



Scottish MPA Project
Assessment against the MPA Selection Guidelines
THE BARRA FAN AND HEBRIDES TERRACE SEAMOUNT NATURE CONSERVATION MPA
<i>JULY 2014</i>

The following documents provide further information about The Barra Fan and Hebrides Terrace Seamount Marine Protected Area (MPA):

- Site Summary Document
- Data Confidence Assessment
- Management Options Paper

The documents are all available at www.jncc.defra.gov.uk/page-6489

Document Distribution List and Version Control				
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Electronic	3.0	15/07/2013	Review of document to take into account MPA Sub-Group comments and release of document for public consultation.	Uploaded to JNCC website
Electronic	4.0	18/07/2014	Document update to align with designation status and text revised in response to consultation and independent review report	Delivery to Marine Scotland to support MPA designation and upload to JNCC website

Background

This document provides details of JNCC's assessment of The Barra Fan and Hebrides Terrace Seamount Nature Conservation MPA (herein referred to as 'MPA') against the [Scottish MPA Selection Guidelines](#). It presents an assessment for each of the protected features. We have used the terminology set out in the Selection Guidelines to describe the five main stages in the assessment process from the identification of MPA search locations through to an MPA.

The main terms used are described below.

MPA search feature - specified marine habitats, species and large-scale features which underpin the selection of Nature Conservation MPAs.

Geodiversity features - specified geodiversity interests of the Scottish seabed categorised under themed 'blocks' that are analogous to the MPA search features for biodiversity.

Protected feature - any feature (habitats, species, large-scale features and/or geodiversity features) which are specified in the MPA Designation Order.

MPA search location - this describes a location identified at stage 1 [of the Selection Guidelines] until it passes the assessment against stage 4.

Potential area for an MPA - if an MPA search location passes assessment against stage 4 it goes on to be considered at stage 5 as a potential area for an MPA.

Nature Conservation MPA – a location that has been approved by Ministers for designation.

Details of evidence supporting the designation of The Barra Fan and Hebrides Terrace Seamount MPA are provided in the Data Confidence Assessment document.

THE BARRA FAN AND HEBRIDES TERRACE SEAMOUNT MPA - APPLICATION OF THE MPA SELECTION GUIDELINES

Stage 1 - Identifying search locations that would address any significant gaps in the conservation of MPA search features

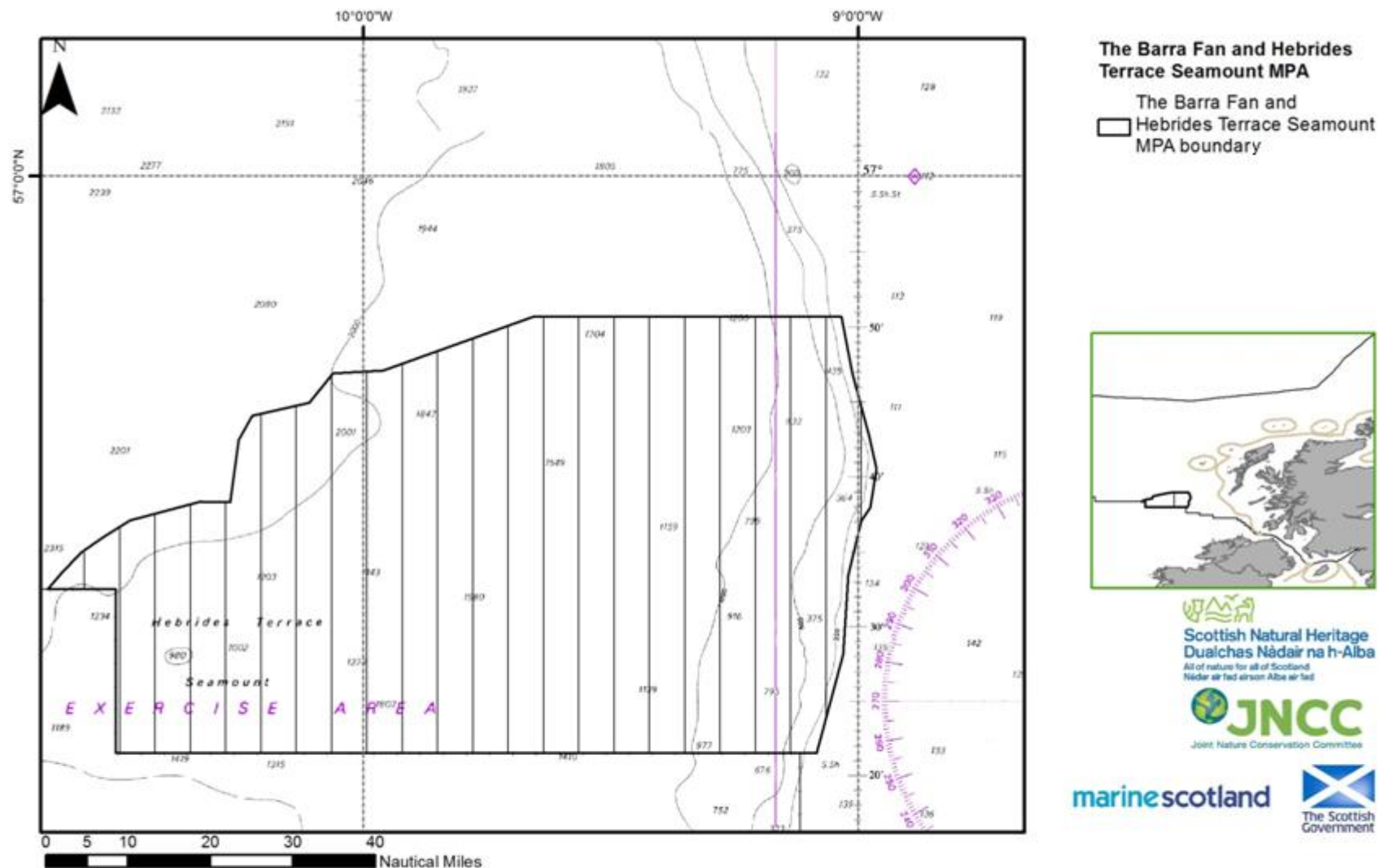
Summary of assessment	<p>The MPA includes eleven protected features. For biodiversity features these comprise a deep-water variant of the seapens and burrowing megafauna component of the burrowed mud habitat, Atlantic influenced offshore deep-sea muds on the continental slope, Atlantic influenced offshore subtidal sands and gravels on the continental slope, orange roughy, seamount communities, seamounts, and an area of the Hebridean continental slope. It also includes geodiversity features representative of The Barra Fan and Peach Slide Complex Key Geodiversity Areas (Brooks <i>et al.</i>, 2013). The seapens and burrowing megafauna component of burrowed mud, orange roughy and seamount communities are considered by the OSPAR Commission to be Threatened and/or Declining features. The geodiversity features representative of The Barra Fan Key Geodiversity Area are regarded as scientifically important in furthering understanding of regional-scale palaeoceanographic changes, as well as fluctuations in the extent of the last British-Irish Ice Sheet, whereas the Peach Slide is one of five examples that are broadly representative of the range of slide features identified across Scotland's seas (Brooks <i>et al.</i>, 2013).</p> <p>The Hebridean slope more broadly is thought to have functional significance to the health and biodiversity of Scotland's seas in the way that it influences water column mixing that leads to a rise biological productivity (Shapiro & Hill, 1997), but there is no empirical evidence available to support this function within the MPA. The Hebrides Terrace Seamount is also thought to have functional significance to the health and biodiversity of Scotland's seas, as an area where hydrographic processes are influenced by the interaction between ocean currents and the topography of the seamount (Inall & Shirwin, 2006), enhancing productivity resulting from enhanced vertical mixing. The seamount is also important as a spawning area for the long-lived deep-water fish orange roughy (ICES, 2010).</p>
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Detailed assessment			
Protected features	Guideline 1a <i>Presence of key features [MPA search features and geodiversity equivalents]</i>	Guideline 1b <i>Presence of features under threat and/or subject to rapid decline</i>	Guideline 1c <i>Functional significance for the overall health and diversity of Scottish seas</i>
<i>Biodiversity</i>			
Burrowed mud	✓	✓ OSPAR T&D ¹	
Seamount communities	✓		
Orange roughy	✓		
Offshore deep-sea muds	✓		
Offshore subtidal sands and gravels	✓		
Continental slope	✓		✓ enhanced productivity
Hebrides Terrace Seamount	✓		✓ enhanced productivity,

