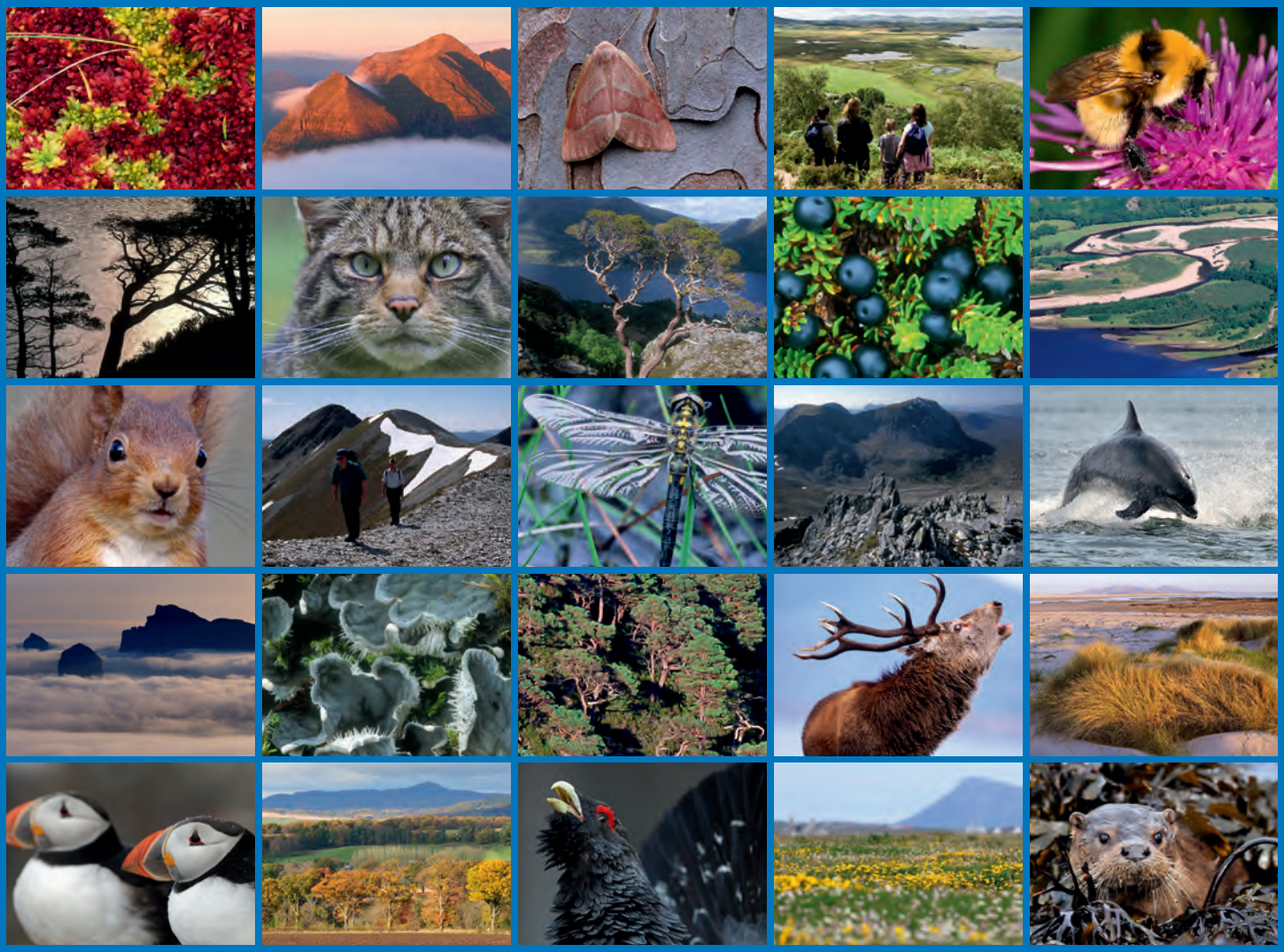
Scottish Natural Heritage
Commissioned Report No. 590

Assessing the sensitivity of geodiversity features in Scotland's seas to pressures associated with human activities



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COMMISSIONED REPORT

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Assessing the sensitivity of geodiversity features in Scotland's seas to pressures associated with human activities

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COMMISSIONED REPORT

Summary

Assessing the sensitivity of geodiversity features in Scotland's seas to pressures associated with human activities

