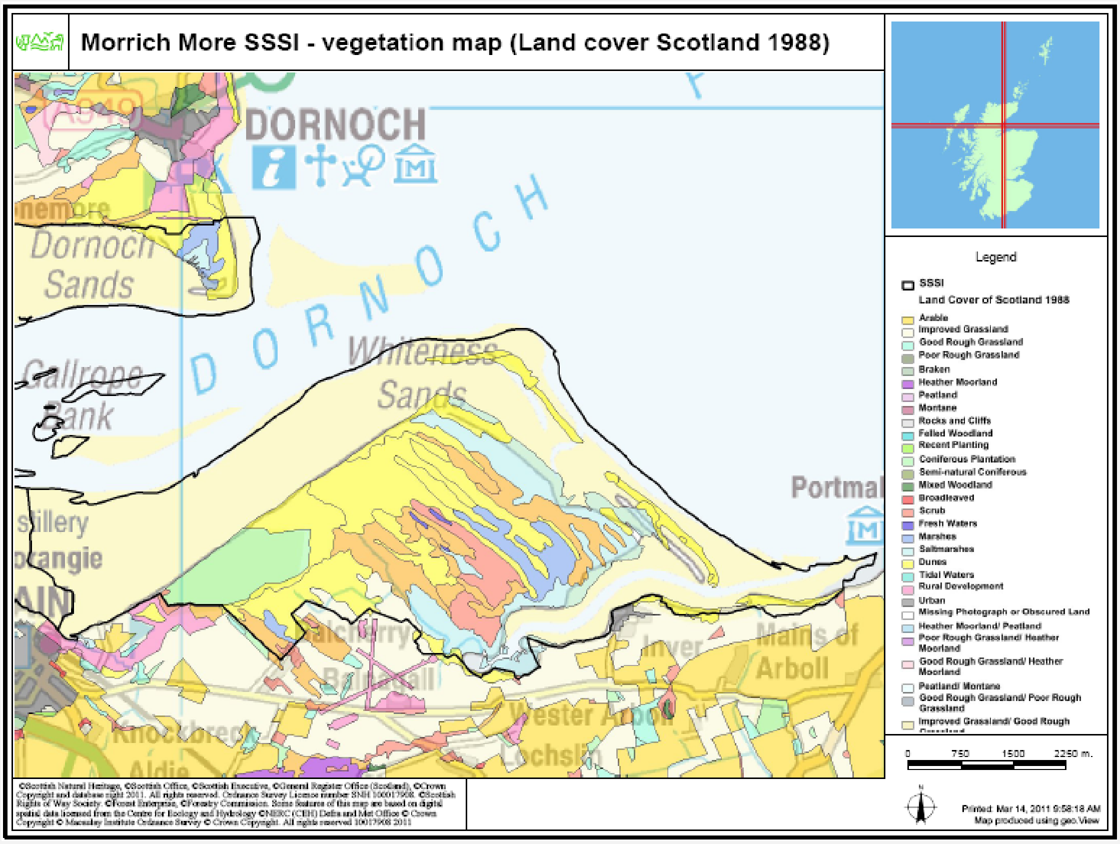

Figure 7. Land cover map (LCS88) of Morrich More, showing broad habitat types.

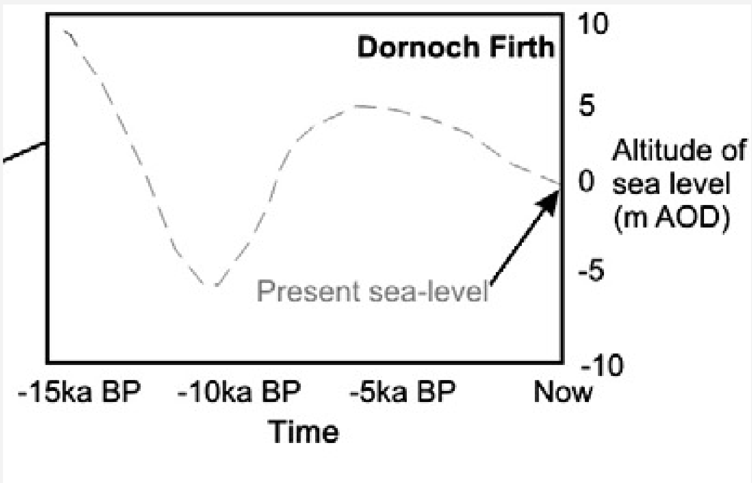

Figure 8. Holocene sea-level change on the Dornoch Firth. Note: the nearby tide gauge in Inverness shows sea-level rise for the last 16 years (+2.66 ± 4.54 mm/yr). (Adapted from Rennie & Hansom, 2011).

Morrich More also reveals how sea-level rise directly and indirectly modifies the physical and chemical conditions of coastal vegetation (e.g. encroachment of brackish water). Evidence of vegetation change following sea-level rise and change in soil salinity have been recorded as changes in species distributions on marginal areas and encroachment by salt-marsh species on dune habitats (Figure 9).

Figure 9. Indications of vegetation change following a change in dune soil salinity. Invasion of acid dune by *America maritima* is visible in the red circle.

4.2 Connectivity and natural processes in the Uplands: landscape scale processes

Although there is no statutory definition for the 'Uplands', those areas which lie above the upper limits of enclosed farmland containing dry and wet dwarf shrub heath species and rough grassland are referred to as such. The UK Uplands include extensive areas of exposed rock, glacial and periglacial landforms, and mass movement and river processes and landforms. It is the scale and diversity of particular assemblages of features, such corries, glacial troughs, mass movements, and rock- and gravel-bed rivers, as well as the range of ages of the rocks and landforms, that make the Uplands such valued landscapes for geodiversity.

Upland ecosystems include many open-type habitats and some of the most spectacular landforms and geodiversity in the UK. Upland ecosystems characteristically show links between the broad-scale pattern of vegetation distribution and altitude, exposure and snow duration. These factors are all related; for example, altitude affects temperature, exposure and snow-cover duration, but topography (and thus geomorphology) also exerts control on all these, especially in relation to the climate on the ground. Within each broad vegetation zone, minor variations in the type of vegetation as well as in the vigour and habit of species within the same community are determined by variations in microclimate and substrate. These are often themselves controlled by the presence of geomorphological features such as geliflucted boulder lobes and solifluction terraces. There are also generally very striking differences in soil moisture content between exposed ridge crests and areas surrounding late-lying snow patches in topographic hollows. Wind is also an important limiting factor for vegetation at altitude, and local topography and regolith-type assume increasing importance. All these factors combine to create the detailed mosaic of vegetation, which is related to the geomorphology on both a large and small scale.

The Uplands contain an important and diverse range of habitats, including large expanses of **Blanket Bog** and **Upland Heathland** that form a mosaic with smaller areas of **Inland Rock Outcrop and Scree Habitats**, **Upland Calcareous Grassland**, **Upland Flushes, Fens and Swamps** and **Limestone Pavements**, and **Mountain Heaths and Willow Scrub** found above the natural treeline. The different habitat types reflect underlying soil conditions and geodiversity processes. UK Upland habitats and their associated species face a number of pressures and threats, which conservation initiatives are trying to address.
The Uplands have suffered huge losses of some habitats and associated species over a long period of time. Since the 1950s, conifer plantations, acid grasslands and so-called 'improved' hill pastures have replaced many of the more natural upland habitats. There have also been reductions in the cover and quality of some of the more natural components of

habitats, largely due to heavy grazing and burning pressures, but also due to atmospheric deposition.

The JNCC website[7] lists a number of pressures on Upland habitats:

- **Grazing.** Over-grazing is an issue for many upland habitats, leading to loss of structure and flowering and the invasion of more grazing tolerant or unpalatable species.

- **Invasive species**. The impacts of heather beetle appear to be increasing and may become a bigger problem (possibly linked to climate or deposition of airborne chemical compounds).

- **Development**. Renewable energy (windfarm), communication mast and access track developments are growing pressures.

- **Fragmentation**. This affects habitats whose extent is limited by geological and hydrological requirements, leading to a scattered distribution and small extent of individual patches. Fragmentation has been exacerbated by past grazing pressure.

- **Burning.** Burning is a traditional tool for management of the upland heathlands, but can lead to damage. Inappropriate burning management, combined with inappropriate grazing, can lead to loss of dwarf-shrubs from wet heath. Wildfires, both deliberate and accidental, can be damaging.

- **Drainage.** Past and continuing loss of area by drainage and conversion to other land uses has led to losses of habitats.

- **Forestry**. Afforestation (mainly by non-native conifers) leads to direct loss of habitat, although temporary and permanent areas of restored habitats are now being created within some existing forests by restructuring after the first rotation.

- **Air pollution.** Based on an assessment of the soil and vegetation exceedence of critical loads, air pollution is considered to be a potentially significant pressure on the structure and function of Upland habitats.

Many geomorphological processes in the Uplands are likely to be affected by changes in temperature, wind speed and the magnitude, duration and intensity of precipitation, resulting in:

- changes in the pattern, magnitude and frequency of wind erosion and deposition, creating more dynamic environments on exposed summits and slopes;

- destabilisation of carbon-rich soils by changes in soil biochemical processes, leading to increased release of greenhouse gases and loss of carbon - this is of particular concern for Scotland's soils which contain the majority of the UK soil 'carbon stock';

- accelerated rates of soil erosion and slope failures, especially during windy or very wet conditions in exposed upland environments;

- changes in the pattern, depth and duration of snow-lie, and consequent snowmelt floods and water recharge of high summits and slopes; for example, a combination of reduced magnitude and duration of snowmelt, combined with pronounced spring drought (as seen in the NW Highlands), may increase subsequent wind and water erosion of vulnerable soils;

[7] http://www.jncc.defra.gov.uk/page-1436

- loss of semi-permanent snow beds and some loss of niche environments associated with late-lying snow beds;
- increased frequency of fluctuations around freezing point, enhancing frost processes on the highest mountains.

Changes in land use and land management can also drive changes in geodiversity processes, for example, through:

- land-use change altering vegetation cover and drainage, leading to overuse of soils;
- over-steepening of slopes by undercutting (e.g. through track construction, pipe laying, stream realignment, quarrying);
- excessive trampling during wet conditions, leading to compaction and enhanced erosion.

A number of these issues and interactions are illustrated in the Cairngorms National Park.

Case study 2: Cairngorms National Park

The Cairngorms National Park (CNP) is 3800 km^2 in area. 39% of the CNP area is designated as important for natural heritage interests, with the central mountain area providing a unique assemblage of geomorphology, vegetation, insects and animals. There are 10 NNRs (491 km^2) and 48 SSSIs within the National Park (31 Biological / 380 km^2, nine mixed / 590 km^2 and eight geological / 0.7 km^2).

At 4.2 people per km^2, the overall population density is very low, but the CNP has a mix of substantial towns, villages, hamlets and houses in the countryside. Tourism-related businesses account for about 80% of the economy, including activities such as skiing, walking, fishing, shooting and stalking.

The central part of the Cairngorm Mountains is of great importance for nature conservation. At an international level, a large part qualifies for designation under the European Habitats Directive and the European Birds Directive. Much of the montane zone is incorporated within SSSI and NNR designations. Geodiversity constitutes a significant part of the natural heritage interest and formed the basis for the inclusion of the area in the UK Tentative List of proposals for World Heritage status (Kirkbride & Gordon, 2010). The adjacent River Spey is designated as an SAC on account of its freshwater pearl mussel, salmon, otter and sea lamprey populations. Its floodplain also includes the internationally important River Spey-Insh Marshes Ramsar site. The Cairngorms have been the focus of considerable research effort on environmental processes, including the Allt a' Mharcaidh Environmental Change Network (ECN) site (Conroy & Johnston 1996, Bayfield *et al* 2005), which demonstrates a strong hydro-geomorphological connectivity.