¹ OSPAR list of Threatened and/or Declining species and habitats (see OSPAR, 2008 a & b)

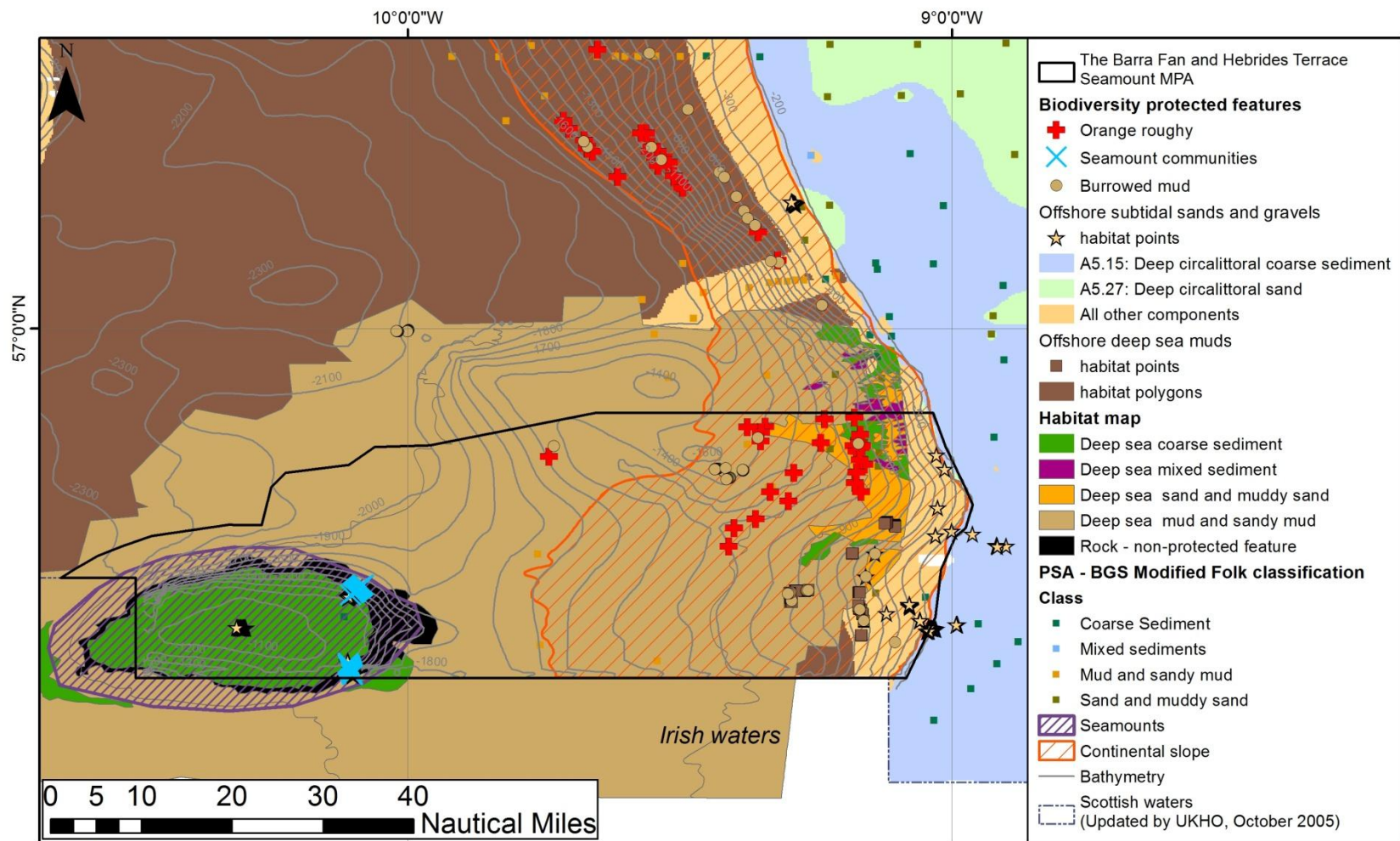
			fish spawning area
<i>Geodiversity</i>			
Iceberg ploughmark fields (Quaternary of Scotland)	✓		
Prograding wedge (Quaternary of Scotland)	✓		
Continental slope turbidite canyons and slide deposits (Submarine Mass Movement)	✓		
Continental slope and Hebrides Terrace Seamount (Cenozoic Structures of the Atlantic Margin)	✓		✓ enhanced productivity, fish spawning and nursery areas