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Background

The Marine (Scotland) Act 2010 and the UK Marine and Coastal Access Act 2009 include new powers for Scottish Ministers to designate Marine Protected Areas (MPAs) in the seas around Scotland as part of a range of measures to manage and protect Scotland's seas for current and future generations. Work to identify these MPAs is coordinated through the Scottish MPA Project, a joint project between Marine Scotland (MS), Scottish Natural Heritage (SNH), the Joint Nature Conservation Committee (JNCC) and Historic Scotland. SNH and JNCC submitted formal advice to Scottish Ministers on the identification of Nature Conservation MPAs in Scotland's seas in December 2012 (SNH and JNCC, 2012). On the 25 July 2013 the Scottish Government launched a 16-week consultation on the full suite of 33 possible Nature Conservation MPAs, noting that a further four MPA search locations remain to be fully evaluated.

This report presents the summary conclusions of an assessment of the sensitivity of proposed geodiversity protected features within the possible Nature Conservation MPAs and the MPA search locations to pressures arising from human activities. This information is required to inform the development of a well-managed network of MPAs. A feature is considered to be 'sensitive' (at a high, medium or low rating) if it is readily adversely affected by external pressures and is expected to recover only over a very long time period, or not at all. Accordingly, the assessment of geodiversity feature sensitivity takes into consideration sediment type / geology (resistance) and the ability of the features to recover from degradation (resilience). The assessment methodology was aligned with parallel assessments being completed for proposed biodiversity protected features of the possible Nature Conservation MPAs. The detailed results have been collated with those for biodiversity and will be disseminated online through FEAST (FEatures Activities Sensitivities Tool - Marine Scotland, 2013).

Main findings

- The assessment used expert-judgement, drawing primarily upon earlier published studies and informed by 'secondary data' that, whilst not directly considering impacts of anthropogenic pressures on geological or geomorphological features, highlight potential disturbance to the sea bed and wider physical processes from various activities and associated pressures.

- In the vast majority of instances, the proposed geodiversity protected feature components of the possible Nature Conservation MPAs within Scottish waters have a low sensitivity to the pressures arising from current human activities. This is because although most of the feature components are relict (thereby having either low or no resilience), they have high resistance to pressures. This is due to the fact that they are typically composed of hard geology which has a low susceptibility to erosion.
- It should be noted that the assessment results do not imply vulnerability (which requires a consideration of both sensitivity and exposure to activities) of a specific feature to a given pressure. Care must therefore be exercised when attempting to 'down-scale' these high-level, regional-scale results to inform assessments at the scale of individual possible MPAs. It is important that the actual magnitude of any identified pressures is taken into consideration. Indeed, in the vast majority of instances, most pressures associated with marine anthropogenic activities will not be sufficient to impact geological and geomorphological seabed features.

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1. INTRODUCTION

Human activities have the potential to cause multiple pressures on different components of the marine ecosystem (Crain *et al*., 2009). For example, aggregate dredging causes abrasion of the sea bed and localised increases in suspended sediment concentrations whilst bottom trawling causes physical disturbance to sediments particularly in shelf areas (e.g. Duplisea *et al*., 2001). It is well known that if incorrectly managed, these various pressures have the potential to adversely impact marine biodiversity. However, under certain circumstances these same pressures may also impact geological and geomorphological features at the sea bed. This report provides details of the sensitivity of the proposed geodiversity protected features of possible Nature Conservation MPAs in Scotland's seas to pressures associated with anthropogenic marine activities. This information is required as part of the development of a well-managed network of MPAs in Scotland's seas.

The diverse landforms and depositional records found on the sea bed in Scottish waters are potentially of great value in furthering understanding of important Earth system processes. Key examples include the dynamics of marine-based ice sheets under changing climates and the linkages between ocean circulation and climate change. The variety of rocks and landforms also has a central role to play in marine biological diversity and a number of internationally important habitats owe their development to the presence of these seabed features (Brooks *et al*., in prep.). The justification for conserving certain marine geological and geomorphological features is therefore apparent. Indeed, the premise that we need to preserve our Earth heritage for future generations and in doing so maintain the resources necessary for continued and future research applies to the same extent beneath the waves as it does terrestrially (Allen *et al*., 1989; NCC, 1984, 1990; Pearce, 1989; Wilson *et al*., 1994; Furze, 2003).