Links between geomorphology and habitats

The upland and freshwater habitats of the Cairngorms and the species they support depend on the underlying geology, soils and geomorphological processes (Kirkbride & Gordon, 2010), notably the:

- cat chment characteristics - geology, landforms and soils;
- river channel geomorphology and sediment properties;
- hydrological pathways and connectivity; and
- geomorphological connectivity between slopes and rivers.

Catchment characteristics, including geology, soils and hydrological pathways, and river channel geomorphology, sedimentary properties and flow characteristics are a fundamental control on water quality and habitat availability (Tetzlaff *et al* 2007). More specifically, detailed process studies have demonstrated critical links between geology, groundwater and surface water chemistry, the influence of catchment characteristics, and particularly soil types, on groundwater residence times and contributions to runoff, groundwater-surface water interactions and the influence of groundwater on surface water chemistry and ecology, stream and surface water acidification and the effects of snowmelt on hydrological regime and water quality (e.g. Soulsby *et al* 2001, Soulsby *et al* 2005, Soulsby *et al* 2006).

As well as hydrological connectivity, there is also geomorphological connectivity between the montane slopes and the rivers in the form of sediment availability and transfer through the catchments. Catchment responses to climate change, in particular to changes in the magnitude, intensity and duration of precipitation, are likely to be accompanied by spatial and temporal changes not only in flow regimes, but also in erosion and sedimentation, with consequent impacts on habitat condition and quality. Changes in connectivity between hillslopes and river channels in response to weather events and longer-term climate trends will have knock-on effects throughout the catchment in terms of sediment inputs, throughputs and storage. For example, if there is increased connectivity between sediment sources and the river as a result of increased discharges, there will be increased sediment input to the system (Figure 10). Downstream reaches will also be highly responsive to changes in discharge and sediment supply from upstream, with changes in sediment delivery, local mobilisation, throughputs and storage resulting in more dynamic environments (Figure 11).

Figure10. The River Feshie at Blackmill, showing a high degree of connectivity between sediment source and the river. (© L. Gill / SNH).

Figure 11. The River Quoich fan forms a large gravel storage area where it enters the Dee valley. Such areas are potentially sensitive to changes in discharge and sediment delivery. (© L. Gill / SNH).

The geodiversity of the Cairngorm plateaux results from a close interdependence of regolith, soils, ephemeral landforms and the vegetation they support (e.g. Gordon *et al* 1998, Haynes *et al* 1998, Morrocco 2005, Kirkbride & Gordon 2010). The wet, windy climate, with cool, short summers and rather patchy winter snow cover, combined with a potentially well drained and base-poor, gravelly substrate, creates what are possibly some of the most hostile environments in Europe for the establishment, growth and survival of plants. Soil disturbance is common and is most intense in the surface layers where plant roots are concentrated and also where the establishment of seedlings takes place. Roots can be broken and plants partly overturned by heaving associated with freezing, and in suitable regolith by the development of lenses of segregation ice. Many of the plants need to be able to survive extreme variations of soil moisture. For a few days or even weeks in spring, soil moisture may approach or exceed the liquid limit, but by the late summer, strong winds and intense insolation can create surface drought, especially since the Cairngorm regolith has a poor water holding capacity. Seedlings which succeed in germinating in soil disturbed by needle ice activity may be killed by later desiccation. The interactions between geomorphology and vegetation are also evident in the form of wind-patterned vegetation forms which are particularly well developed in the Cairngorms.

Links between soil and habitats

Towers *et al* (2005) developed a methodology to assess the conservation value of soil (Figure 12). This was compared to National Vegetation Classification (NVC) data. None of the extensive Aggregated Soil categories recorded in the CNP has been classified as rare in a local CNP context. However, all of the montane soil categories are rare within Scotland as a whole, and they, along with peat soil, are considered rare in a European context.

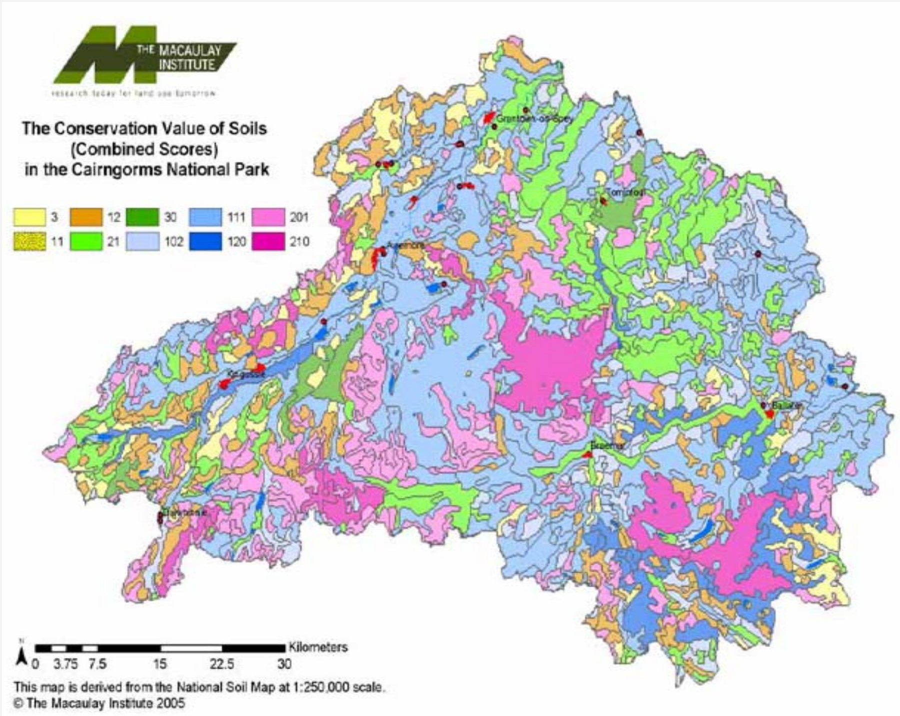

Figure 12. Conservation values of soil in the Cairngorms National Park. High scores indicate greater potential conservation values of soils. (From Towers *et al* 2005).

The relationships between soils and habitats was further analysed by Towers *et al* (2005) for those areas where detailed NVC maps were available (Figure 13). The main conclusions of this work are summarised below.

NVC Heathland (H)

Some of the NVC classes are concentrated on a small number of soil units, whereas others are more ubiquitous. Almost 60% of the H types are found on soil units that are predominantly alpine and subalpine soils, whereas approximately 32% occur on peaty and humus-iron podzols. At first this might appear to be counter-intuitive, but this can be at least partly explained by three factors. First, there is an inherent bias in the area that has been mapped into NVC classes. It is centred on the core area of the Cairngorms massif and therefore the higher land forms a larger proportion than if the whole of the CNP had been mapped. If the land to the north, west and east of the current study area had also been mapped, then a much larger proportion of the 'H' NVC type would be supported by peaty or humus-iron podzols. Second, the soil units representing the highest ground are broad in character, and include a range of site types, from gently sloping, very exposed, partly vegetated plateaux to relatively sheltered, steep valley sides with continuous, often *Calluna*- or *Vaccinium*-dominated vegetation cover. Third, on closer examination, a large proportion of the 'H' NVC types in the montane soil units is H13. This bears many similarities to the character of NVC montane communities, in that the vegetation is patchy and has a very prostrate and stunted growth form. Approximately 55% of the soils with NVC 'H' types have been classified as belonging to map units characterised by the presence of a unique soil type. This suggests that 'H' vegetation is often associated with soil landscapes that have relatively uniform soil patterns (for example peaty podzol, humus iron podzol, alpine and subalpine soil categories). The remaining 45% is equally distributed between the soil complex mapping unit where some level of disaggregation of soil patterns is possible, and the soil mosaic mapping unit where it is not.

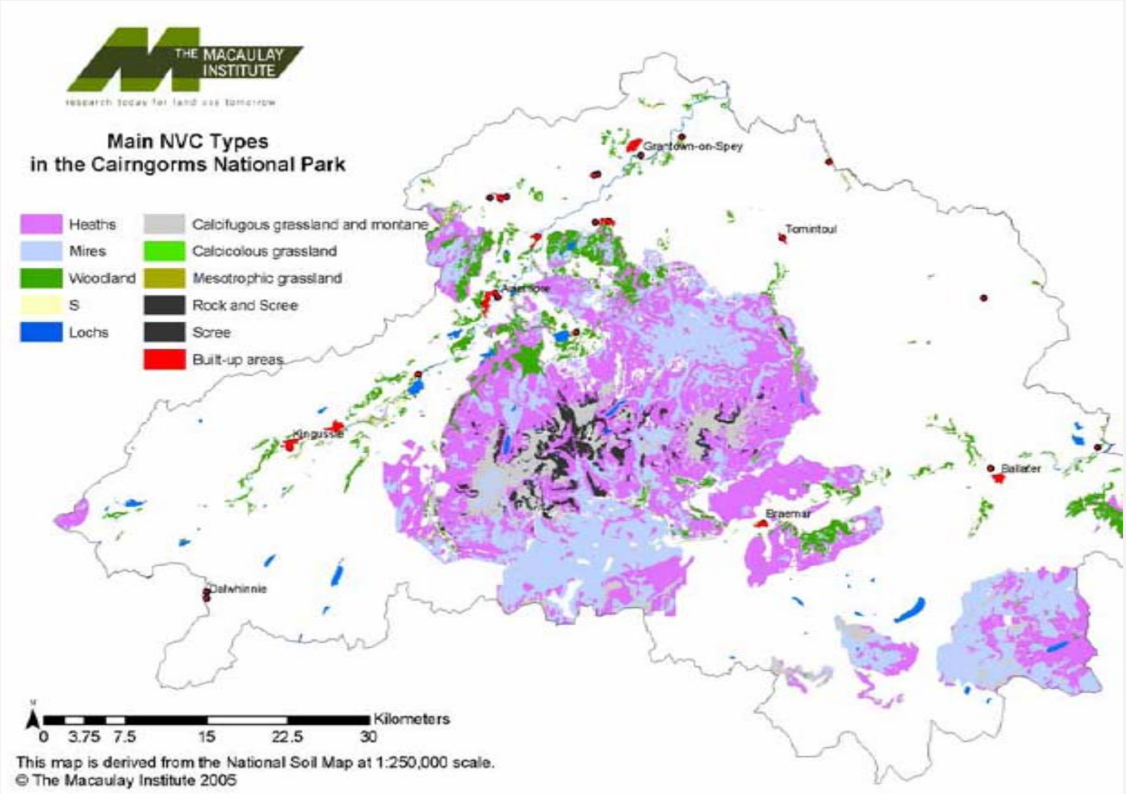

Figure 13. Main NVC types in the Cairngorms National Park. (From Towers *et al* 2005).

NVC Mire (M)
The 'M' NVC mire types are also spread across a number of soil categories, although the top three (X2, O2 and N7) have peat as the sole, main or secondary components within them. A number of the soil categories which have mire vegetation, however, do not have peat or other poorly drained soils as a component. The main explanation for this apparent mismatch is probably the contrasting scale of the datasets and that the 1:250,000 scale soil data do not pick out this detail. Mire is associated primarily with map units characterised by the presence of a unique soil type. Peat, the soil that mire communities are largely associated with, either occurs as large homogeneous units or as discrete components within soil complexes and with sharp boundaries with the other components.