Map showing the location of The Barra Fan and Hebrides Terrace Seamount MPA

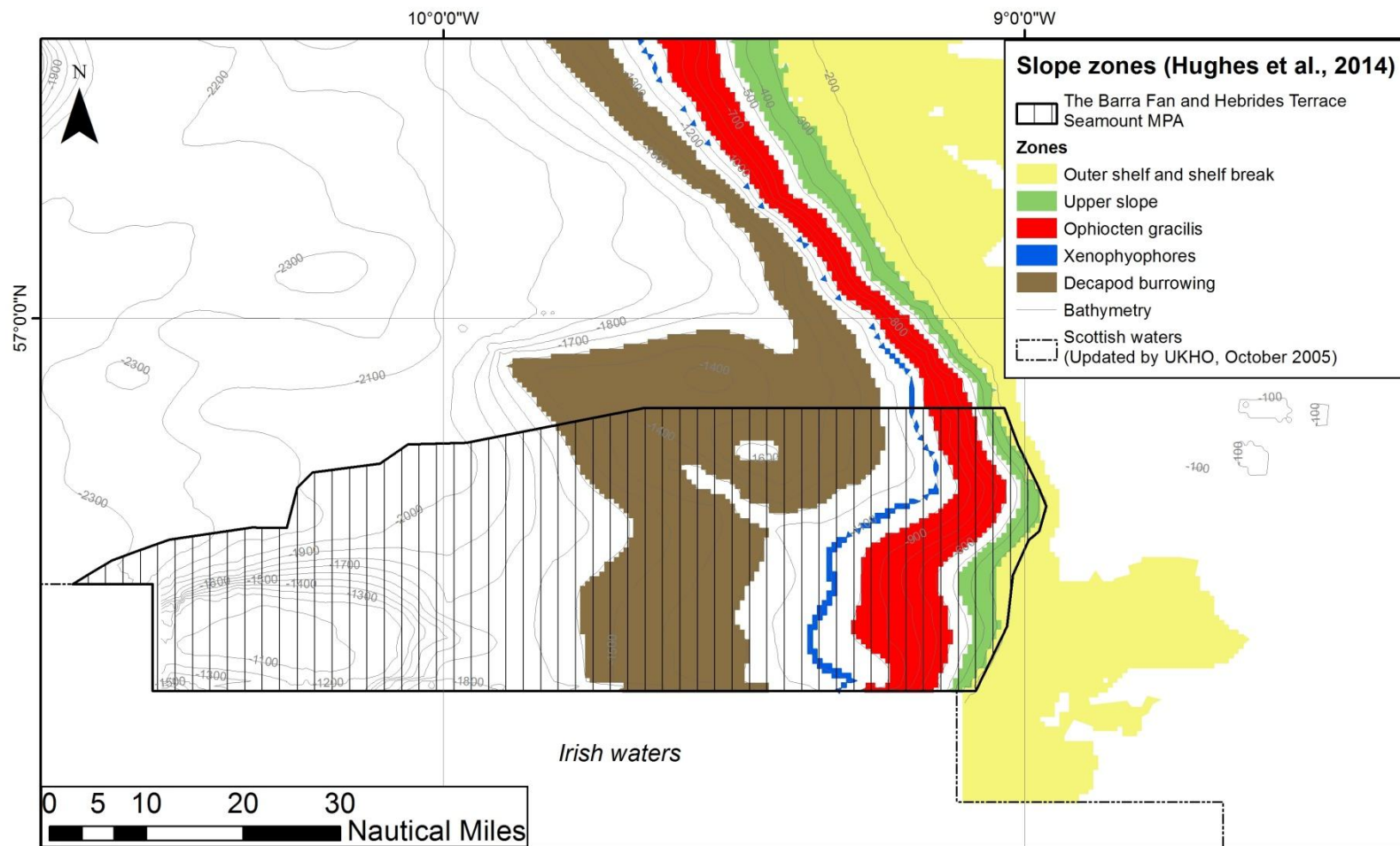


Map displayed in geographic coordinates WGS84. The exact limits of the UK Continental Shelf are set out in the Continental Shelf (Designation of Areas) Order 2013, Statutory Instrument 2013/3162 (© Crown Copyright). Landmass Ordnance Survey © Crown Copyright and database right 2011. All rights reserved. Scotland (Adjacent waters) Updated by the Law of the Sea Division, United Kingdom Hydrographic Office October 2005. Bathymetry © GEBCO, 2011. MPA © JNCC and SNH 2014. All rights reserved. Admiralty chart © Crown Copyright 2013. All rights reserved. License No. EK001-20120405. Map not to be used for navigation.

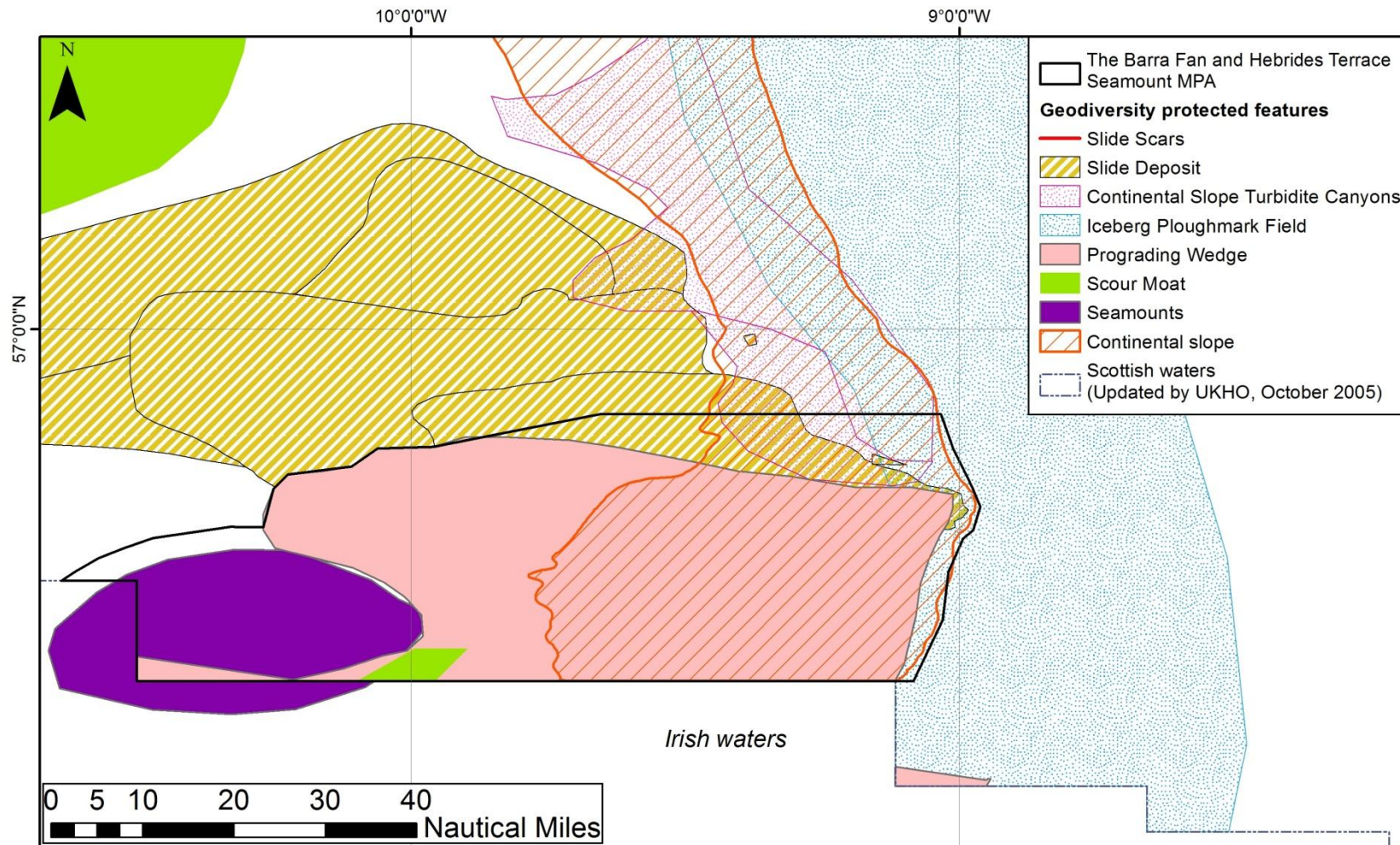
Map of The Barra Fan and Hebrides Terrace Seamount MPA showing the distribution of biodiversity protected features



Map of The Barra Fan and Hebrides Terrace Seamount MPA showing the distribution of biological community depth-zones as defined by Hughes *et al.* (2014)



Map of The Barra Fan and Hebrides Terrace Seamount MPA showing the distribution of geodiversity protected features



Stage 2 - Prioritisation of search locations according to the qualities of the MPA search features they contain

Summary of assessment

There are combinations of protected features within the MPA with evidence to indicate functional linkages between them. The Hebrides Terrace Seamount supports a biologically diverse assemblage of seamount communities (Cross *et al.*, 2014), which includes cold-water corals and sponges. The seamount is thought to support a spawning aggregation of orange roughy (ICES. 2010) and is therefore considered to be important to the life history of the species. There are also functional linkages between the area of the Hebridean slope included within the MPA and the habitats and species present. For instance there are depth related trends in habitat type and megafaunal distribution (Hughes *et al.*, 2014), with areas of reduced hydrographic influence with depth being characterised by finer sediments and vice versa. In addition to these functional linkages, there is evidence to support the role of the Hebridean slope and Hebrides Terrace Seamount more generally in the health and biodiversity of Scotland's seas.

There is limited information available to undertake a detailed assessment of the stage 2b guideline for burrowed mud, offshore deep-sea muds and offshore subtidal sands and gravels because of a lack of information on characterising species of these habitats. Nevertheless, JNCC consider all three seabed habitats are likely to be coherent examples within the MPA since the biological zones present extend more widely along the Hebridean slope (Hughes *et al.*, 2014). This assessment is supported by the habitat map from Sotheran *et al* (2014) for this MPA. There are limited data against which JNCC could consider natural levels of biological diversity of seamount communities and so we are uncertain as to whether the stage 2b guideline is met. Seamount communities recorded on The Hebrides Terrace Seamount are considered typical given the presence of all four types of the feature within the MPA. The extent of The Hebrides Terrace Seamount within Scottish waters is included within the MPA boundary and so the MPA is considered to represent a coherent example of the feature.