A significant amount of work has already been undertaken in support of the development of Scottish MPAs. Studies specifically considering the spatial distribution of geological and geomorphological seabed features include the Defra-led Biophysical Datalayers project (MB0102 Report No 8 Task 2A - ABPmer, 2009) and the Deep Sea Habitat Classification map (MB0105 - Jacobs and Porritt, 2009). These geological and geomorphological GIS data layers have been combined with existing BGS data as well as other geodiversity datasets to provide an up-to-date catalogue of Scottish seabed features (Brooks *et al*., in prep.). An assessment identifying key geodiversity areas in Scottish waters has previously been undertaken (Brooks *et al*., 2013) and the findings from this assessment were incorporated into the Nature Conservation MPA identification and selection process. The proposed geodiversity protected features and components of possible Nature Conservation MPAs and MPA search locations in Scottish waters are shown in Table 1.

The geodiversity sensitivity assessment described in this report builds upon the earlier work of ABPmer (2009) which presents an assessment of the sensitivity of geodiversity features mapped on the UK seabed to a number of activities taking place in the marine environment. The ABPmer (2009) investigation was adapted from the techniques developed by the University of Bangor for the Irish Sea Pilot study (Furze and Roberts, 2004). This was the first conservation assessment of Earth science features in the marine environment, although an extensive conservation assessment of terrestrial sites was undertaken as part of the Geological Conservation Review (e.g. Ellis *et al*., 1996).

Table 1 Proposed geodiversity protected feature components within the Scottish MPA network

Feature	Component	Description
Quaternary of Scotland	Continental slope channels	Open channel feature 10-15 m deep, up to 200 m wide and over 15 km in length. Found on the continental slope and are thought to have formed from cascading currents of dense glacial melt-water flowing down the continental shelf (Kenyon, 1987).
	Glaciated channel/trough	Feature formed by channelled ice flow causing bedrock erosion. Commonly steep-sided and may be several hundred metres deep and several 10's of kilometres long (Summerfield, 1991).
	Iceberg ploughmark field	Feature formed when the keel of an iceberg makes contact with the seabed. In UK offshore waters, ploughmarks are commonly found at 140-500 m water depth with a width of c.20 m, depth of c.2 m and length of up to 5.5 km. Associated with Quaternary (c.2 myr - 20 kyr ago) glacial episodes (Belderson *et al*., 1973).
	Landscape of areal glacial scour	An irregular rock surface which has everywhere been dominantly shaped by the action of erosion by ice (Sugden, 1978).
	Mega-scale glacial lineations	Large-scale (10 - 100 km) landform signature in which both positive and negative features are moulded in soft sediment (Stokes and Clark, 1999) or cut into bedrock (Bradwell *et al*., 2008). They are formed by subglacial erosion processes in former areas of fast ice flow.
	Moraines	Generic term given to feature comprising unconsolidated glacial debris. May be orientated parallel or transverse to the direction of ice flow. Moraines may form beneath or on-top of moving ice or may form at the ice margin (Summerfield, 1991).
	Prograding wedge	Stacked glacigenic debris flow deposits lain down in front of large glacial troughs. Located along the continental shelf margin and associated with large-scale sub-marine landslides (Dahlgren *et al*., 2005).
	Sub-glacial tunnel valley	Channel feature cut by glacial meltwater flowing beneath an ice sheet/glacier. May be several hundred metres deep and several kilometres long (Summerfield, 1991).
Submarine Mass Movement	Continental slope turbidite canyons	Deep, steep-sided valley feature whose axis slopes seaward at up to 80 m/km. Development relates to erosion by turbidity currents (Allaby, 2008).
	Slide deposit	Large-scale accumulation of sediment in response to gravitational instability along particular shear planes. Many of the slides in UK offshore waters are associated with glacial depocentres and range in age from >2 Ma to <10 ka. The common association of slides and tectonic features suggests that seismic activity has had a major influence on slide location and distribution (Evans *et al*., 2005).
	Slide scars	Feature which is left on the seabed slope after a sub-marine slide has taken place
Marine Geomorphology of the Scottish Deep Ocean Seabed	Contourite sand/silt	Contourites are the deposits formed by oceanic boundary currents that flow along the contours at depths determined by water density. The currents usually operate over very great periods of time, right up to the present day, and build up extensive and thick, fine grained bodies of sediment called drifts.
	Sand wave field	Examples of sand waves in Scottish deep ocean settings are found in the Faroe-Shetland Channel. Here sand wave wavelengths are irregular, but generally between 1 and 2 km. Amplitudes are typically less than 5 m (Masson, 2001).