NVC Upland (U)
In contrast, and as might be expected, the 'U' NVC upland types, are much more concentrated in their distribution across the soil types. 75% of the 'U' types are associated with three Aggregated Soil categories (peat, alpine soil and rankers) which all contain alpine or subalpine soils. The remainder of the area containing 'U' NVC types is associated with a range of other soils, and this again is almost certainly due to the coarse resolution of the soil data compared to the fine precision of the NVC data.

Of the four main NVC types, this is the one most often associated with the map unit composed of a range of different soil types. This is almost entirely due to the large area of the P2 Aggregated Soil type where it is judged to be difficult to separate the range of soils contained within it.

NVC Woodland (W)

The 'W' NVC woodland types occur predominantly on soil units dominated by podzols and in places associated with rankers; combined, these six categories account for 80% of the area under NVC 'W' types. This association is to be expected given the area of native pinewood within the mapped area and where soil forming processes leading to podzolisation have occurred and will continue to occur. A small area of 'W' NVC is associated with brown earths, the likelihood being that this is an area of broadleaved woodland.

The NVC woodlands are most commonly associated with the map unit characterised by the presence of a unique soil type, suggesting that native pinewoods prefer relatively uniform sites. Although pinewoods do exhibit diversity when examined in detail, for example in the depth of surface litter and organic matter accumulation, the predominant soils are podzolic and the Scottish soils classification system separates them into humus-iron podzols and peaty podzols.

Other NVC types

The scarcity of other NVC types in the CNP makes an investigation of the soil/vegetation relationships particularly prone to difficulties associated with the resolution differences between the datasets. Nevertheless, 79% of the ‘MG’ mesotrophic grassland is associated with alluvial soils, and the largest single soil category associated with calcicolous grasslands (‘CG’ NVC) is one of brown earths. Both of these are what would be expected from first principles, but a larger dataset would be required to confirm these preliminary soil / vegetation relationships.

5 Discussion: challenges and information gaps

Ecosystem service assessment is a new approach to evaluating the relationships between biotic and abiotic factors and their interactions with human activities and pressures (Millennium Ecosystem Assessment, 2005). Geodiversity underpins many different types of ecosystem service that support and influence biodiversity, such as the formation of different types of soils and hydrological cycling (Gordon & Barron, 2011). The Millennium Ecosystem Assessment (2005) noted that “both the supply and resilience of ecosystem services are affected by changes in biodiversity” (p. 46). The same may be said for changes in geodiversity.

Our brief review and case studies show that the links between geodiversity and biodiversity are fundamental to ecosystem functioning and that their understanding requires an integrated approach.

The ecosystem approach is now being adopted in the UK and provides both a potentially powerful framework for developing much better integration of geodiversity and biodiversity, as well as a means of demonstrating the wider values and benefits of geodiversity through its contribution to delivering ecosystem services. For example, the UK National Ecosystem Assessment[8] has attempted to determine the main services provided by functioning coastal systems. One of the most critical is their role in the regulation of hazards, especially flooding. Adopting an ecosystem approach means looking at whole ecosystems, including geodiversity as well as biodiversity, during decision-making and valuing the ecosystem services they provide. However, geodiversity has not yet been fully integrated into the National Ecosystem Assessment and the challenges now are for the geodiversity and biodiversity communities to work more closely together to achieve that integration. The examples in this report show some of the potential opportunities.

Habitats and species are fundamentally dependent on the availability of appropriate physical environments and natural processes. Ecosystem sensitivity and responses to climate change impacts and sea-level rise will therefore be conditioned by how the underlying geomorphological and soil processes respond. The assessment of the functional links between geodiversity and biodiversity requires an integrated approach (Gordon *et al* 2002, Jonasson *et al* 2005). Changes in geomorphological processes are likely to have significant implications for most ecosystems that are episodically dynamic in space and time, in response to geomorphological processes of different magnitudes and frequencies. The dynamic equilibrium of terrestrial environments can be disturbed by human pressures and natural changes and there is potential for irreversible changes if thresholds are crossed. Integrated management therefore needs to recognise and incorporate the links between process dynamics and terrain sensitivity.

Conservation strategies for managing ecosystem responses to climate change and sea-level rise need to be informed by understanding of the spatial and temporal dynamism of natural processes, and to work in sympathy with natural processes. Understanding Earth surface processes can help mitigate future impacts, inform appropriate policies and guidance for adaptive management, and contribute to restoration of ecosystems already damaged by human activities. Although we need more information on a number of key issues, as outlined above, uncertainty should not be an excuse for inaction. The immediacy of climate change and its implications for the natural heritage require that we start now with existing information/knowledge to develop policy and plan and target sustainable conservation management.

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[8] UKNEA draft synthesis report - http://uknea.unep-wcmc.org/LinkClick.aspx?fileticket=UIQr0mgTWWU%3d&tabid=82

5.1 Lessons from coastal case studies

In relation to the **coastal** environment, the MCCIP report (Rees *et al* 2010) identifies a series of issues which will need to be considered for the coastal margin as a whole:

- Relative sea-level rise will alter the mosaic of habitats. There will be complex morphodynamic responses over different spatial and temporal scales, including impacts on longshore drift.
- Coastal cells will respond differently depending on the type of coast and the legacy of past human intervention/present-day practices.
- Impacts will be greater where there is a sediment deficit. This is particularly relevant to the rate at which estuaries will infill to reach an 'equilibrium' form.
- Storm surges will also affect the potential of systems to adjust to new equilibrium states.
- Land drainage may be affected as sea levels rise, thus reducing the 'fall' available (as rivers attempt to flow into a higher sea level) and with implications for low-lying land behind the coast. In addition, sediment movement may block outfalls. (Increased flow rates, planning developments (increasing the 'flashiness' of catchments and reducing the space/buffers between river and built assets) and relative sea-level rise also result in increased risk of flooding in our river mouths and impact on coastal squeeze).

The priority knowledge gaps that need to be addressed in the short term to provide better advice to be given to policy makers are:

- Coastal change needs to be fully evaluated at a coastal cell level against the UKCP09 predictions for a wide range of climatic factors to improve confidence in predictions and reduce uncertainty. This needs to include the responses of key species across a range of habitats.
- Successional processes in vegetation will be affected by climate and other factors such as nutrient deposition. Work in Wales on dunes indicates that there is a need for more information on the interaction of these factors, which is relevant to future management strategies.
- Studies in progress in Scotland indicate that the relationships between coastal habitats and the landward areas are not fully understood. More work is needed to inform measures to restore the coastal flood plain in order to plan for and enable effective adaptation to climate change.

5.2 Lessons from upland case studies

In relation to the montane environment, Brazier *et al* (in prep.) identify the following process changes that are likely to occur in the uplands if the trends in weather observed over the last 40 years continue into the future:

- changes in the magnitude and/or frequency of slope failures and potential consequent increased slope-river connectivity and increased rates of sediment input, transport and deposition;

- long readjustment-time of gullied slopes following mass movements, thereby increasing the risk of further slope instability;

- changes in the rates and patterns of soil erosion due to both wind stress and/or storm runoff;

- shorter snow-lie, increased frequency of snowmelt events, but a reduction in higher magnitude snowmelt events;

- enhanced frost processes on the highest mountains due to increased frequency of fluctuations around freezing point, but decreased periglacial activity on some lower mountains.

The principal knowledge gaps that need to be addressed in the short term to allow better advice to be given to policy makers concern:

- better understanding of terrain sensitivity and responses in relation to soil erosion, habitat loss and slope stability;

- better understanding of the sensitivities of geomorphological processes and landforms and their responses to the speed and scale of projected climate changes;

- development of evidence-based principles and guidelines to inform climate change adaptation strategies.

6 Conclusions

i Effective implementation of an ecosystem approach requires a multidisciplinary approach addressing the functional links between geodiversity and biodiversity. JNCC is uniquely placed to promote and co-ordinate more joined-up working between the country agencies to develop the necessary integration and understanding of the linkages between geodiversity and biodiversity at the UK level, particularly with regard to managing ecosystems in the context of climate change and sea-level rise.

ii Interactions between geodiversity and biodiversity occur across a range of scales from the microscopic to the landscape scale. However, from a conservation management perspective, spatially integrated approaches at the landscape/ecosystem scale are arguably most critical in a changing world. It will be important to consider the wider landscape, not only sites, and the management of designated features within a wider ecosystem context. Changes at the wider landscape/ecosystem scale may significantly impact on the condition of designated features. In future, some site boundaries may need to be wider to enable inclusion of dynamic features or changes in the distribution of species and habitats as a result of climate change or changes in natural processes. Also, maintaining some sites in favourable condition may simply not be practical in the face of geomorphological changes.

iii Priority areas for attention are those dynamic systems that are likely to be most sensitive to climate change, sea-level rise and land-use change (viz. coastal, upland and river systems).

iv In the short-term, an appraisal is required of management principles and practical guidance on how existing understanding of physical processes might be better integrated and applied to meet current conservation priorities and actual management issues the needs of in a changing environment. Crucially there is a need for management advice and guidance on how to how to design adaptive management to work with natural/physical processes at the landscape/ecosystem scale, supported by evidence-based case studies. One approach to understanding the links between geodiversity and biodiversity is through risk-based scenario modelling of geomorphological and ecological sensitivity and the likely catchment-scale responses, to help inform management strategies for protected areas, habitats and species. Three linked priority issues are proposed for attention with a focus on demonstrating more clearly what ‘working with natural processes’ actually means in practice:

- catchment management/restoration to facilitate nature conservation adaptation (including floodplain restoration/reconnection and natural flood management);

- coastal management/restoration involving closer integration between work on wetlands, freshwater and coastal habitats from the perspective of a wider ecosystem that is linked by geomorphological processes;

- sustainable management of organic soils and their associated habitats at the landscape scale for the benefit of both biodiversity and carbon sequestration.

v There is a need to target a wider audience beyond the specialists and to communicate the key messages about the value of more integrated approaches linking geodiversity and biodiversity, including working with change in natural systems. Linkages between geodiversity and biodiversity also need to be incorporated into relevant policy areas which may vary between the devolved administrations, but likely to include such areas as planning, climate change, flood protection, soil protection, biodiversity strategies and action plans, the emerging UK Geodiversity Action Plan and Local Geodiversity Action Plans. Linkages should also be encouraged across research programmes.

vi As these issues transcend national interests, there is a key role for interagency collaboration to promote a joined-up approach to improve understanding and to identify generic options for sustainable management and adaptation.