There is limited or no information on the condition of the protected features within the MPA, but information on the sensitivity of the protected features to pressures associated with activities to which they are exposed suggest all the biodiversity protected features, as well as the geodiversity protected feature iceberg ploughmark fields, may have been modified by human activity. For orange roughy, although there is now a zero Total Allowable Catch on the species, evidence suggests orange roughy numbers have been affected by human activity. Within the MPA Region², JNCC consider that there is a high risk to seamount communities and orange roughy and a medium risk to burrowed-mud habitat of significant damage from human activity. For offshore subtidal sand and gravel habitats in The Far West and West (Offshore) MPA Regions, and offshore deep sea mud habitats in The Far West MPA Region, the risk of damage by human activity varies. This range in risk is a reflection of the range in sensitivity of different sub-types of these habitats to pressures associated with activities to which they are exposed. Iceberg ploughmark fields are considered to be at medium risk of damage and continental slope turbidite canyons and slide deposits and prograding wedges are at low risk of damage across Scotland's seas.

Three of the five parts of the stage five guidelines (2a, 2c and 2e) have been met for all features, but there is limited evidence with which to make a conclusive assessment against the stage 2b guideline for all protected features. The stage 2d guidelines have not been met for all biodiversity features and the iceberg ploughmark fields geodiversity feature.

² Far West MPA Region as described in the [Scottish MPA Selection Guidelines](#)

Detailed assessment	
Guideline 2a	The search location contains combinations of features, rather than single isolated features, especially if those features are functionally linked
<p>There are combinations of protected features present within the MPA. The seamounts in Scotland's seas support a biologically diverse assemblage of cold-water corals and sponges, which suggests that local biological productivity is coupled with important retention mechanisms to support these communities (e.g. Frederiksen <i>et al.</i>, 1992). Evidence from a survey of the Hebrides Terrace Seamount conducted in 2012 supports this statement, with direct evidence illustrating the presence of solitary corals such as antipatharians, reefs of hard cold-water coral, deep-water sponges including encrusting and lamellate forms, and a rich associated epifauna comprising animals such as crinoids, ophiuroids, <i>Cidaris cidaris</i>, cerianthid anemones, and fields of Xenophyophores (Cross <i>et al.</i>, 2014).</p> <p>There are depth-related trends in habitat type and megafaunal distribution (Hughes <i>et al.</i>, 2014), with areas of reduced hydrographic influence with depth being characterised by finer sediments. Zones of biological variance coincide with the bathymetric extent of the slope current flowing northwards along the Scottish continental margin, known as the 'mud-line'. Transport of organic particles in the northwards-flowing slope current may play an important role in sustaining the high benthic biomass seen in this mud-line (Hughes <i>et al.</i>, 2014).</p> <p>In addition to the functional linkages between the protected features within the MPA, there is evidence to support the role of the Hebridean slope more generally in the health and biodiversity of Scotland's seas. Buoyancy-driven cold-water cascades associated with the continental shelf break (Shapiro & Hill, 1997) may serve to increase levels of primary biological productivity, although there is no direct evidence available from within the MPA to support this hypothesis. The Hebrides Terrace Seamount influences local currents affecting the transport of salt and heat across the wider North Atlantic (Inall and Sherwin, 2006). The topography of the seamount also causes accelerated current flow leading to downwelling and enhanced vertical mixing, which in turn may ensure a good food supply to seamount communities. The biodiversity on seamounts attracts rich fish communities that may use the seamount for foraging, breeding and spawning. The Hebrides Terrace Seamount for example is considered to support a spawning aggregation of orange roughy and is therefore regarded as important to the life history of the species (ICES, 2010). Cetaceans are known to frequent seamounts and the migration route through the Rockall Trough towards the Faroe-Shetland Channel is considered important (Evans 1997; Swift <i>et al.</i> 2002; Macleod <i>et al.</i> 2003).</p>	

Guideline 2b	The search location contains example(s) of features with a high natural biological diversity (for habitats only)
Burrowed mud	<p>Marine Scotland Science by-catch records from 2008 and 2009 identify species that are indicative of deep-water burrowed mud in the MPA – particularly the deep-water seapens <i>Umbellula sp.</i> The majority of these records intersect with the Decapod burrowing zone and the <i>Ophiecten gracialis</i> zone by Hughes <i>et al.</i> (2014), which are largely characterised by fine sand, muddy sand or sandy mud substrates. These records are further supported by the predictive seabed habitat modelling data from EUSeaMap³. However, a small number of MSS by-catch records considered characteristic of the burrowed mud habitat feature intersect the biological zone identified by Hughes <i>et al.</i> (2014) as the upper slope, which is more frequently characterised by coarser sediments. EUSeaMap also suggests these burrowed mud records fall on an area of the seabed predicted to be offshore subtidal sands and gravels. This indicates some uncertainty in the known extent of burrowed mud within the MPA. Overall, we consider that there is evidence for the presence of deep-water burrowed mud within the MPA, but a lack of data on associated species diversity of the habitat means we are not able to undertake a detailed assessment of the stage 2b guideline.</p>
Offshore deep-sea muds	<p>On the slope in OSPAR Region V, EUSeaMap predicts one type of offshore deep-sea mud to occur (Atlantic slope mud and sandy mud) and the MPA encompasses an example of this habitat. There are 50 archived still images from 1996 and 51 from 1995 from the SEA7 region of Scotland's seas that are assigned to offshore deep-sea mud habitats within the MPA. Of these, 26 are classed as uncertain. Of those which are assessed as certain, epifaunal species such as urchins (<i>Cidaris cidaris</i>), cerianthid anemones, brittlestars (<i>Ophiecten gracillius</i>) and Xenopyophores are present (Hughes <i>et al.</i>, 2014). All records occur on what EUSeaMap predicts to be muddy sediments.</p> <p>Further evidence of the range of offshore deep-sea mud habitat types in this site is provided by the habitat map from Sotheran <i>et al.</i>, 2014. The predominant habitat on the slope is lower bathyal mud and sandy mud, stretching across the site, with mid bathyal and upper bathyal muds occupying the east to south-east part of the slope in the MPA.</p> <p>Overall, JNCC consider that there may be high levels of natural biological diversity within offshore deep-sea muds in the MPA but without further information on the infaunal species composition, our judgement is uncertain.</p>
Offshore subtidal sands and gravels	<p>Within a given depth range the underlying substrate characteristics are likely to be a strong determinant of the types of species present (Eleftheriou & Basford, 1989). Therefore, biodiversity might be expected to be highest within a given area that contains a range of different physical types of sand and gravel habitats. The MPA boundary was developed to include the range of offshore subtidal sand and gravel habitats predicted to occur on the continental slope by EUSeaMap.</p> <p>On the slope in OSPAR Region V, EUSeaMap predicts three different types of offshore subtidal sand and gravel habitats to occur: Atlantic Slope coarse sediment, Atlantic Slope mixed sediment and Atlantic Slope sand and muddy sand. The MPA represents examples of two of these habitat types representing coarse to muddy sediments. There are 47 archived still images from the SEA7 region of Scotland's seas from 1995, and 16 from 1996, which are assigned to offshore subtidal sand and gravel habitats within the MPA. Of these, seven are classified as an uncertain assignment due to the quality of resolution of the images analysed. Of those which are assessed as certain, 17 occur on the Hebridean slope and include epifaunal species such as seastars, squat lobsters (<i>Mudina sp.</i>) and brittlestars (<i>Ophiura sp.</i>) (Hughes <i>et al.</i>, 2014). Further evidence for the presence of offshore subtidal sand and</p>