Feature	Component	Description
Marine Geomorphology of the Scottish Deep Ocean Seabed *cont.*	Scour moat	Feature created by accelerated persistent currents directed around changes of seabed slope in deep-water, offshore environments. Usually several kilometres across and over 100 m deep and are indicators of energetic and stable long-term environments (Holmes *et al*., 2006).
	Sediment drift	Large-scale accumulation of sediment formed by deep oceanic bottom-current activity. Commonly covers an area of many thousand square kilometres and forms over a period of several million years.
	Sediment wave field	Generic term given to regular sediment waves identified by seabed surveys in north and north-west UK offshore waters.
	Polygonal faults	Feature formed from dewatering processes associated with excess pore fluids (Lonergan *et al*., 1998).
Seabed Fluid and Gas Seep	Pockmarks	Shallow seabed depressions, typically several tens of metres across and a few metres deep. Commonly formed in soft, fine-grained seabed sediments by the escape of fluids (gas or water) into the water column (Judd, 2001).
Cenozoic Structures of the Atlantic Margin	Continental slope	Relatively steeply sloping surface extending from the outer edge of the shelf to the continental rise. Slope angle commonly ranges from 1 to 150 (average 40) (Allaby, 2008).
	Hebrides Terrace Seamount	Large-scale undersea topographic feature rising relatively steeply several hundred meters from the surrounding deep-ocean floor.
	Mud diapirs	A muddy sediment structure that has intruded into a denser overlying rock causing doming of the seabed (Judd and Hovland, 2007).
	Rosemary Bank Seamount	The Bank is an extinct volcano, over 75 km in diameter and 1,500 m high, and average water depths are about 500 m across its summit.
Marine Geomorphology of the Scottish Shelf Seabed	Bank (unknown substrate)	(Seabed sediment data lacking)
	Longitudinal bedform field	Generic term given to areas containing sand streaks, sand ribbons and/or longitudinal sand patches.
	Sand bank	Significant feature encountered on the continental shelf and in coastal regions. Active banks are found where current velocity exceeds 0.9 ms^{-1} and where there is abundant sand. Usually formed from medium or coarse sand and may extend to 80 km in length, 3 km in width and tens of metres in height (Belderson, 1986; Bearman, 1993; Dyer and Huntley, 1999).
	Sand ribbon field	Low relief, elongate sand strips which may be up to 15 km long, 200 m wide and 1 m high. Indicative of sediment starved environments with strong tidal flows (Kenyon, 1970).
	Sand wave field	Submerged transverse ridges of sand with wave-lengths of c.30 - 1,000 m and heights of c.3 - 18 m. Occur where sand is abundant and where current velocities are between c. 0.55 ms^{-1} to c.0.9 ms^{-1}. May be symmetric or asymmetric depending on the direction of the net-tidal sand transport (Bearman, 1993).
	Sediment wave field	Generic term given to regular sediment waves identified by seabed surveys in north and north-west UK offshore waters.

(Adapted from SNH and JNCC (2012) and Brooks *et al*. (2013))

This report comprises five main sections:

Section 1: Delivers an introduction to the rationale behind the geodiversity sensitivity assessment;

Section 2: Identifies those anthropogenic marine activities and associated pressures which have the potential to impact marine geodiversity;

Section 3: Provides details of the methodology used to asses the potential sensitivity of geodiversity feature components to the pressures identified in Section 2;

Section 4: Describes the methodology used to assess confidence in the individual geodiversity sensitivity assessments; and

Section 5: Gives an overview of the key findings of the geodiversity sensitivity assessment.

The results of the geodiversity sensitivity assessment are provided separately within the FEAST online tool (Marine Scotland, 2013).

2. IDENTIFICATION OF ANTHROPOGENIC ACTIVITIES AND PRESSURES ON THE MARINE ENVIRONMENT

The OSPAR Biological Diversity and Ecosystems Strategy includes a list of human activities that can adversely affect the marine environment (OSPAR, 2013). These have been reviewed and those activity themes and activities giving rise to pressures to which the proposed geodiversity protected feature components are considered potentially sensitive have been listed in Table 2. This list is broadly consistent with that presented in ABPmer (2009) albeit with the addition of some new categories (e.g. 'shipping' and 'extraction of living resources'). Some discussion with regards to these marine activities and their potential impacts on the sea bed are presented in Defra (2010).