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Glossary

Ecosystem	An ecosystem is a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit.
Ecosystem approach	An ecosystem approach is a set of principles to apply to any policy, plan or project that manages the natural environment, whether directly or indirectly. It is about sustainably using natural resources and integrating this with social and economic needs without damaging the health of the ecosystems they depend on.
Ecosystem services	This describes the collective resources and processes supplied by natural ecosystems. Usually divided into provisioning services (e.g. food, water, energy), regulating services (carbon sequestration, purification of water), supporting services (nutrient cycling) and cultural services (tourism, scientific discovery).
Favourable Conservation Status	This refers to the condition assessment used to fulfil the requirement to report on Annex I habitats under the EU Habitats Directive Article 17.
Geomorphological processes	Natural processes (i.e. weathering, erosion and deposition) that modify the Earth's surface material and its landforms.
Geodiversity	Geodiversity is the variety of rocks, minerals, fossils, landforms, sediments and soils, together with the natural processes which form and alter them.
National Vegetation Classification (NVC)	NVC is the key common standards developed for the country nature conservation agencies for the classification of UK plant communities using a phytosociological approach and concentrating on the rigorous recording of floristic data. (For further detail see http://www.jncc.defra.gov.uk/page-4259).
Natural capital	By extending the notion of the economic capital (manufactured means of production) to the goods and services provided by ecosystems, natural capital refers to the stock of natural ecosystems that may yield a flow of valuable ecosystem goods or services into the future.
Soft engineering	A term used to characterise low intervention management techniques (i.e. making use of sediment/vegetation processes to absorb water energy or use of flood plains to store flood water).

Appendix 1

This appendix presents the outcomes of the questionnaire sent to UK country agency LCN specialist advisers to assess their perceptions of the interactions between geomorphological processes and habitats and species.

The methodology used in this exercise is described in Section 3.3 which also includes details of the terminology used to describe the geomorphology processes and impacts (see Table 2).

The assessment considers habitats and species listed under the EU Habitats Directive which are under the remit of each LCN group. Further information on individual species and habitats can be accessed from the following JNCC web sites:

- Handbook on the UK status of EC Habitats Directive interest features - Appendix 2: Guidance on the relationship between Annex I habitat types and the National Vegetation Classification (NVC) http://www.defra.jncc.gov.uk/page-2457
- UK Interest Features - http://www.jncc.defra.gov.uk/Publications/JNCC312/UK_habitat_list.asp

For all relevant combinations of processes / impacts and habitats, each LCN was asked to provide a ‘consensus’ view of the level and direction of the interactions between biodiversity and geodiversity features.

The expert assessment considered five responses codified as follows:

0	unable to provide an answer because there is a lack of evidence base
a	I don't know but I might get the information later
1	positive interactions (beneficial to habitats)
2	negative interactions (detrimental to habitats)
3	negative and positive interactions
4	no detectable change (from evidence base data)

The default answer was set at 0 (unable to answer). However, when no interaction was expected (for example between upland processes and coastal habitats), the default was set at 4 (no detectable change).

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Section	Key processes and impacts (see Table 2 for details)	Habitats: H7110- Active raised bogs	H7120 - Degraded raised bogs still capable of natural regeneration	H7140 - Transition mires and quaking bogs	H7150 - Depressions on peat substrates of the *Rhynchosporion*	H7210 - Calcareous fens with *Cladium mariscus* and species of the *Caricion davallianae*	H7230 - Alkaline fens	H7130 - Blanket bogs	H7220 - Petrifying springs with tufa formation (*Cratoneurion*)		Species: S1409 - *Sphagnum spp.*	S1903 - *Liparis loeselii*	others (add new columns as appropriate)
Regolith: soils, slopes & summits	*Change in soil forming processes*												
	* biological processes	2	2	2	2	2	2	2	2		2	2	0
	* chemical and biochemical processes	2	2	2	2	2	2	2	2		2	2	0
	Change in slope morphology	2	2	2	2	2	2	2	2		2	2	0
	Increased erosion processes (by water and / or wind, and / or frost or snow)	2	2	2	2	2	2	2	2		2	2	0
	Changes in extent of snow cover and length of snow lie, changes in thaw patterns, seasonal length												
	* decrease of snow cover and length of snow lie	1	1	1	1	1	1	1	1		1	1	0
	* increase of snow cover and length of snow lie	2	2	2	2	2	2	2	2		2	2	0
	* changes in freeze/thaw patterns - reduction in number of degree days of frost	1	1	1	1	1	1	1	1		1	1	0
	* changes in freeze/thaw patterns - increase in number of degree days of frost	2	2	2	2	2	2	2	2		2	2	0
	* changes in freeze/thaw patterns - reduction in frequency of fluctuations about freezing point	1	1	1	1	1	1	1	1		1	1	0
	* changes in freeze/thaw patterns - increase in frequency of fluctuations about freezing point	2	2	2	2	2	2	2	2		2	2	0
	Change in atmospheric deposition patterns												
	* increase in soil acidification and eutrophication from change in atmospheric deposition patterns	2	2	2	2	2	2	2	2		2	2	0
	* decrease in soil acidification and eutrophication from change in atmospheric deposition patterns	1	1	1	1	1	1	1	1		1	1	0
	Variation in soil moisture status												
	* wetter (e.g. permanent or seasonal waterlogging)	3	3	3	3	3	3	3	3		3	3	0
	* drier (e.g. permanent or seasonal drought)	2	2	2	2	2	2	2	2		2	2	0
	Drying up and oxidation of organic soil	2	2	2	2	2	2	2	2		2	2	0
	Fertility and nutrient status change												
	* loss of soil fertility and nutrient depletion by processes other than physical loss of topsoil	1	1	1	1	1	1	1	1		1	1	0
	• nutrient enrichment	2	2	2	2	2	2	2	2		2	2	0
Rivers	*Upslope processes affecting river systems*												
	* increased hillslope erosion - change in surface sediment transport	2	2	2	2	2	2	2	2		2	2	0
	* increased runoff and changes in water quality arising from diffuse pollution	2	2	2	2	2	2	2	2		2	2	0
	Change in river sediment type and availability												
	* increasing trends	1	1	1	1	1	1	1	1		1	1	0
	* decreasing trends	2	2	2	2	2	2	2	2		2	2	0
	Changes in catchment slope morphology and river margin morphology	1	1	1	1	1	1	1	1		1	1	0
	Impacts on flooding												
	* increased flooding (duration and intensity of flooding)	3	3	1	1	1	1	1	1		1	1	0

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Key processes and impacts (see Table 2 for details)

	Key processes and impacts	H7110- Active raised bogs	H7120 - Degraded raised bogs still capable of natural regeneration	H7140 - Transition mires and quaking bogs	H7150 - Depressions on peat substrates of the *Rhynchosporion*	H7210 - Calcareous fens with *Cladium mariscus* and species of the *Caricion davallianae*	H7230 - Alkaline fens	H7130 - Blanket bogs	H7220 - Petrifying springs with tufa formation (*Cratoneurion*)		S1409 - *Sphagnum spp.*	S1903 - *Liparis loeselii*	others (add new columns as appropriate)
	* increased flooding (change in location and extent of flood-prone areas)	3	3	1	1	1	1	1	1		1	1 0	
	Impacts on flood defence management												
	* increased river catchment flood defence (soft engineering)	3	3	2	3	3	2	2	2		2	3 0	
	* increased river catchment flood defence (hard engineering)	2	2	2	2	2	2	2	2		2	2 0	
	Change in river sediment type and availability (through channel re-profiling / gravel and sand extraction)	2	2	2	2	2	2	2	2		2	2 0	
Soft sediment coast (including till cliff sediment source areas)	*Change in coastal sediment type and availability*												
	* natural processes - increased supply	1	1	1	1	1	1	1	1		1	1 0	
	* natural processes - decreased supply, leading to increased coastal erosion	2	2 0		1	2 0		4	4		2	2 0	
	* change in beach profile and / or coastal landscape	2	2 4		4	2 4		4	4		4	2 0	
	Wave processes												
	* decrease in wave energy - amplitude	1	1 4		1	1 4		4	4		1	1 0	
	* change in wave energy - amplitude	2	2 4		2	2 4		4	4		2	2 0	
	General sea-level rise												
	* threat to and loss of habitat footprint	2	2	2	2	2	2	4	2		2	2 0	
	* salinisation threats	2	2	2	2	2	2	4	2		2	2 0	
	* coastal squeeze	2	2	2	2	2	2	4	2		2	2 0	
	Increased flooding in coastal areas	2	2	2	2	2	2	4	2		2	2 0	
	Coastal defence												
	* coastal realignment	2	2	2	2	2	2	4	2		2	2 0	
	* soft engineering defence	1	1	1	1	1	1	4	1		1	1 0	
	* hard engineering defence	2	2	2	2	2	2	4	2		2	2 0	
Other human responses to adapt or mitigate climate change	*Planning system*												
	* planning developments (not related to energy needs)	2	2	2	2	2	2	2	2		2	2 0	
	* renewable energy (water)	2	2	2	2	2	2	2	2		2	2 0	
	* renewable energy (winds)	2	2	2	2 4		2	2	2		2 4		0
	Change in land use												
	* expansion of energy crops (arable + short rotation coppices)	2	2	2	2	2	2	2	2		2	2 0	
	* land use change (toward forestry)	2	2	2	2	2	2	2	2		2	2 0	
	* land use change (from arable to grass)	1	1	1	1	1	1	1	1		1	1 0	
	* land use change (towards semi-natural)	1	1	1	1	1	1	1	1		1	1 0	
	* increase recreational use of land	4	4	4	4	4	4	1 4			1 4		0
	Change in land practices and land management												
	* land practices change (grazing pressure increase)	2	2	3	2	3	3	3	2		3	3 0	
	* land practices change (extensification of marginal areas)	2	2	2	2	2	2	2	2		2	2 0	

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Key processes and impacts (see Table 2 for details)

	H7110- Active raised bogs	H7120 - Degraded raised bogs still capable of natural regeneration	H7140 - Transition mires and quaking bogs	H7150 - Depressions on peat substrates of the *Rhynchosporion*	H7210 - Calcareous fens with *Cladium mariscus* and species of the *Caricion davallianae*	H7230 - Alkaline fens	H7130 - Blanket bogs	H7220 - Petrifying springs with tufa formation (*Cratoneurion*)		S1409 - *Sphagnum spp.*	S1903 - *Liparis loeselii*	others (add new columns as appropriate)
* land practices change (intensification of farming on more productive land)	2	2	2	2	2	2	1	2		2	2 0	
Perpetuation of current practices												
* impact of variation in soil moisture (wetter and more waterlogging)	3	3	3	3	3	3	3	3		3	3 0	
* impact of variation in soil moisture (more permanent or seasonal drought)	2	2	2	2	2	2	2	2		2	2 0	