³ This project modelled a combination of physical data describing the marine environment with information from biological sampling to refine ecologically-relevant thresholds to produce a broad-scale predictive map of seabed habitats across Europe. Further information is available online at <http://jncc.defra.gov.uk/EUSeaMap>

Guideline 2b	The search location contains example(s) of features with a high natural biological diversity (for habitats only)
	<p>gravel habitats has been derived by processing of <i>Nephrops</i> video trawl data held by Marine Scotland Science. The three sampling records within the MPA support the presence of predominantly fine sand, with some surface gravel and epifauna consisting mainly of sea urchins (<i>Spatangus raschi</i>; <i>Echinus acutus</i>) and hermit crabs (Allen <i>et al.</i>, 2014a & b).</p> <p>Further evidence of the range of offshore subtidal sand and gravel habitat types in this site is provided by the habitat map from Sotheran <i>et al.</i>, 2014. The habitats on the slope are mapped as upper bathyal coarse, mid bathyal sand & muddy sand, mid bathyal mixed, mid bathyal coarse, lower bathyal sand & muddy sand and lower bathyal mixed sediment. Their extent is limited to the north-east of the survey area, with mid bathyal sand & muddy sand modelled as extending across a large part of the MPA.</p> <p>Overall, we consider that there may be high levels of natural biological diversity within offshore subtidal sands and gravels in the MPA, but without further information on the infaunal species composition our judgement is uncertain.</p>
Seamount communities	<p>Communities living on seamounts are thought to predominantly comprise four different types – the reef framework-forming colonial scleractinian corals; soft coral species such as <i>Stichopathes</i> spp.; deep water sponges; and seamount-associated sediments on the top and base of seamounts that are frequently rich in protists known as Xenophyophores, cerianthid sea anemones, crinoids, brittlestars, sea urchins, and ascidians.</p> <p>A survey of The Hebrides Terrace Seamount in 2012 showed all four types of seamount community were present. The results showed examples of live and dead frameworks of hard coral reef associated with <i>Cidaris cidaris</i> (sea urchins), deep-sea sponges including encrusting and lamellate forms, soft corals including <i>Stichopathes</i> sp., <i>Paramuricea</i> sp. and antipatharians, and fields of Xenophyophores with echinoids, cerianthid anemones, crinoids and ophiuroids (Cross <i>et al.</i>, 2014). Those biotopes identified (either previously published proposals, or newly proposed) are as follows:</p> <ul style="list-style-type: none"> ○ Barnacles, antipatharians, and encrusting sponges on sediment-draped exposed bedrock and mixed substrate, ○ Antipatharians, crinoids and seapens on coarse sand mixed with pebbles and cobbles, ○ Lamellate sponges and caryophyllids on sand mixed with gravel/pebbles and occasional boulders, ○ <i>Stichopathes cf. gravieri</i>, encrusting sponges, anemones, ascidians and cup corals on bedrock with sand veneer, ○ <i>Lophelia pertusa</i> reef framework with crinoids, encrusting sponges, antipatharians on coral rubble framework and bedrock with patches of sand <p>Overall, there are limited data from seamount communities within the wider region against which we could consider the natural levels of biological diversity of seamount communities within the MPA, and so we are uncertain as to whether the stage 2b guideline is met.</p>

Guideline 2c The search location contains coherent examples of features, rather than smaller, potentially more fragmented ones	
Burrowed mud	<p>The EUSeaMap habitat modelling project predicts offshore deep-sea muds and offshore subtidal sands and gravels to be present on the continental slope and into the bathyal region of the Rockall Trough within the MPA. This habitat coverage on the slope and into the abyssal sea is further supported by the habitat map from Sotheran <i>et al.</i>, 2014.</p> <p>Hughes <i>et al.</i> (2014) characterised the biological diversity on the Hebridean slope based on archive stills data from 1988-1998. The findings indicate five distinct biological zones with associated communities that change with depth are present along the Hebridean slope:</p> <ul style="list-style-type: none"> • Outer shelf and shelf break zone (135-227m) – characterised by coarse sediments ranging from strongly rippled sand and gravel plains to dense fields of cobbles and small boulders. Visible fauna is sparse in this zone and predominantly comprises echinoderms such as the pencil urchin <i>Cidaris cidaris</i> and sea stars. • Upper slope zone (279-470m) – generally characterised by coarser sediments with sand and gravel patches and predominantly includes echinoderms as visible fauna. • <i>Ophiecten gracialis</i> zone (600-1020m) – a biological zone dominated by large numbers of the small brittlestar <i>Ophiecten gracialis</i> on fine sandy, muddy sand or sandy mud, with some areas of gravel or cobbles. • Xenophyophore zone (1088-1180m) – a biological zone characterised by the Xenophyophore <i>Syringammina fragilissima</i> in rippled muddy sand or sandy mud. • Decapod burrowing zone (1293-1595m) – a biological zone characterised by the burrows of large decapods such as <i>Munida tenuimanica</i> in fine muds. <p>The MPA includes examples of four of these biological zones - the Outer shelf and shelf break zone predominantly occur on the continental shelf that is not part of the site. As such, we consider that the three seabed habitats on the continental slope included as protected features of the MPA are coherent examples of these habitats, since they form part of a the greater extent of these biological communities that extend both northward and southward of the MPA boundary along the continental slope.</p>
Offshore deep-sea muds	
Offshore subtidal sands and gravels	
Seamount communities	<p>The Hebrides Terrace Seamount hosts all four types of the seamount communities MPA search feature (reef-forming cold-water corals, soft corals, deep-sea sponges, and seamount-associated sediments), together with other features typically found in association with these benthic communities on seamounts such as orange roughy. It is likely that the distribution of the communities living on seamounts will be patchy depending on the local distribution of the key environmental factors that determine community structure. Survey data from 2012 from the Hebrides Terrace Seamount, although limited in coverage, confirms a patchy distribution of seamount communities in the areas sampled. However, the MPA boundary incorporates the full extent of The Hebrides Terrace Seamount that falls within Scottish waters, and includes all verified records of seamount communities. Consequently, JNCC consider the MPA is represents a coherent example of this feature.</p>
Orange roughy	<p>Multiple records of orange roughy were recorded from trawl surveys between 2000 and 2012. The Hebrides Terrace Seamount is thought to support a spawning aggregation of orange roughy and is therefore considered to be of importance to the life history of the species (ICES, 2010).</p>
Continental slope	<p>In general, the Hebridean slope is regarded as a productive environment with nutrient-rich, cooler waters being drawn up the slope as a consequence of topographic relief. These buoyancy-driven cold-water cascades (Shapiro & Hill, 1997) may serve to increase</p>