Each of the activities described in Table 2 has the potential to give rise to a set of 'pressures' at the sea bed. The types of pressures to which proposed geodiversity protected feature components are likely to be considered sensitive are listed in Table 3. These pressures are also captured within Annex III, Table 2 of the Marine Strategy Framework Directive of the European Union (Table 3.1) (Anon., 2008). A number of the pressures listed in Table 3 can be more readily linked to threats to biodiversity rather than geodiversity interests. Particular examples include temperature and water clarity changes. However, these pressures have been included here as several of the (active) component bedforms included within the Marine Geomorphology of the Scottish Shelf Seabed feature group are composed of carbonate sands and gravels. Significant changes to the water column characteristics could, in theory, affect long term rates of biogenic sediment supply to these bedforms. It should also be noted that beach replenishment is not included in Table 2 since there is little potential for nearshore (sub-tidal) shelf bedforms to be affected by this activity. (There is higher potential for intertidal features such as bars and spits to be influenced by beach replenishment although these features are not included within this assessment).

Table 2 Existing activity themes and activities giving rise to pressures to which the proposed geodiversity protected features and components are considered sensitive

Activity theme	Activity
Energy production	Energy production and assoc infrastructure - at sea (wind turbines)
	Energy production and assoc infrastructure - at sea (wave turbines)
	Energy production and assoc infrastructure - at sea (tidal turbines)
Extraction of non-living resources	Extraction - capital / maintenance dredging
	Extraction - sand and gravel
	Extraction - oil and gas
Extraction of living resources	Harvesting - seaweed
	Fishing - beam trawling
	Fishing - demersal seine netting
	Fishing - mussels and oysters - dredging
	Fishing - otter trawling
	Fishing - razor and surf clam fisheries - hydraulic dredging
	Fishing - scallop dredging
	Fishing - set (fixed) netting
Food production	Aquaculture - fin fish
	Aquaculture - shell fish
Infrastructure	Infrastructure - cables and pipelines (operation and installation)
	Infrastructure - coastal (ports, marinas, leisure facilities)
	Infrastructure - coastal defence and land claim
	Infrastructure - offshore (oil and gas platforms)
Military activities	Military activities - aerial activity[1]
	Military activities - sea surface activity
	Military activities - water column activity
	Military activities - seabed activity
Shipping	Anchor use & propeller scour
Waste disposal	Sewerage disposal
	Waste disposal - munitions (chemical and conventional)
	Waste disposal - navigational dredging (capital, maintenance) and quarrying (geological material)

[1] included within this category are activities such as bomb detonation

Table 3 Pressures to which proposed geodiversity protected features and components are likely to be considered sensitive

Generic pressures to which geodiversity features might be sensitive	**Pressure definition**	**Associated activities**
Physical change (to another seabed type)	The permanent change of one marine habitat type to another marine habitat type, through the change in substratum. For instance a change from sediment to solid substrate including artificial (e.g. concrete mattresses, rock dumping, and moorings), or from one type of sediment to another. This pressure concerns disposal or the deposit of material, whilst the removal of material is covered under abrasion pressures.	Energy production and assoc infrastructure - at sea (wind turbines)
		Energy production and assoc infrastructure - at sea (wave turbines)
		Energy production and assoc infrastructure - at sea (tidal turbines)
		Aquaculture - fin fish
		Aquaculture - shell fish
		Infrastructure - cables and pipelines (operation and installation)
		Infrastructure - coastal (ports, marinas, leisure facilities)
		Infrastructure - coastal defence and land claim
		Infrastructure - offshore (oil and gas platforms)
		Military activities - seabed activity
		Waste disposal - munitions (chemical and conventional)
		Waste disposal - navigational dredging (capital, maintenance) and quarrying (geological material)
Physical removal (extraction of substratum)	Potential extraction of sediment to 30 cm or more.	Extraction - capital / maintenance dredging
		Extraction - sand and gravel
		Extraction - oil and gas
		Infrastructure - cables and pipelines (operation and installation)
		Infrastructure - coastal (ports, marinas, leisure facilities)
		Military activities - seabed activity
Siltation changes (high)	30 cm (or more) of material added to the seabed in a single event or the deposition of material over the lifetime of the development.	Extraction - capital / maintenance dredging
		Extraction - sand and gravel
		Military activities - aerial activity
		Military activities - sea surface activity
		Military activities - water column activity
		Military activities - seabed activity
		Waste disposal - munitions (chemical and conventional)
		Waste disposal - navigational dredging (capital, maintenance) and quarrying (geological material)
Surface abrasion/penetration	Damage to geological and geomorphological structures at the seabed surface	Harvesting - seaweed
		Fishing - beam trawling
		Fishing - mussels and oysters - dredging
		Fishing - otter trawling
		Fishing - razor and surf clam fisheries - hydraulic dredging