Freshwater habitats

	Key processes and impacts (see Table 2 for details)	H3110 - Oligotrophic waters containing very few minerals of sandy plains: *Littorelletalia uniflorae*	H3130 - Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or of the *Isoëto-Nanojuncetea*	H3140 - Hard oligo-mesotrophic waters with benthic vegetation of *Chara spp.*	H3150 - Natural eutrophic lakes with *Magnopotamion* or *Hydrocharition*-type vegetation	H3160 - Natural dystrophic lakes and ponds	H3170 - Mediterranean temporary ponds	H3180 - Turloughs	H3260 - Water courses of plain to montane levels with the *Ranunculion fluitantis* and *Callitricho-Batrachion* vegetation	S-*Barbus barbus*	S1029 - *Margaritifera margaritifera*	S1092 - *Austropotamobius pallipes*	S1095 - *Petromyzon marinus*	S1096 - *Lampetra planeri*	S1102 - *Alosa alosa*	S1103 - *Alosa fallax*	S1106 - *Salmo salar*	S1109 - *Thymallus thymallus*	S1149 - *Cobitis taenia*	S1163 - *Cottus gobio*	S2492 - *Coregonus albula*	S2494 - *Coregonus lavaretus*	S1034 - *Hirudo medicinalis*	S1044 - *Coenagrion mercuriale*	S1355 - *Lutra lutra*	S1831 - *Luronium natans*	S1833 - *Najas flexilis*	S4056 - *Anisus vorticulus*	Brown trout, Eel, Arctic charr, Pollan
Regolith: soils, slopes & summits	*Change in soil forming processes*																												
	* biological processes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	* chemical and biochemical processes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0 0		0	0 0		0	0	0	0	0	0	0	0
	Change in slope morphology	2	2	2	2	2	0	2	2	0	0	0	0	0	0	0	0 0		0	0 0		0	0	0	0	0	0	0	0
	Increased erosion processes (by water and / or wind, and / or frost or snow)	2	2	2	2	2	0	2	2	0	2	2	3	3	2	2	2	2	0	2	2	2	4	0	2	0	0	0	0
	Changes in extent of snow cover and length of snow lie, changes in thaw patterns, seasonal length																												
	* decrease of snow cover and length of snow lie	0	2 4		4	2	0	4	2	0	2 0		0	0	0	0	2 0		0	0	2	2	0	0 0		0	0	0	0
	* increase of snow cover and length of snow lie	0	a	a	a	a	0	a	a	0	1 0		0	0	0	0	1 0		0	0	1	1	0	0 0		0	0	0	0
	* changes in freeze/thaw patterns - reduction in number of degree days of frost)	3	3	3	3	3	0	3	3	0	2 0		0	0	0	0	2 0		0	0	2	2	0	0 0		0	0	0	0
	* changes in freeze/thaw patterns - increase in number of degree days of frost	3	3	3	3	3	0	3	3	0	1 0		0	0	0	0	1 0		0	0	1	1	0	0 0		0	0	0	0
	* changes in freeze/thaw patterns - reduction in frequency of fluctuations about freezing point	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0 0		0	0 0		0	0	0	0	0	0	0	0
	* changes in freeze/thaw patterns - increase in frequency of fluctuations about freezing point	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0 0		0	0 0		0	0	0	0	0	0	0	0
	Change in atmospheric deposition patterns																												
	* increase in soil acidification and eutrophication from change in atmospheric deposition patterns	2	2	2	2	2	0	2	2	4	2	2	2	4	4	4	2	2	0	2	2	2	0	0	2	4	0	0	0
	* decrease in soil acidification and eutrophication from change in atmospheric deposition patterns	1	1	1	1	1	0	1	1	4	1	1	1	4	4	4	1	1	0	1	1	1	0	0	1	4	0	0	0
	Variation in soil moisture status																												
	* wetter (e.g. permanent or seasonal waterlogging)	3	3	3	3	3	0	3	3	0	1	3	2	2	2	2	1 1		0	0 0		0	0	0	3	0	0	0	0
	* drier (e.g. permanent or seasonal drought)	2	2	2	2	2	0	2	2	0	2	3	3	1	1	1	2	2	0	0 0		0	0	0	3	0	0	0	0
	Drying up and oxidation of organic soil	2	2	2	2	2	0	2	2	0	2	2	0	0	0	0	2 0		0	0 0		0	0	0	2	0	0	0	0
	fertility and nutrient status change																												
	* loss of soil fertility and nutrient depletion by processes other than physical loss of topsoil	3	3	3	3	3	0	3	3	0	1	1	0	0	0	0	1	1	0	0	1	1	0	0	1	1 0		0	3
	* nutrient enrichment	2	2	2	2	2	0	2	2	0	2	2	0	0	0	0	2	2	0	0	2	2	0	0	2	2 0		0	2
Rivers	*Upslope processes affecting river systems*																												
	* increased hillslope erosion - change in surface sediment transport	2	2	2	2	2	0	2	2	0	2	2	3	3	2	2	2	2	0	2	2	2	4	0	2	2 0		0	2
	* increased runoff and changes in water quality arising from diffuse pollution	2	2	2	2	2	0	2	2	2	2	2	2	2	2	2	2	2	0	2	2	2	2	0	2	2 0		0	2
	Change in river sediment type and availability																												

Freshwater habitats

Key processes and impacts (see Table 2 for details)

Group	Key processes and impacts	H3110 - Oligotrophic waters containing very few minerals of sandy plains: *Littorelletalia uniflorae*	H3130 - Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or of the *Isoëto-Nanojuncetea*	H3140 - Hard oligo-mesotrophic waters with benthic vegetation of *Chara spp.*	H3150 - Natural eutrophic lakes with *Magnopotamion* or *Hydrocharition*-type vegetation	H3160 - Natural dystrophic lakes and ponds	H3170 - Mediterranean temporary ponds	H3180 - Turloughs	H3260 - Water courses of plain to montane levels with the *Ranunculion fluitantis* and *Callitricho-Batrachion* vegetation	S-*Barbus barbus*	S1029 - *Margaritifera margaritifera*	S1092 - *Austropotamobius pallipes*	S1095 - *Petromyzon marinus*	S1096 - *Lampetra planeri*	S1102 - *Alosa alosa*	S1103 - *Alosa fallax*	S1106 - *Salmo salar*	S1109 - *Thymallus thymallus*	S1149 - *Cobitis taenia*	S1163 - *Cottus gobio*	S2492 - *Coregonus albula*	S2494 - *Coregonus lavaretus*	S1034 - *Hirudo medicinalis*	S1044 - *Coenagrion mercuriale*	S1355 - *Lutra lutra*	S1831 - *Luronium natans*	S1833 -*Najas flexilis*	S4056 - *Anisus vorticulus*	Brown trout, Eel, Arctic charr, Pollan
	* increasing trends	0	0	0	0	0	0	0	0	0	3 0		3	3	0	0	0 0		0	0 0		0	0	0	0	0	0	0	0
	* decreasing trends	0	0	0	0	0	0	0	0	0	3 0		3	3	0	0	0 0		0	0 0		0	0	0	0	0	0	0	0
	Changes in catchment slope morphology and river margin morphology	3	3	3	3	3	0	3	3	3	3	3	3	3	3	3	3	3	0	3	3	3	0	0	0	3 0		0	3
	Impacts on flooding																												
	* increased flooding (duration and intensity of flooding)	0	3	2	3	3	0	2	3	3	2	3	3	3	3	3	3	3	0	3	3	3	3	0	3	3 0		0	2
	* increased flooding (change in location and extent of flood-prone areas)	0	3	3	3	3	0	3	3	3	2	3	3	3	3	3	3	3	0	3	3	3	3	0	3	3 0		0	2
	Impacts on flood defence management																												
	* increased river catchment flood defence (soft engineering)	3	3	3	3	3	0	3	3	3	3	3	3	3	3	3	3	3	0	3	3	3	0	0	3	3 0		0	3
	* increased river catchment flood defence (hard engineering)	2	2	2	2	2	0	2	2	2	2	2	2	2	2	2	2	2	0	2	2	2	0	0	2	2 0		0	2
	Change in river sediment type and availability (through channel re-profiling / gravel and sand extraction)	2	2	2	2	2	0	2	2	2	2	2	2	2	2	2	2	2	0	2	2	2	0	0	2	2 0		0	3
Soft sediment coast (including till cliff sediment source areas)	*Change in coastal sediment type and availability*																												
	* natural processes - increased supply	0	4	1	1	4	0	4	1	4	4	4	0	4	0	0	0 4		0	4 4		4	0	0	0	4	0	0	0
	* natural processes - decreased supply, leading to increased coastal erosion	0 4		2	2	4	0	4	2	4	4	4	0	4	0	0	0 4		0	4 4		4	0	0	0	4	0	0	0
	* change in beach profile and / or coastal landscape	0	4	3	3	4	0	4	3	4	4	4	0	4	0	0	0 4		0	4 4		4	0	0	0	4	0	0	0
	Wave processes																												
	* decrease in wave energy - amplitude	0	4	4	4	4	0	4	4	4	4	4	0	4	0	0	0	4	0	4	4	4	0	0	0	4	0	0	0
	* change in wave energy - amplitude	0	4	4	4	4	0	4	4	4	4	4	0	4	0	0	0	4	0	4	4	4	0	0	0	4	0	0	0
	General sea-level rise																												
	* threat to and loss of habitat footprint	0	4	2	2	4	0	4	2	2	2	2	2	2	2	2	2	2	0	2 4		4	0	0	0	4	0	0	0
	* salinisation threats	0	4	2	2	4	0	4	2	2	2	2	2	2	2	2	2	2	0	2 4		4	0	0	0	4	0	0	0
	* coastal squeeze	0	4	2	2	4	0	4	2	2	2	2	2	2	2	2	2	2	0	2 4		4	0	0	0	4	0	0	0
	Increased flooding in coastal areas	0 4		2	2	4	0	4	2	2	2	2	2	2	2	2	2	2	0	2 4		4	0	0	0	4	0	0	0
	Coastal defence																												
	* Coastal realignment	0	4	2	2	4	0	4	2	2	2	2	2	2	2	2	2	2	0	2 4		4	0	0	0	4	0	0	0
	* soft engineering defence	0	4	3	3	4	0	4	3	2	2	2	2	2	2	2	2	2	0	2 4		4	0	0	0	4	0	0	0
	* hard engineering defence	0	4	3	3	4	0	4	3	2	2	2	2	2	2	2	2	2	0	2 4		4	0	0	0	4	0	0	0
Other human	*Planning system*																												
	* planning developments (not related to energy needs)	2	2	2	2	2	0	2	2	2	2	2	2	2	2	2	2	2	0	2	2	2	0	0	2	2 0		0	2
	* renewable energy (water)	2	2	2	2	2	0	2	2	2	2	2	2	2	2	2	2	2	0	2	2	2	0	0	2	2 0		0	2
	* renewable energy (winds)	2	2	2	2	2	0	2	2	2	2	2	3	3	2	2	2	2	0	0 0		0	0	0	2	4	0	0	2

Freshwater habitats

Key processes and impacts (see Table 2 for details)	H3110 - Oligotrophic waters containing very few minerals of sandy plains: *Littorelletalia uniflorae*	H3130 - Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or of the *Isoëto-Nanojuncetea*	H3140 - Hard oligo-mesotrophic waters with benthic vegetation of *Chara spp.*	H3150 - Natural eutrophic lakes with Magnopotamion or *Hydrocharition*-type vegetation	H3160 - Natural dystrophic lakes and ponds	H3170 - Mediterranean temporary ponds	H3180 - Turloughs	H3260 - Water courses of plain to montane levels with the *Ranunculion fluitantis* and *Callitricho-Batrachion* vegetation
Change in land use								
* expansion of energy crops (arable + short rotation coppices)	2	2	2	2	2	0	2	2
* land use change (toward forestry)	3	3	3	3	3	0	3	3
* land use change (from arable to grass)	1	1	1	1	1	0	1	1
* land use change (towards semi-natural)	1	1	1	1	1	0	1	1
* increase recreational use of land	3	3	3	3	3	0	3	3
Change in land practices and land management								
* land practices change (grazing pressure increase)	2	2	2	2	2	0	2	2
* land practices change (extensification of marginal areas)	1	1	1	1	1	0	1	1
* land practices change (intensification of farming on more productive land)	2	2	2	2	2	0	2	2
Perpetuation of current practices								
* impact of variation in soil moisture (wetter and more waterlogging)	3	3	3	3	3	0	2	3
* impact of variation in soil moisture (more permanent or seasonal drought)	2	2	2	2	2	0	2	2