Guideline 2c	The search location contains coherent examples of features, rather than smaller, potentially more fragmented ones
	<p>levels of primary biological productivity, although there is no direct evidence available to support this within the MPA. The Hebridean slope may provide enhanced feeding conditions for a number of species occurring in the area including cetaceans and deep-water sharks, although there is no direct evidence available to support this assertion within the MPA.</p>
Seamounts	<p>The Hebrides Terrace Seamount is thought to be of functional significance to the health and biodiversity of Scotland's seas. The topography of the seamount impinges on local currents affecting the transport of salt and heat across the wider North Atlantic (Inall and Sherwin, 2006) and causing accelerated current flow leading to downwelling and enhanced vertical mixing, which ensures a good food supply to benthic invertebrates such as cold-water corals <i>Lophelia pertusa</i> (Frederiksen <i>et al.</i>, 1992; Davies <i>et al.</i>, 2009). One result of these interactions is that there is a predominantly south-westerly surface flow above 500 m near The Hebrides Terrace Seamount (Ellet and Martin, 1973), which reduces the incursion of salty warm Eastern North Atlantic Water onto the Scottish shelf. The accelerated current flow, downwelling, food supply mechanisms and enhanced vertical mixing associated with seamount hydrography may ensure a good quality food supply to cold-water corals and deep-sea sponges – all of present on The Hebrides Terrace Seamount (Cross <i>et al.</i>, 2014). This suggests that local productivity is coupled with important retention mechanisms to support these communities. The three-dimensional structure of these communities serves to increase species richness on seamounts, providing support for crustaceans, cephalopods, echinoderms and anemones as observed on The Hebrides Terrace Seamount (Cross <i>et al.</i>, 2014)</p> <p>The biodiversity on seamounts attracts rich fish communities that may use the seamount for foraging, breeding and spawning. Diverse fish assemblages found in association with seamounts make them important foraging areas for marine mammal species. The Hebrides Terrace Seamount is considered to support a spawning aggregation of orange roughy and is therefore regarded as important to the life history of the species (ICES, 2010). This species is known to occur in areas of increased vertical water mixing, and the populations on Hebrides Terrace seem to constitute their own stock, suggesting the importance of possible hydrographical retention mechanisms, such as concentrated high-quality food sources (ICES 2007).</p> <p>The positive relationship between the steep slopes of the seamounts and enhanced vertical mixing supports higher fish and cephalopod prey densities. This in turn supports cetacean populations. Scottish seamounts are used as foraging and aggregating grounds for many marine mammals (Weir <i>et al.</i>, 2001; Boisseau <i>et al.</i>, 2011). Many marine mammals are long-ranging species, travelling hundreds to thousands of kilometres along traditional migration routes. Along the way, cetaceans are known to frequent seamounts as part of their life histories. For the cetaceans found in the vicinity of Scottish seamounts, the migration route through the Rockall Trough sweeping past the Hebrides Terrace Seamount and through the Faroe-Shetland Channel is considered important (Evans, 1997; Swift <i>et al.</i>, 2002; Macleod <i>et al.</i>, 2003).</p>

Guideline 2d	The search location contains features considered least damaged / more natural, rather than those heavily modified by human activity ⁴
Burrowed mud	There is limited specific information on the ecological condition of the burrowed mud within the MPA, although Hughes <i>et al.</i> (2014) report evidence of trawl damage across burrowed-mud habitat in two images. Consequently, information on the sensitivity of burrowed mud to pressures associated with activities to which they are exposed has been used as a proxy for determining the possible condition of burrowed mud within the MPA (Marine Scotland, 2013). Rasterised Vessel Monitoring System (VMS) data from fishing vessels from 2006-2009, which have a coarse resolution, and VMS point data from 2009-2011, indicate that the majority of records within the MPA are exposed to activities (otter trawling and line fishing) linked to pressures to which the feature has a medium sensitivity. We conclude that the burrowed mud habitat may have been modified by human activity and this guideline is not considered to be met.
Offshore deep-sea muds	There is no specific information on the condition of offshore deep-sea mud habitats within the MPA. Consequently, information on the sensitivity of offshore deep-sea mud habitats to pressures associated with activities to which they are exposed has been used as a proxy for determining the possible condition of offshore deep-sea mud habitats within the MPA (Marine Scotland, 2013). Rasterised Vessel Monitoring System (VMS) data from fishing vessels from 2006-2009, which have a coarse resolution, and VMS point data from 2009-2011, indicate approximately half of the predicted extent and all ground-truthed records of offshore deep-sea mud habitats within the MPA are exposed to activities (otter trawling and line fishing) linked to pressures to which the feature has a sensitivity that may range from not sensitive to highly sensitive. This range in sensitivity is due to biological variation between low and higher-energy sub-types of offshore deep-sea muds that may be present within the MPA. The EUSeaMap model indicates a moderate to low level of energy at the seabed in the MPA at the depths where offshore deep-sea mud habitats are likely to occur. This evidence suggests a likely sensitivity at the upper range for the feature but given the range in sensitivity, and the uncertainty regarding the true extent of the feature, the ecological significance of such modification is uncertain. We conclude that the offshore deep-sea mud habitats may have been modified by human activity and this guideline is not considered to be met.
Offshore subtidal sands and gravels	There is limited specific information on the condition of offshore subtidal sands and gravel habitats within the MPA, although Hughes <i>et al.</i> (2014) report evidence of trawl damage across offshore subtidal sand and gravel habitats in five images analysed. Consequently, information on the sensitivity of offshore subtidal sand and gravel habitats to pressures associated with activities to which they are exposed has been used as a proxy for determining the possible condition of offshore subtidal sand and gravel habitats within the MPA (Marine Scotland, 2013). Rasterised Vessel Monitoring System (VMS) data from fishing vessels from 2006-2009, which have a coarse resolution, and VMS point data from 2009-2011, indicate that approximately half of the predicted extent and all ground-truthed records of offshore subtidal sand and gravel habitats within the MPA are exposed to activities (otter trawling and line fishing) linked to pressures to which the feature has a sensitivity that may range from not sensitive to highly sensitive. This range in sensitivity is due to biological variation between low and high-energy sub-types of offshore subtidal sand and gravel communities. The EUSeaMap model indicates a moderate to high level of energy at the seabed in the MPA at the depths where offshore subtidal sand and gravel habitats are likely to occur. This evidence suggests a likely sensitivity at the lower range for the

⁴ The Least damaged/more natural stage 2d assessment considers protected feature exposure to activities associated with pressures to which the features are sensitive. This is distinct from the work outlined in Chaniotis *et al.* (2011), which mapped available activities data at the scale of Scotland's seas to identify broad areas of low/no activity from which to identify MPA search locations in the initial phase of the MPA selection process. Unlike the stage 2d assessment Chaniotis *et al.* (2011) did not consider the location of features or their sensitivity to pressures.

Guideline 2d	The search location contains features considered least damaged / more natural, rather than those heavily modified by human activity ⁴
	feature but given the range in sensitivity, and the uncertainty regarding the true extent of the feature, the ecological significance of such modification is uncertain. We conclude that the offshore subtidal sand and gravel habitats may have been modified by human activity and this guideline is not considered to be met.
Orange roughy	Spawning aggregations of orange roughy used to be targeted by fishing activities on The Hebrides Terrace Seamount, but catches have now significantly declined and the French fishery has been abandoned (ICES 2007; 2010). Although there is now a zero Total Allowable Catch on the species, evidence suggests orange roughy populations have been modified by human activity.
Seamount communities	There is no direct evidence on the condition of seamount communities within the MPA. Consequently, the possible condition of the protected feature has been inferred from information on exposure to activities associated with pressures to which the feature is considered to be sensitive (Marine Scotland, 2013). Rasterised Vessel Monitoring System (VMS) data from fishing vessels for 2006-2009, which have a coarse resolution, and VMS point data from 2009-2011, indicate that all seamount community records within the MPA are exposed to activities (otter trawling) linked to pressures to which the feature has a high sensitivity. We conclude that the seamount communities may have been modified by human activity and this guideline is not considered to be met
Continental slope turbidite canyons, iceberg ploughmark fields, prograding wedge, slide deposits.	<p>There is no specific information on the condition of the geodiversity protected features representative of The Barra Fan and Peaches Slide Complex Key Geodiversity Areas within the MPA. Consequently, the possible condition of the protected features has been inferred from information on exposure to activities associated with pressures to which it is considered to be sensitive (Brooks, 2013). Rasterised Vessel Monitoring System (VMS) data from fishing vessels from 2006-2009, which has a coarse resolution, and VMS point data from 2009-2011, indicates that half of the extent of the prograding wedge feature and three-quarters of the extent of the contourite slope turbidite canyons are exposed to activities (otter trawling) to which the protected features have a low sensitivity, and that three-quarters of the extent of iceberg ploughmark fields and half of the extent of the slide deposit feature are exposed to activities (otter trawling) to which the protected features have a medium sensitivity.</p> <p>For the slide deposit, prograding wedge and contourite slope turbidite canyons, we consider that the degree of exposure to activities to which they are sensitive or the level of sensitivity of the features to pressures associated with activities is not significant to suggest that these features may have been significantly modified by human activity. Based on this, we consider that only the iceberg ploughmark fields may have been significantly modified by human activity. The stage 2d guideline has been met for all geodiversity features with the exception of the iceberg ploughmark fields.</p>