Generic pressures to which geodiversity features might be sensitive	Pressure definition	Associated activities
Surface abrasion/penetration *cont.*	Damage to geological and geomorphological structures at the seabed surface *cont.*	Fishing - scallop dredging
		Infrastructure - cables and pipelines (operation and installation)
		Infrastructure - coastal (ports, marinas, leisure facilities)
		Infrastructure - coastal defence and land claim
		Infrastructure - offshore (oil and gas platforms)
		Military activities - aerial activity
		Military activities - sea surface activity
		Military activities - water column activity
		Military activities - seabed activity
		Shipping
Sub-surface abrasion/penetration	Indirect removal of surface sediment via accelerated flow (e.g. from scour around foundations or from propeller jets) or penetration by structure/ equipment (e.g. fishing gear).	Energy production and assoc infrastructure - at sea (wind turbines)
		Energy production and assoc infrastructure - at sea (wave turbines)
		Energy production and assoc infrastructure - at sea (tidal turbines)
		Extraction - capital / maintenance dredging
		Extraction - sand and gravel
		Extraction - oil and gas
		Fishing - beam trawling
		Fishing - mussels and oysters - dredging
		Fishing - otter trawling
		Fishing - razor and surf clam fisheries - hydraulic dredging
		Fishing - scallop dredging
		Infrastructure - cables and pipelines (operation and installation)
		Infrastructure - coastal (ports, marinas, leisure facilities)
		Infrastructure - coastal defence and land claim
		Infrastructure - offshore (oil and gas platforms)
		Military activities - aerial activity
		Military activities - sea surface activity
		Military activities - water column activity
		Military activities - seabed activity
		Shipping
Temperature changes - national	1.5 - 4 ºC change in sea temperature by 2100 (from UKCP09 predictions).	n/a

Generic pressures to which geodiversity features might be sensitive	Pressure definition	Associated activities
Water clarity changes	A change in one rank on the WFD scale, e.g. from clear to turbid for one year.	Energy production and assoc infrastructure - at sea (wind turbines)
		Energy production and assoc infrastructure - at sea (wave turbines)
		Energy production and assoc infrastructure - at sea (tidal turbines)
		Extraction - capital / maintenance dredging
		Extraction - sand and gravel
		Infrastructure - cables and pipelines (operation and installation)
		Infrastructure - coastal (ports, marinas, leisure facilities)
		Infrastructure - coastal defence and land claim
		Infrastructure - offshore (oil and gas platforms)
		Military activities - aerial activity
		Military activities - sea surface activity
		Military activities - water column activity
		Military activities - seabed activity
Water flow (tidal current) changes - local	A change in peak mean spring tide flow of up to 5% for > 1 year.	Energy production and assoc infrastructure - at sea (wind turbines)
		Energy production and assoc infrastructure - at sea (wave turbines)
		Energy production and assoc infrastructure - at sea (tidal turbines)
		Extraction - capital / maintenance dredging
		Extraction - sand and gravel
		Infrastructure - coastal (ports, marinas, leisure facilities)
		Infrastructure - coastal defence and land claim
		Infrastructure - offshore (oil and gas platforms)
Wave exposure changes - local	A change in significant wave height of up to 5% for > 1 year.	Energy production and assoc infrastructure - at sea (wind turbines)
		Energy production and assoc infrastructure - at sea (wave turbines)
		Energy production and assoc infrastructure - at sea (tidal turbines)
		Extraction - capital / maintenance dredging
		Infrastructure - coastal (ports, marinas, leisure facilities)
		Infrastructure - coastal defence and land claim

3. SENSITIVITY ASSESSMENT METHODOLOGY

3.1 Overview

A feature that is said to be 'sensitive' (quantified with a high, medium or low rating) is one that is readily adversely affected by external pressures arising from human activities, and is expected to recover only over a very long time period, or not at all. Accordingly, any assessment of feature sensitivity needs to take into consideration both the feature sediment type or geology and the ability of the feature to recover from degradation. These two aspects of sensitivity are considered further below under the headings 'feature resistance' (tolerance) and 'feature resilience' (recoverability).

3.2 Feature component resistance (tolerance)

Feature resistance to a given pressure reflects sediment type and other aspects of the geology of the given feature. Features composed of hard or compacted material (e.g. glacial moraines) or cut in bedrock (e.g. glacial troughs) are likely to be far more resistant than features composed of soft, unconsolidated material (e.g. sand waves). In this investigation, feature resistance has been defined on a four point scale, as specified in Table 4.