Key processes and impacts (see Table 2 for details)	S-*Barbus barbus*	S1029 - *Margaritifera margaritifera*	S1092 - *Austropotamobius pallipes*	S1095 - *Petromyzon marinus*	S1096 - *Lampetra planeri*	S1102 - *Alosa alosa*	S1103 - *Alosa fallax*	S1106 - *Salmo salar*	S1109 - *Thymallus thymallus*	S1149 - *Cobitis taenia*
Change in land use										
* expansion of energy crops (arable + short rotation coppices)	2	2	2	2	2	2	2	2	2	0
* land use change (toward forestry)	2	2	2	2	2	2	2	2 4		0
* land use change (from arable to grass)	1	1	1	1	1	1	1	1	1	1
* land use change (towards semi-natural)	1	1	1	1	1	1	1	1	1	0
* increase recreational use of land	3	2	3	3	3	3	3	3	3	0
Change in land practices and land management										
* land practices change (grazing pressure increase)	2	2	2	2	2	2	2	2	2	0
* land practices change (extensification of marginal areas)	1	1	1	1	1	1	1	1	1	0
* land practices change (intensification of farming on more productive land)	2	2	2	2	2	2	2	2	2	0
Perpetuation of current practices										
* impact of variation in soil moisture (wetter and more waterlogging)	3	3	3	3	3	3	3	3	3	0
* impact of variation in soil moisture (more permanent or seasonal drought)	2	2	2	1	2	1	1	2	2	0

Key processes and impacts (see Table 2 for details)	S1163 - *Cottus gobio*	S2492 - *Coregonus albula*	S2494 - *Coregonus lavaretus*	S1034 - *Hirudo medicinalis*	S1044 - *Coenagrion mercuriale*	S1355 - *Lutra lutra*	S1831 - *Luronium natans*	S1833 -*Najas flexilis*	S4056 - *Anisus vorticulus*	Brown trout, Eel, Arctic charr, Pollan
Change in land use										
* expansion of energy crops (arable + short rotation coppices)	2	2	2	2	0	2	2 0		0	2
* land use change (toward forestry)	2 4		4	4	0	2	4	0	0	2
* land use change (from arable to grass)	1	1	1	1	0	1	3 0		0	1
* land use change (towards semi-natural)	1	1	1	1	0	1	1 0		0	1
* increase recreational use of land	3	3	3	3	0	3	1	0	0	3
Change in land practices and land management										
* land practices change (grazing pressure increase)	2	2	2	1	0	2	2 0		0	2
* land practices change (extensification of marginal areas)	1	1	1	0	0	1	1 0		0	1
* land practices change (intensification of farming on more productive land)	2 4		4	0	0	2	4	0	0	2
Perpetuation of current practices										
* impact of variation in soil moisture (wetter and more waterlogging)	3	3	3	0	0	3	3 0		0	3
* impact of variation in soil moisture (more permanent or seasonal drought)	2	2	2	0	0	2	2 0		0	2

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Key processes and impacts (see Table 2 for details)

	Key processes and impacts	H5110 - Stable xerothermophilous formations with *Buxus sempervirens* on rock slopes (Berberidion p.p.)	H9120 - Atlantic acidophilous beech forests with *Ilex* and sometimes also Taxus in the shrublayer (*Quercion robori-petraeae* or *Ilici-Fagenion*)	H9130 - *Asperulo-Fagetum* beech forests	H9160 - Sub-Atlantic and medio-European oak or oak-hornbeam forests of the *Carpinion betuli*	H9180 - *Tilio-Acerion* forests of slopes, screes and ravines	H9190 - Old acidophilous oak woods with *Quercus robur* on sandy plains	H91A0 - Old sessile oak woods with *Ilex* and *Blechnum* in the British Isles	H91C0 - Caledonian forest	H91D0 - Bog woodland	H91E0 - Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion*, *Alnion incanae*, *Salicion albae*)	H91J0 - *Taxus baccata* woods of the British Isles	H5130 - *Juniperus communis* formations on heaths or calcareous grasslands		S1400 - *Leucobryum glaucum*	S1849 - *Ruscus aculeatus*	Other (insert columns as appropriate)
Regolith: soils, slopes & summits	*Change in soil forming processes*																
	* biological processes	2	2	2	2	2	2	2	2	2	2	2	2		0	0	0
	* chemical and biochemical processes	2	2	2	2	2	2	2	2	2	2	2	2		0	0	0
	Change in slope morphology	2	2	2	4	2	4	2	2	4	2	2	4		0	0	0
	Increased erosion processes (by water and / or wind , and / or frost or snow)	2	2	2	2	2	2	2	2	2	2	2	2		0	0	0
	Changes in extent of snow cover and length of snow lie, changes in thaw patterns, seasonal length																
	* decrease of snow cover and length of snow lie	4	4	4	4	4	4	4	4	4	4	4	4		0	0	0
	* increase of snow cover and length of snow lie	4	4	4	4	4	4	2	4	4	4	4	4		0	0	0
	* changes in freeze/thaw patterns - reduction in number of degree days of frost	4	4	4	4	4	4	4	4	4	4	4	4		0	0	0
	* Changes in freeze/thaw patterns - increase in number of degree days of frost	4	4	4	4	4	4	2	4	4	4	4	4		0	0	0
	* changes in freeze/thaw patterns - reduction in frequency of fluctuations about freezing point	4	4	4	4	4	4	4	4	4	4	4	4		0	0	0
	* changes in freeze/thaw patterns - increase in frequency of fluctuations about freezing point	4	4	4	4	4	4	4	4	4	4	4	4		0	0	0
	Change in atmospheric deposition patterns																
	* increase in soil acidification and eutrophication from change in atmospheric deposition patterns	a	2	2	2	2	2	2	2	2	2	2	2		0	0	0
	* decrease in soil acidification and eutrophication from change in atmospheric deposition patterns	a	1	1	1	1	1	1	1	1	1	1	1		0	0	0
	Variation in soil moisture status																
	* wetter (e.g. permanent or seasonal waterlogging)	2	2	2	2	2	2	2	2	2	2	2	2		0	0	0
	* drier (e.g. permanent or seasonal drought)	1	2	2	2	2	2	2	2	2	2	2	2		0	0	0
	Drying up and oxidation of organic soil	4	4	4	4	4	4	2	2	2	2	4	4		0	0	0
	Fertility and nutrient status change																
	* loss of soil fertility and nutrient depletion by processes other than physical loss of topsoil	4	2	2	2	2	2	2	2	2	2	2	2		0	0	0
	* nutrient enrichment	4	2	2	2	2	2	2	2	2	2	2	2		0	0	0

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Key processes and impacts (see Table 2 for details)

	Key processes and impacts	H5110 - Stable xerothermophilous formations with *Buxus sempervirens* on rock slopes (Berberidion p.p.)	H9120 - Atlantic acidophilous beech forests with *Ilex* and sometimes also Taxus in the shrublayer (*Quercion robori-petraeae* or *Ilici-Fagenion*)	H9130 - *Asperulo-Fagetum* beech forests	H9160 - Sub-Atlantic and medio-European oak or oak-hornbeam forests of the *Carpinion betuli*	H9180 - *Tilio-Acerion* forests of slopes, screes and ravines	H9190 - Old acidophilous oak woods with *Quercus robur* on sandy plains	H91A0 - Old sessile oak woods with *Ilex* and *Blechnum* in the British Isles	H91C0 - Caledonian forest	H91D0 - Bog woodland	H91E0 - Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion, Alnion incanae, Salicion albae*)	H91J0 - *Taxus baccata* woods of the British Isles	H5130 - *Juniperus communis* formations on heaths or calcareous grasslands		S1400 - *Leucobryum glaucum*	S1849 - *Ruscus aculeatus*	Other (insert columns as appropriate)
Rivers	*Upslope processes affecting river systems*																
Rivers	* increased hillslope erosion - change in surface sediment transport	4	4	4	4	4	4	4	4	2	2 4		4		0	0	0
Rivers	* increased runoff and changes in water quality arising from diffuse pollution	4	4	4	4 4		4 4		4	2	2 4		4		0	0	0
Rivers	*Change in river sediment type and availability*																
Rivers	* increasing trends	4	4	4	4	4	4	4	4	4	2 4		4		0	0	0
Rivers	* decreasing trends	4	4	4	4 4		4 4		4	4	2 4		4		0	0	0
Rivers	*Changes in catchment slope morphology and river margin morphology*	4 4		4	4	2 4		4	4	4	2 4		4		0	0	0
Rivers	*Impacts on flooding*																
Rivers	* increased flooding (duration and intensity of flooding)	4 4		4	4	2 4		4	4	4	3	4	4		0	0	0
Rivers	* increased flooding (change in location and extent of flood-prone areas)	4 4		4	4	2 4		4	4	4	3	4	4		0	0	0
Rivers	*Impacts on flood defence management*																
Rivers	* increased river catchment flood defence (soft engineering)	4	4	4	4 4		4 4		4	4	2 4		4		0	0	0
Rivers	* increased river catchment flood defence (hard engineering)	4	4	4	4 4		4 4		4	4	2 4		4		0	0	0
Rivers	*Change in river sediment type and availability (through channel re-profiling / gravel and sand extraction)*	4	4	4	4 4		4 4		4	4	2 4		4		0	0	0
Soft sediment coast (including till cliff sediment source areas)	*Change in coastal sediment type and availability*																
Soft sediment coast (including till cliff sediment source areas)	* natural processes - increased supply	4	4	4	4	4	4	4	4	4	4	4	4		0	0	0
Soft sediment coast (including till cliff sediment source areas)	* natural processes - decreased supply, leading to increased coastal erosion	4	4	4	4 4		4 4		4	4	4	4	4		0	0	0
Soft sediment coast (including till cliff sediment source areas)	* change in beach profile and / or coastal landscape	4	4	4	4 4		4 4		4	4	4	4	4		0	0	0
Soft sediment coast (including till cliff sediment source areas)	*Wave processes*																
Soft sediment coast (including till cliff sediment source areas)	* decrease in wave energy - amplitude	4	4	4	4 4		4 4		4	4	4	4	4		0	0	0
Soft sediment coast (including till cliff sediment source areas)	* change in wave energy - amplitude	4	4	4	4 4		4 4		4	4	4	4	4		0	0	0
Soft sediment coast (including till cliff sediment source areas)	*General sea-level rise*																
Soft sediment coast (including till cliff sediment source areas)	* threat to and loss of habitat footprint	4	4	4	4 4		4 4		4	4	2 4		4		0	0	0
Soft sediment coast (including till cliff sediment source areas)	* salinisation threats	4	4	4	4 4		4 4		4	4	2 4		4		0	0	0
Soft sediment coast (including till cliff sediment source areas)	* coastal squeeze	4	4	4	4 4		4 4		4	4	2 4		4		0	0	0
Soft sediment coast (including till cliff sediment source areas)	*Increased flooding in coastal areas*	4	4	4	4 4		4 4		4	4	2 4		4		0	0	0
Soft sediment coast (including till cliff sediment source areas)	*Coastal defence*																

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Key processes and impacts (see Table 2 for details)