Guideline 2e The search location contains features considered to be at risk⁵ of significant damage by human activity	
Burrowed mud	The protected feature is considered to be at medium risk in the MPA Region (Chaniotis <i>et al.</i> , 2014). Risk to the feature is primarily associated with the use of bottom-contact mobile fishing gears.
Offshore deep-sea muds	The protected feature is considered to be subject to levels of risk that range from low to high in the MPA Region (Chaniotis <i>et al.</i> , 2014). The range in risk is due to the variation in sensitivity of different sub-types of offshore deep-sea mud habitats to activities to which they are exposed. Habitats in relatively higher energy environments are generally less sensitive than habitats in lower energy environments to pressures related to physical disturbance for example. This risk to the feature within The MPA Region is primarily associated with the use of bottom-contact mobile fishing gears.
Offshore subtidal sands and gravels	The protected feature is considered to be subject to levels of risk that range from low to high in the MPA Region (Chaniotis <i>et al.</i> , 2014). The range in risk is due to the variation in sensitivity of different sub-types of offshore subtidal sand and gravel habitats to activities to which they are exposed. Habitats in higher energy, naturally disturbed, environments are generally less sensitive than habitats in lower energy environments to pressures related to physical disturbance for example. This risk to the feature within the MPA Region is primarily associated with the use of bottom-contact mobile fishing gears.
Orange roughy	Although there is now a zero Total Allowable Catch on orange roughy across the north-east Atlantic, orange roughy may be taken as by-catch as part of a mixed fishery and so are considered to be at high risk in the MPA Region (Chaniotis <i>et al.</i> , 2014).
Seamount communities	The protected feature is considered to be at high risk in the MPA Region (Chaniotis <i>et al.</i> , 2014). This risk is primarily driven by pressures associated with otter trawling, but to a lesser extent pressures associated with creeling and potting and set (fixed) netting.
Continental slope turbidite canyons, iceberg ploughmark fields, prograding wedge and slide deposits	Iceberg ploughmark fields are considered to be at medium risk of damage across Scotland's seas (Brooks, 2013). The risk is primarily associated with otter trawling. Continental slope turbidite canyons, slide deposits, prograding wedges are considered to be at low risk of damage across Scotland's seas. This risk is primarily associated with otter trawling.
Stage 3 - Assessment of the appropriate scale of the search location in relation to the search features it contains	
Summary of assessment	On the Hebridean slope to the east of the MPA, the boundary captures the biological diversity of sediments that change with depth (Hughes <i>et al.</i>, 2014) and include burrowed mud data points in the bathyal zone. To the west, the boundary has been drawn to encompass the full extent of The Hebrides Terrace Seamount in Scottish waters to support seamount communities and an orange roughy spawning aggregation (ICES, 2010).

⁵ Information on the sensitivity of the biodiversity protected features to pressures and their associated activities was taken from Marine Scotland (2013). The degree to which a feature is exposed to activities associated with pressures to which it is sensitive in each MPA Region (as described in the Scottish MPA Selection Guidelines) was assessed to provide a qualitative measure of risk. Risk assessments for the various activities were examined to produce an overall qualitative risk assessment by MPA Region. The conclusions do not reflect the level of risk at the scale of the MPA. The sensitivity of the geodiversity protected features to pressures and their associated activities was taken from Brooks (2013) and an assessment of risk was undertaken at the national level.

	Between the biodiversity protected features to the east and west of the MPA are numerous geodiversity interests across the Rockall Trough, most notably the full extent of the prograding wedge feature which represents The Barra Fan Key Geodiversity Area (Brooks <i>et al.</i>, 2013).
Detailed assessment	
The size of the search location should be adapted where necessary to ensure it is suitable for maintaining the integrity of the features for which the MPA is being considered. Account should also be taken where relevant of the need for effective management of relevant activities	
Burrowed mud	The MPA boundary has been drawn to encompass all clustered records of burrows in the area based on data from Marine Scotland Science deep-water towed video surveys, and records of the location of seapens taken as by-catch from Marine Scotland Science trawl surveys.
Offshore deep-sea muds Offshore subtidal sands and gravels	The MPA encompasses a corridor down through the different biological zones that characterise the Hebridean slope as defined by Hughes <i>et al.</i> (2014).
Seamount communities and orange roughy	The MPA encompasses all seamount community records on the Hebrides Terrace Seamount. The extent of the Hebrides Terrace Seamount that falls within Scotland's seas is also included to support a spawning aggregation of orange roughy, and is therefore regarded important to the life history of the species (ICES, 2010).
Continental slope turbidite canyons, iceberg ploughmark fields, prograding wedge, slide deposit	The MPA encompasses the geodiversity features representative of The Barra Fan and Peaches Slide Complex Key Geodiversity Areas (Brooks <i>et al.</i> , 2013). In particular, the northern extent of the MPA tracks the entirety of the prograding wedge geodiversity feature, which primarily represents The Barra Fan Key Geodiversity Area. To a lesser degree, other features representative of The Barra Fan and Peach Slide Complex Key Geodiversity Areas are also included.

Stage 4 - Assessing the potential effectiveness of managing features within a search location as part of a Nature Conservation MPA

Summary of assessment	Mechanisms exist through the EU Common Fisheries Policy to introduce spatial and/or temporal management measures of fishing activities to conserve the protected features within the MPA. Should licensed activities occur within the possible MPA in the future, JNCC considered potential impacts could be addressed through the Environmental Impact Assessment (EIA) process. There is therefore potential for management measures to be implemented successfully for the protected features to achieve their conservation objectives in the MPA.
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Detailed assessment

There is a high probability that management measures, and the ability to implement them, will deliver the objectives of the MPA

The conservation objectives of the protected features of the MPA are to 'conserve – feature condition uncertain'. This uncertainty is a consequence of the lack of direct evidence available to confirm that features' condition. JNCC consider the biodiversity protected features and the iceberg ploughmark geodiversity feature may have been modified by human activity (see 2d).but that there is still potential for these features to be conserved.

Mechanisms exist through the EU Common Fisheries Policy to introduce spatial and/or temporal management measures on fisheries activities to conserve the protected features within the MPA. Should licensed activities occur within the MPA in the future, JNCC consider any potential impacts could be addressed through the Environmental Impact Assessment (EIA) process. There is therefore potential for management measures to be implemented successfully and the conservation objectives of the protected features of the MPA to be achieved.

Note: the ICES\NAFO Joint Working Group on Deep-water Ecology (WGDEC) which met in March 2013 recommended a closure to all bottom fishing that encompasses the steep flanks around the entirety of the Hebrides Terrace Seamount (i.e. in both UK and Irish waters) (ICES, 2013).This closure protecting vulnerable marine ecosystems, which includes the species characteristic of the seamount communities identified on the Hebrides Terrace Seamount (Cross *et al.*, 2014).

Further discussion concerning management of the protected features of the MPA is provided in The Barra Fan and Hebrides Terrace Seamount Management Options Paper.