Table 4 Description of geodiversity feature component resistance

Resistance	Description
None	Complete destruction or removal of the feature.
Low	Widespread disruption to the feature's surface or stratigraphy.
Medium	Partial and localised damage to the feature's surface or stratigraphy.
High	Negligible change to the feature.

Expert judgement was used to assign a resistance rating for each of the feature components described in Table 1. These judgements were informed by available literature (referenced within the geodiversity sensitivities matrix and within the online FEAST programme (Marine Scotland, 2013)) and also the ABPmer (2009) investigation which assessed the sensitivity of geodiversity features mapped on the UK sea bed to a number of activities taking place in the marine environment. In order to inform the UK-scale assessment of geodiversity sensitivity as part of the ABPmer (2009) investigation, an 'expert working group' comprising geologists and marine process specialists was established. This working group provided methodological input at a number of stages during the development and implementation of the assessment, including discussion on the resistance of various mapped seabed features to anthropogenic pressures.

3.3 Feature component resilience (recoverability)

Feature resilience reflects the capacity of a given feature to recover from degradation and to be restored to its original (natural) state. The ability of the identified features to recover is considered with regards to a defined time interval. This is because there are a wide variety of geological and geomorphological processes responsible for the creation and maintenance of the identified features and these processes are operational over differing timescales. For example, a sand wave field and a sediment drift may both have been identified as 'active' features, yet whilst the former may exhibit morphological change over sub-annual time-scales, the latter may take many millennia to exhibit noticeable signs of change. Here, feature resilience has been defined on a four point scale, as specified in Table 5.

Table 5 Description of geodiversity feature component resilience

Resilience	Description
None	No potential for regeneration over decadal to centennial timescales (e.g. relict or extremely inactive feature).
Low	Partial regeneration over decadal to centennial timescales.
Medium	Full regeneration over decadal to centennial timescales.
High	Full regeneration over sub-decadal timescales.

As with the assessments of resistance to anthropogenic pressures, all assessments of resilience were made on the basis of expert judgement. These judgements were informed by available literature as well as the ABPmer (2009) UK-scale assessment of geodiversity sensitivity.

3.4 Overall assessment of feature sensitivity

An overall assessment of feature sensitivity has been made by combining the individual assessments of both resistance and resilience, using a look-up table (Table 6). This table enables an overall rating of either 'high sensitivity', 'medium sensitivity', 'low sensitivity' or 'not sensitive' to be applied to each assessment (Table 6).

Table 6 Look-up table for the geodiversity sensitivity assessment

Resilience	Resistance			
	None	Low	Medium	High
None	High	High	Medium	Low
Low	High	High	Medium	Low
Medium	Medium	Medium	Medium	Low
High	Medium	Low	Low	Not sensitive

It should be noted here that in those instances where the defined pressure will clearly have no impact on a feature (e.g. water temperature changes on glacial moraines) no assessment has been undertaken. These occurrences are recorded as 'not assessed' in the accompanying assessment matrix. Similarly, there are instances where a feature will not be exposed to a pressure (e.g. small changes in wave height will not affect deep ocean seabed features). These occurrences are recorded as 'not exposed'.

4. FEATURE SENSITIVITY CONFIDENCE ASSESSMENT

4.1 Overview

All of the scores associated with both the feature resistance and resilience assessments outlined in Section 3 have an associated confidence rating, reflecting the reliability of each individual score. Definitions for the different confidence ratings and an explanation of how confidence scores were generated for each feature are outlined in the following section.

4.2 Feature component resistance confidence definitions

Confidence in each assessment of feature component resistance has been defined on a three point scale, as defined in Table 7.

Table 7 Confidence definitions for assessments of feature component resistance

Resistance confidence definition	Description
High	High level of confidence in the assigned judgement of feature resistance to specified pressure reflecting a good understanding of the morphological characteristics of the mapped feature and the extent to which the specified pressure may disturb the sea bed.
Medium	Reasonable level of confidence in the assigned judgement of feature resistance to specified pressure reflecting a generally sound understanding of the morphological characteristics of the mapped feature and the extent to which the specified pressure may disturb the sea bed.
Low	Low level of confidence in the assigned judgement of feature resistance to specified pressure reflecting a poor understanding of either the morphological characteristics of the mapped feature and/or an incomplete understanding how the specified pressure may disturb the sea bed.

4.3 Feature component resilience confidence definitions

Confidence in each assessment of feature component resilience has been defined on a three point scale, as defined in Table 8.