	Key processes and impacts	H5110 - Stable xerothermophilous formations with *Buxus sempervirens* on rock slopes (Berberidion p.p.)	H9120 - Atlantic acidophilous beech forests with *Ilex* and sometimes also Taxus in the shrublayer (*Quercion robori-petraeae* or *Ilici-Fagenion*)	H9130 - *Asperulo-Fagetum* beech forests	H9160 - Sub-Atlantic and medio-European oak or oak-hornbeam forests of the *Carpinion betuli*	H9180 - *Tilio-Acerion* forests of slopes, screes and ravines	H9190 - Old acidophilous oak woods with *Quercus robur* on sandy plains	H91A0 - Old sessile oak woods with *Ilex* and *Blechnum* in the British Isles	H91C0 - Caledonian forest	H91D0 - Bog woodland	H91E0 - Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion, Alnion incanae, Salicion albae*)	H91J0 - *Taxus baccata* woods of the British Isles	H5130 - *Juniperus communis* formations on heaths or calcareous grasslands		S1400 - *Leucobryum glaucum*	S1849 - *Ruscus aculeatus*	Other (insert columns as appropriate)
	* Coastal realignment	4	4	4	4	4	4	4	4	4	2 4		4		0	0	0
	* soft engineering defence	4	4	4	4	4	4	4	4	4	4	4	4		0	0	0
	* hard engineering defence	4	4	4	4	4	4	4	4	4	4	4	4		0	0	0
Other human responses to adapt or mitigate climate change	*Planning system*																
	* planning developments (not related to energy needs)	2	2	2	2	2	2	2	2	2	2	2	2		0	0	0
	* renewable energy (water)	4	4	4	4	2 4		2	2	4	2 4		4		0	0	0
	* renewable energy (winds)	4	4	4	4	4	4	4	4	4	4	4	4		0	0	0
	Change in land use																
	* expansion of energy crops (arable + short rotation coppices)	4	3	3	3	3	3	3	3	3	3	3	3		0	0	0
	* land use change (toward forestry)	4	1	1	1	1	1	1	1	1	1	1	1		0	0	0
	* land use change (from arable to grass)	4	1	1	1	1	1	1	1	1	1	1	1		0	0	0
	* land use change (towards semi-natural)	4	1	1	1	1	1	1	1	1	1	1	1		0	0	0
	* increase recreational use of land	4	3	3	3	3	3	3	3	2	3	3	3		0	0	0
	Change in land practices and land management																
	* land practices change (grazing pressure increase)	4	3	3	3	3	3	3	3	3	3	3	3		0	0	0
	* land practices change (extensification of marginal areas)	4	1	1	1	1	1	1	1	1	1	1	1		0	0	0
	* land practices change (intensification of farming on more productive land)	2	2	2	2	2	2	2	2	2	2	2	2		0	0	0
	Perpetuation of current practices																
	* impact of variation in soil moisture (wetter and more waterlogging)	4	2	2	2	2	2	2	2	2	2	2	2		0	0	0
	* impact of variation in soil moisture (more permanent or seasonal drought)	4	2	2	2 2		2 2		2	2	2	2	2		0	0	0

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	Key processes and impacts (see Table 2 for details)	H4060 - Alpine and Boreal heaths	H4080 - Sub-Arctic Salix spp. scrub	H6150 - Siliceous alpine and boreal grasslands	H6170 - Alpine and subalpine calcareous grasslands	H6230 - Species-rich Nardus grassland, on siliceous substrates in mountain areas (and submountain areas in continentrope)	H6430 - Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels	H7130 - Blanket bogs	H7220 - Petrifying springs with tufa formation (*Cratoneurion*)	H7240 - Alpine pioneer formations of the *Caricion bicoloris-atrofuscae*	H8110 - Siliceous scree of the montane to snow levels (*Androsacetalia alpinae* and *Galeopsietalia ladani*)	H8120 - Calcareous and calcshist screes of the montane to alpine levels (*Thlaspietea rotundifolii*)	H8210 - Calcareous rocky slopes with chasmophytic vegetation	H8220 - Siliceous rocky slopes with chasmophytic vegetation	H8240 -Limestone pavements	H4010 - Northern Atlantic wet heaths with *Erica tetralix*	H4030 - European dry heaths	H6130 -Calaminarian grasslands of the *Violetalia calaminariae*	H6210 - Semi-natural dry grasslands and scrubland facies on calcareous substrates (*Festuco-Brometalia*)	H7140 -Transition mires and quaking bogs	H7150 - Depressions on peat substrates of the *Rhynchosporion*	H7230 - Alkaline fens	H5130 - *Juniperus communis* formations on heaths or calcareous grasslands		S1393 - *Drepanocladus (Hamatocaulis) vernicosus*	S1413 - *Lycopodium spp.*	S1528- *Saxifraga hirculus*	others (add new columns as appropriate)
Regolith: soils, slopes & summits	*Change in soil forming processes*																											
	* biological processes	0	0	0	0	0	0	2	0 0		0	0 0	0		0	0	0	0	0	2	2	2	0		0	0	0	0
	* chemical and biochemical processes	0	0	0 0		0	0	0	0 0		0	0 0	0		0	0	0	0	0	0	0	0	0		0	0	0	0
	Change in slope morphology	0	0	0 0		0	0	0	0 0		0	0 0	0		0	0	0	0	0	0	0	0	0		0	0	0	0
	Increased erosion processes (by water and / or wind, and / or frost or snow)	2	2	0 0		0	2	2	2 0		0	0 0	0		0	0	0	0	0	2	2	2	0		0	0	0	0
	Changes in extent of snow cover and length of snow lie, changes in thaw patterns, seasonal length																											
	* decrease of snow cover and length of snow lie	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0
	* increase of snow cover and length of snow lie	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0
	* changes in freeze/thaw patterns - reduction in number of degree days of frost)	0	0	0 0		0	0	0	0 0		0	0 0	0		0	0	0	0	0	0	0	0	0		0	0	0	0
	* changes in freeze/thaw patterns - increase in number of degree days of frost	0	0	0 0		0	0	0	0 0		0	0 0	0		0	0	0	0	0	0	0	0	0		0	0	0	0
	* changes in freeze/thaw patterns - reduction in frequency of fluctuations about freezing point	0	0	0 0		0	0	0	0 0		0	0 0	0		0	0	0	0	0	0	0	0	0		0	0	0	0
	* changes in freeze/thaw patterns - increase in frequency of fluctuations about freezing point	0	0	0 0		0	0	0	0 0		0	0 0	0		0	0	0	0	0	0	0	0	0		0	0	0	0
	Change in atmospheric deposition patterns																											
	* Increase in soil acidification and eutrophication from change in atmospheric deposition patterns	2 0		0	0	0	0	2	2 0		0	0 0	0		0	0	0	0	0	0	0	0	0		0	0	0	0
	* Decrease in soil acidification and eutrophication from change in atmospheric deposition patterns	0	0	0 0		0	0	0	0 0		0	0 0	0		0	0	0	0	0	0	0	0	0		0	0	0	0
	Variation in soil moisture status																											
	* wetter (e.g. permanent or seasonal waterlogging)	0	0	0	0	0	0	1	0 0		0	0 0	0		0	0	2	0	0	1	1	1	0		0	0	0	0
	* drier (e.g. permanent or seasonal drought)	2	2	0 0		0	2	2 0		2	2	2	2	2 0		2	2	0	0	2	1	2	0		0	0	0	0
	Drying up and oxidation of organic soil	0 0		0	0	0	0	2	0 0		0	0 0	0		0	2	2	0	0	2	2	2	0		0	0	0	0
	fertility and nutrient status change																											
	* loss of soil fertility and nutrient depletion by processes other than physical loss of topsoil	0	0	0 0		0	0	0	0 0		0	0 0	0		0	0	0	0	0	0	0	0	0		0	0	0	0
	* nutrient enrichment	2 0		2	2	2 0		2	2	2	0	0 0	0		0	2	2	2	2	2	2	2	0		0	0	0	0
Riv	*Upslope processes affecting river systems*																											

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	Key processes and impacts (see Table 2 for details)	H4060 - Alpine and Boreal heaths	H4080 - Sub-Arctic Salix spp. scrub	H6150 - Siliceous alpine and boreal grasslands	H6170 - Alpine and subalpine calcareous grasslands	H6230 - Species-rich Nardus grassland, on siliceous substrates in mountain areas (and submountain areas in continentrope)	H6430 - Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels	H7130 - Blanket bogs	H7220 - Petrifying springs with tufa formation (*Cratoneurion*)	H7240 - Alpine pioneer formations of the *Caricion bicoloris-atrofuscae*	H8110 - Siliceous scree of the montane to snow levels (*Androsacetalia alpinae* and *Galeopsietalia ladani*)	H8120 - Calcareous and calcshist screes of the montane to alpine levels (*Thlaspietea rotundifolii*)	H8210 - Calcareous rocky slopes with chasmophytic vegetation	H8220 - Siliceous rocky slopes with chasmophytic vegetation	H8240 -Limestone pavements	H4010 - Northern Atlantic wet heaths with *Erica tetralix*	H4030 - European dry heaths	H6130 -Calaminarian grasslands of the *Violetalia calaminariae*	H6210 - Semi-natural dry grasslands and scrubland facies on calcareous substrates (*Festuco-Brometalia*)	H7140 -Transition mires and quaking bogs	H7150 - Depressions on peat substrates of the *Rhynchosporion*	H7230 - Alkaline fens	H5130 - *Juniperus communis* formations on heaths or calcareous grasslands		S1393 - *Drepanocladus (Hamatocaulis) vernicosus*	S1413 - *Lycopodium spp.*	S1528- *Saxifraga hirculus*	others (add new columns as appropriate)
	* increased hillslope erosion - change in surface sediment transport	2	2	2	2	2	2	2 0		2	0	0 0	0		0	2	2	2	2	2	2	2	0		0	0	0	0
	* increased runoff and changes in water quality arising from diffuse pollution	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2		0	0	0	0
	Change in river sediment type and availability																											
	* increasing trends	4	4	4	4	4	4	4	4 4		4	4 4	4		4	4	4	4	4	4	4	2	4		0	0	0	0
	* decreasing trends	4	4	4	4	4	4	4	4 4		4	4 4	4		4	4	4	4	4	4	4	2	4		0	0	0	0
	Changes in catchment slope morphology and river margin morphology	0	0	0	0	0	0	0	0 0		0	0 0	0		0	0	0	0	0	0	0	0	0		0	0	0	0
	Impacts on flooding																											
	* increased flooding (duration and intensity of flooding)	0	0	0	0	0	0	0	0 0		0	0 0	0		0	0	0	0	0	0	0	0	0		0	0	0	0
	* increased flooding (change in location and extent of flood-prone areas)	0	0	0	0	0	0	0	0 0		0	0 0	0		0	0	0	0	0	0	0	0	0		0	0	0	0
	Impacts on flood defence management																											
	* increased river catchment flood defence (soft engineering)	0	0	0	0	0	0	0	0 0		0	0 0	0		0	0	0	0	0	0	0	0	0		0	0	0	0
	* increased river catchment flood defence (hard engineering)	4	4	4	4	4	4	4	4 4		4	4 4	4		4	4	4	4	4	4	4	2	4		0	0	0	0
	Change in river sediment type and availability (through channel re-profiling / gravel and sand extraction)	4	4	4	4	4	4	4	4 4		4	4 4	4		4	4	4	4	4	4	4	4	4		0	0	0	0
Soft sediment coast (including till cliff sediment source areas)	*Change in coastal sediment type and availability*																											
	* natural processes - increased supply	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4		0	0	0	0
	* natural processes - decreased supply, leading to increased coastal erosion	4	4	4	4	4	4	4	4 4		4	4 4	4		4	4	4	4	4	4	4	4	4		0	0	0	0
	* change in beach profile and / or coastal landscape	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4		0	0	0	0
	Wave processes																											
	* decrease in wave energy - amplitude	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4		0	0	0	0
	* change in wave energy - amplitude	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4		0	0	0	0
	General sea-level rise																											
	* threat to and loss of habitat footprint	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4		0	0	0	0
	* salinisation threats	4	4	4	4	4	4	4	4 4		4	4 4	4		4	4	4	4	4	4	4	4	4		0	0	0	0
	* coastal squeeze	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4		0	0	0	0
	Increased flooding in coastal areas	4	4	4	4	4	4	4	4 4		4	4 4	4		4	4	4	4	4	4	4	4	4		0	0	0	0
	Coastal defence																											
	* Coastal realignment	4	4	4	4	4	4	4	4 4		4	4 4	4		4	4	4	4	4	4	4	4	4		0	0	0	0
	* soft engineering defence	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4		0	0	0	0
	* hard engineering defence	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4		0	0	0	0