Table 8 Confidence definitions for assessments of feature component resilience

Resilience confidence definition	Description
High	High level of confidence in the assigned judgement of how the feature is to likely to recover from disruption. Reflects a good level of knowledge about the feature under consideration in terms of both the processes behind its inception and whether it is currently active or relict.
Medium	Reasonable level of confidence in the assigned judgement of how the feature is to likely to recover from disruption. Reflects some knowledge gaps with regards to either the processes behind its inception and/or whether the feature is currently active or relict.
Low	Low level of confidence in the assigned judgement of how the feature is likely to recover from disruption. Reflects a poor level of knowledge about the feature under consideration either in terms of the processes behind its inception and/or whether it is currently active or relict.

4.4 Overall assessment of confidence in feature sensitivity

An overall assessment of confidence in the individual feature sensitivity assessments has been made by combining the confidence assessments of both resistance and resilience, using a look-up table (Table 9). This table enables an overall rating of either 'high confidence', 'medium confidence' or 'low confidence' to be applied to each assessment result.

In summary, a 'high confidence' score reflects a good level of confidence in the feature sensitivity assessment. This may relate to the fact that direct evidence is readily available to support assessments of resistance and resilience. However, the availability of direct supporting evidence is not necessarily a prerequisite for a high confidence score. This is because in a number of instances, assessments of feature sensitivity are straightforward to undertake, even without recourse to published literature (e.g. assessing the sensitivity of large, hard rock features (such as seamounts) to small changes in flow speed).

Table 9 Confidence score look-up table for the geodiversity sensitivity assessment

Resilience confidence	**Resistance confidence**		
	Low	**Medium**	**High**
Low	Low	Low	Low
Medium	Low	Medium	Medium
High	Low	Medium	High

A 'medium confidence' score generally means that there is some specific evidence or proxy information on the sensitivity of the feature to the relevant pressure. A 'low confidence' score means that there is limited confidence in the feature sensitivity assessment. Such instances typically arise where there is little or no specific proxy information on the sensitivity of the feature to the relevant pressure and that the assessment is based largely on expert judgement.

5. SUMMARY OF RESULTS

A summary of the results of the geodiversity sensitivity assessment is provided within the FEAST online tool (Marine Scotland, 2013). It should be noted, however, that there are no equivalent frameworks for geodiversity features linking pressures to feature sensitivity as there are for biodiversity features. For example, the derivation of Ecological Quality Standards (EQS) based on the toxicity of a substance which define the concentration in the water below which authorities are confident that the substance will not have a polluting effect or cause harm to plants and animals. Accordingly, the assessment undertaken here follows an expert-judgement led approach which primarily draws upon the earlier work of ABPmer (2009). The assessments are also informed by 'secondary data' that, whilst not directly considering impacts of anthropogenic pressures on geological or geomorphological features, provide discussion on the potential disturbance to the sea bed and wider physical processes regime from various activities and pressures. Examples include monitoring results of scour around marine structures located in a range of physical settings (e.g. ABPmer *et al*., 2010) and studies looking at the extent to which propeller jets may mobilise seabed sediments (e.g. Colomer *et al*., 1998; Maynord, 1998).

In the vast majority of instances, the proposed geodiversity protected feature components identified in Table 1 have a low sensitivity to the pressures identified in Table 3. This is because although most of the feature components in Table 3 are relict (thereby having either low or no resilience), they have high resistance to pressures. This is due to the fact that they are typically composed of hard geology which has a low susceptibility to erosion.

It is important to note here that the assessment results are highly conservative and do not imply vulnerability of a specific feature to a given pressure. Care must therefore be exercised when attempting to 'down-scale' these high-level, regional-scale results to inform assessments at the local scale. In such instances, it is important that the actual magnitude of any identified pressures is taken into consideration. Indeed, in the vast majority of instances, most pressures associated with marine anthropogenic activities will not be sufficient to impact geological and geomorphological seabed features.

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7. ABBREVIATIONS

ABPmer	ABP Marine Environmental Research Ltd
BGS	British Geological Survey
COWRIE	Collaborative Offshore Wind Research Into the Environment
Defra	Department for Environment, Food and Rural Affairs
EQS	Ecological Quality Standard
MarLIN	Marine Life Information Network
MCZ	Marine Conservation Zone
NCC	Nature Conservancy Council
OSPAR	Oslo and Paris Convention for the protection of the marine environment of the North-East Atlantic
UKMMAS	UK Marine Monitoring and Assessment Strategy

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