UPLAND

	Key processes and impacts (see Table 2 for details)	H4060 - Alpine and Boreal heaths	H4080 - Sub-Arctic Salix spp. scrub	H6150 - Siliceous alpine and boreal grasslands	H6170 - Alpine and subalpine calcareous grasslands	H6230 - Species-rich Nardus grassland, on siliceous substrates in mountain areas (and submountain areas in continentrope)	H6430 - Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels	H7130 - Blanket bogs	H7220 - Petrifying springs with tufa formation (*Cratoneurion*)	H7240 - Alpine pioneer formations of the *Caricion bicoloris-atrofuscae*	H8110 - Siliceous scree of the montane to snow levels (*Androsacetalia alpinae* and *Galeopsietalia ladani*)	H8120 - Calcareous and calcshist screes of the montane to alpine levels (*Thlaspietea rotundifolii*)	H8210 - Calcareous rocky slopes with chasmophytic vegetation	H8220 - Siliceous rocky slopes with chasmophytic vegetation	H8240 -Limestone pavements	H4010 - Northern Atlantic wet heaths with *Erica tetralix*	H4030 - European dry heaths	H6130 -Calaminarian grasslands of the *Violetalia calaminariae*	H6210 - Semi-natural dry grasslands and scrubland facies on calcareous substrates (*Festuco-Brometalia*)	H7140 -Transition mires and quaking bogs	H7150 - Depressions on peat substrates of the *Rhynchosporion*	H7230 - Alkaline fens	H5130 - *Juniperus communis* formations on heaths or calcareous grasslands		S1393 - *Drepanocladus (Hamatocaulis) vernicosus*	S1413 - *Lycopodium spp.*	S1528- *Saxifraga hirculus*	others (add new columns as appropriate)
Other human responses to adapt or mitigate climate change	*Planning system*																											
	* planning developments (not related to energy needs)	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2		0	0	0	0
	* renewable energy (water)	0	0	0	2	2 0		2	2 0		0	0 0 0			0	2	2	2	2	2	2	2	2		0	0	0	0
	* renewable energy (winds)	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2		0	0	0	0
	Change in land use																											
	* expansion of energy crops (arable + short rotation coppices)	4	4	4	2	2 4		2	2 4		4	4 4 4			4	2	2	2	2	2	2	2	2		0	0	0	0
	* land use change (toward forestry)	4	4	4	2	2 4		2	2 4		4	4 4 4			4	2	2	2	2	2	2	2	0		0	0	0	0
	* land use change (from arable to grass)	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	0		0	0	0	0
	* land use change (towards semi-natural)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		0	0	0	0
	* increase recreational use of land	2	2	2	2	2 0		2 0		2	2	2	2	2	2	2	2	2	2 0		0	0	2		0	0	0	0
	Change in land practices and land management																											
	* land practices change (grazing pressure increase)	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	2		0	0	0	0
	* land practices change (extensification of marginal areas)	0	0	0	0	2	2	2	2 0		0	0 0 0			0	2	2	2	2	2	2	2	2		0	0	0	0
	* land practices change (intensification of farming on more productive land)	4	4	4	4	4	4	4	4 4		4	4 4 4			4	4	4	4	4	4	4	4	4		0	0	0	0
	Perpetuation of current practices																											
	* impact of variation in soil moisture (wetter and more waterlogging)	0	0	0	0	0	0	0	0 0		0	0 0 0			0	0	0	0	1 0		0	0	0	0	0	0	0	2
	* impact of variation in soil moisture (more permanent or seasonal drought)	0 0		0	0	0	0	0	0	0	0	0	2	2 0		0 0		2	2 0		2	2	2	2	2 0		2	2

COASTAL

	Key processes and impacts (see Table 2 for details)	H1210 - Annual vegetation of drift lines	H1220 - Perennial vegetation of stony banks	H1230 - Vegetated sea cliffs of the Atlantic and Baltic coasts	H1310 - *Salicornia* and other annuals colonising mud and sand	H1320 - Spartina swards (*Spartinion maritimae*)	H1330 - Atlantic salt meadows (*Glauco-Puccinellietalia maritimae*)	H1420 - Mediterranean and thermo-Atlantic halophilous scrubs (*Sarcocornetea fruticosi*)	H2110 - Embryonic shifting dunes	H2120 - Shifting dunes along the shoreline with *Ammophila arenaria* ("white dunes")	H2130 - Fixed dunes with herbaceous vegetation ("grey dunes")	H2140 - Decalcified fixed dunes with *Empetrum nigrum*	H2150 - Atlantic decalcified fixed dunes (*Calluno-Ulicetea*)	H2160 - Dunes with *Hippophae rhamnoides*	H2170 - Dunes with *Salix repens* ssp. *argentea* (*Salicion arenariae*)	H2190 -Humid dune slacks	H21A0 - Machairs	H2250 - Coastal dunes with *Juniperus* spp.	H1130 - Estuaries	H1140 - Mudflats and sandflats not covered by seawater at low tide	H1150 - Coastal lagoons	H1160 - Large shallow inlets and bays		S1014 - *Vertigo angustior*	S4035 - *Gortyna borelli lunata*	S1166 - *Triturus cristatus*	S1202 - *Epidalea calamita*	S1261 - *Lacerta agilis*	S1395 - *Petalophyllum ralfsii*	S1441 - *Rumex rupestris*	S1654 - *Gentianella anglica*	S1903 - *Liparis loeselii*	others (add new columns as appropriate)
Soft sediment coast (including till cliff sediment source areas)	*Change in coastal sediment type and availability*																																
	* natural processes - increased supply	1	1	3	3	3	3	3	1	1	3	3	3	3	3	3	1	1	1	1	3	1		a	a	a	a	a	a	a	a	a	0
	* natural processes - decreased supply, leading to increased coastal erosion	2	2	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2		2	2	2	2	2	2	2	2	2	0
	* change in beach profile and / or coastal landscape	a	a	3	3	3	3	3	3	3	3	2	2	3	3	3	3	3	3	3	3	3		a	a	a	a	a	a	a	a	a	0
	Wave processes																																
	* decrease in wave energy - amplitude	3	1	3	1	1	1	1	1	1	1	1	1	1	1	2	1	1	3	3	1	3		a	a	a	a	a	a	a	0	a	0
	* change in wave energy - amplitude	a	a	3	3	3	3	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3		a	a	a	a	a	a	a	0	a	0
	General sea-level rise																																
	* threat to and loss of habitat footprint	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2		2	2	2	2	2	2	2	2	2	0
	* salinisation threats	a	a	a	4	4	4	3	3	3	2	2	2	2	2	2	2	2	3	3 4		3		2	2	2	2	2	2	2	2	2	0
	* coastal squeeze	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2		2	2	2	2	2	2	2	2	2	0
	Increased flooding in coastal areas	3	2	a	1	1	1	1	2	2	2	2	2	2	2	2	2	2	1	1	1	1		2	2	2	2	2	2	2	2	2	0
	Coastal defence																																
	* Coastal realignment	3	3	3	1	1	1	1	1	1	3	2	2	2	2	2	2	2	1	1	3	1		3	3	3	3	3	3	3	3	3	0
	* soft engineering defence	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	1	1	1	3	1		3	3	3	3	3	3	3	3	3	0
	* hard engineering defence	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2		2	2	2	2	2	2	2	2	2	0

COASTAL

	Key processes and impacts (see Table 2 for details)	H1210 - Annual vegetation of drift lines	H1220 - Perennial vegetation of stony banks	H1230 - Vegetated sea cliffs of the Atlantic and Baltic coasts	H1310 - *Salicornia* and other annuals colonising mud and sand	H1320 - Spartina swards (*Spartinion maritimae*)	H1330 - Atlantic salt meadows (*Glauco-Puccinellietalia maritimae*)	H1420 - Mediterranean and thermo-Atlantic halophilous scrubs (*Sarcocornetea fruticosi*)	H2110 - Embryonic shifting dunes	H2120 - Shifting dunes along the shoreline with *Ammophila arenaria* ("white dunes")	H2130 - Fixed dunes with herbaceous vegetation ("grey dunes")	H2140 - Decalcified fixed dunes with *Empetrum nigrum*	H2150 - Atlantic decalcified fixed dunes (*Calluno-Ulicetea*)	H2160 - Dunes with *Hippophae rhamnoides*	H2170 - Dunes with *Salix repens ssp. argentea* (*Salicion arenariae*)	H2190 -Humid dune slacks	H21A0 - Machairs	H2250 - Coastal dunes with *Juniperus spp.*	H1130 - Estuaries	H1140 - Mudflats and sandflats not covered by seawater at low tide	H1150 - Coastal lagoons	H1160 - Large shallow inlets and bays		S1014 - *Vertigo angustior*	S4035 - *Gortyna borelii lunata*	S1166 - *Triturus cristatus*	S1202 - *Epidalea calamita*	S1261 - *Lacerta agilis*	S1395 - *Petalophyllum ralfsii*	S1441 - *Rumex rupestris*	S1654 - *Gentianella anglica*	S1903 - *Liparis loeselii*	others (add new columns as appropriate)
Other human responses to adapt or mitigate climate change	*Planning system*																																
	* planning developments (not related to energy needs)	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2		2	2	2	2	2	2	2	2	2	0
	* renewable energy (water)	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a		a	a	a	a	a	a	a	a	a	0
	* renewable energy (winds)	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a		a	a	a	a	a	a	a	a	a	0
	Change in land use																																
	* expansion of energy crops (arable + short rotation coppices)	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a		a	a	a	a	a	a	a	a	a	0
	* land use change (toward forestry)	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a		a	a	a	a	a	a	a	a	a	0
	* land use change (from arable to grass)	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a		a	a	a	a	a	a	a	a	a	0
	* land use change (towards semi-natural)	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a		a	a	a	a	a	a	a	a	a	0
	* increase recreational use of land	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2		2	2	2	2	2	2	2	2	2	0
	Change in land practices and land management																																
	* land practices change (grazing pressure increase)	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a		a	a	a	a	a	a	a	a	a	0
	* land practices change (extensification of marginal areas)	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a		a	a	a	a	a	a	a	a	a	0
	* land practices change (intensification of farming on more productive land)	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a		a	a	a	a	a	a	a	a	a	0
	Perpetuation of current practices																																
	* impact of variation in soil moisture (wetter and more waterlogging)	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a		a	a	3	3	2	a	a	a	a	0
	* impact of variation in soil moisture (more permanent or seasonal drought)	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a		a	a	2	2	3	a	a	a	a	0