Stage 5 - Assessment of the contribution of the potential area to the MPA network	
Summary of assessment	<p>The MPA makes a contribution to the MPA network by representing the deep-water variant of the seapens and burrowing megafauna burrowed-mud habitat type in OSPAR Region V, and a range of different types of offshore subtidal sand and gravel and offshore deep-sea mud habitats at the southern extent of the Hebridean slope in OSPAR Region V. It also includes an area of the Hebridean continental slope considered of functional significance to the overall health and biodiversity of Scotland's seas. The MPA also makes a significant contribution to the representation of seamount communities in the only OSPAR Region the feature is recorded in Scotland's seas – OSPAR Region V, and includes the entire extent of The Hebrides Terrace Seamount in Scottish waters.</p> <p>The geodiversity features representative of The Barra Fan Key Geodiversity area are regarded as scientifically important in furthering understanding of regional-scale palaeoceanographic changes, as well as fluctuations in the extent of the last British-Irish Ice Sheet, whereas the Peach Slide is one of five examples that are broadly representative of the range of slide features identified across Scotland's seas (Brooks <i>et al.</i>, 2013).</p>
Detailed assessment	
The potential area contributes significantly to the coherence of the MPA network in the seas around Scotland	
Assessment of biodiversity features	
Feature	Summary
Burrowed mud	The MPA provides representation of the seapens and burrowing megafauna type of burrowed mud in OSPAR Region V at the southern extent of its geographical range on the Hebridean slope. As an OSPAR Threatened and/or Declining habitat, it is considered important to have greater replication for the feature on the grounds of increasing resilience. The Barra Fan and Hebrides Terrace Seamount MPA makes a contribution to one of at least two recommended examples of burrowed mud in OSPAR Region V. Further information is provided in the burrowed-mud habitat adequacy assessment (SNH and JNCC, 2014).
Offshore deep-sea muds Offshore subtidal sand and gravels	The MPA provides representation for Atlantic-influenced offshore deep-sea mud and offshore subtidal sand and gravel habitats on the continental slope in OSPAR Region V. It represents one of two recommended examples of slope Atlantic-influenced offshore deep-sea mud and offshore subtidal sand and gravel habitats recommended for protection in OSPAR Region V. Further information is provided in the offshore deep-sea muds and offshore subtidal sand and gravels habitat adequacy assessments (SNH and JNCC, 2014).
Seamount communities	The MPA provides representation for seamount communities in the only OSPAR Region they are recorded in Scotland's seas – OSPAR Region V. As an OSPAR Threatened and/or Declining habitat in OSPAR Region V, it is considered important to have greater replication for the feature on the grounds of increasing resilience. The MPA makes a contribution to one of only three possible areas for seamount communities in Scotland's seas as only three seamounts have been recorded. Further information is provided in the seamount communities adequacy assessment (SNH and JNCC, 2014).
Continental	The MPA provides representation for one of two recommended areas of the Scottish continental slope to be included within the MPA

Assessment of biodiversity features	
Feature	Summary
slope	network. The Hebridean slope is considered ecologically and hydrographically distinct to the Faroe-Shetland Channel slope and so the recommendation is for at least one example of each area of the slope to be included. Further information is provided in the continental slope adequacy assessment (SNH and JNCC, 2014).
Seamounts	The MPA provides representation for seamounts in the only OSPAR Region they are recorded in Scotland's seas – OSPAR Region V. From a linkages perspective, The Hebrides Terrace Seamount is considered important as a foraging area for marine mammals, and plays an important role in the advection of salt, heat and organic material across the wider Atlantic. Further information is provided in the seamounts adequacy assessment (SNH and JNCC, 2014).
Assessment of geodiversity features	
Geodiversity features ⁶	<p>The Barra Fan is a large composite fan of Neogene to Pleistocene age that has built out into the deep-water basin of the Rockall Trough. The Barra Fan is regarded as a Key Geodiversity Area because the morphology and sedimentary sequences identified on the Fan are scientifically important in furthering understanding of regional-scale palaeoceanographic changes as well as fluctuations in the extent of the last British Ice Sheet (Brooks <i>et al.</i>, 2013).</p> <p>Large-scale slides are a characteristic feature along the Scottish continental slope and a number of mass-failure events have now been recognised. However, these slides vary in terms of both age and morphology: most of the older (pre Holocene) slide deposits have been partially or completely buried within the sedimentary column whilst other (predominantly Holocene age) slides have retained clear seabed expression. The Peach Slide Complex represents one of five large-scale slide events identified in Scotland's seas. The features included in the MPA are considered to be broadly representative of the range of slides found offshore in Scotland's seas (Brooks <i>et al.</i>, 2013).</p>

⁶ For geodiversity the stage 5 assessment primarily considers the contribution of the MPAs to the principal 'networks' of marine geodiversity interests present in Scottish waters (representation). The MPA Selection Guidelines propose that there should be minimal duplication of geodiversity features at a national level

Data sources and bibliography

- Allen, C., Dewey, S. and Axelsson, M. (2014a). *Biotope analysis of Marine Scotland Science underwater footage from the Hebridean Slope*. A report by Seastar Survey Ltd. for the Joint Nature Conservation Committee. JNCC Report 511.
- Allen, C., Dewey, S., and Axelsson, M., (2014b). *Biotope analysis of Marine Scotland Science underwater footage from the Hebridean Slope*. A report by Seastar Survey Ltd. For the Joint Nature Conservation Committee. JNCC Report 511 Addendum.
- Boisseau, O., Moscrop, A., Cucknell, A., McLanaghan, R., and Wall, D. (2011). *An acoustic survey for beaked whales in the Rockall Trough*. International Whaling Commission, SC/63/SM2.
- Brooks, A.J., Kenyon, N.H., Leslie, A., Long, D. and Gordon, J.E. (2013). *Characterising Scotland's marine environment to define search locations for new Marine Protected Areas. Part 2: The identification of Key Geodiversity Areas in Scottish waters*. Scottish Natural Heritage Commissioned Report No. 432.
- Brooks, A.J., (2013). *Assessing the sensitivity of geodiversity features in Scotland's seas to pressures associated with human activities*. Scottish Natural Heritage Commissioned Report No 590.
- Chaniotis., P.D., Crawford-Avis, O.T., Cunningham, S., Gillham, K., Tobin, D., Linwood, M. (2011). *Identifying locations considered to be least damaged/more natural in Scotland's seas*. Report produced by the Joint Nature Conservation Committee, Scottish Natural Heritage and Marine Scotland for the Scottish Marine Protected Areas Project.
- Chaniotis, P.D., Cunningham, S., Gillham, K., Epstein, G. (2014). *Assessing risk to Scottish MPA search features at the MPA regional scale*. Final report produced by the Joint Nature Conservation Committee, Scottish Natural Heritage and Marine Scotland for the Scottish Marine Protected Areas Project.
- Cross, T., Howell, K.L., Hughes, E., Seeley, R. (2014). *Analysis of seabed imagery from the Hebrides Terrace Seamount (2013)*. JNCC Report No. 510.
- Davies, A.J., Duineveld, G., Lavaleye, M., Bergman, M.J., van Haren, H., and Roberts, J.M. (2009). Downwelling and deep-water bottom currents as food supply mechanisms to the coldwater *Lophelia pertusa* (Scleractinia) at the Mingulay reef complex. *Limnology and Oceanography*, **54**. 620–629.
- Ellett, D.J., and Martin, J.H.A. (1973). *The physical and chemical oceanography of the Rockall Channel*. Deep Sea Research and Oceanographic Abstracts, **20**: 585–625.
- Eleftheriou, A. and Basford, D.J. (1989). *The macrobenthic infauna of the offshore northern North Sea*. Journal of the Marine Biological Association of the U.K. **69**: 123-43.
- Evans, P.G.H. (1997). *Ecology of sperm whales (Physeter macrocephalus) in the Eastern North Atlantic, with special reference to sightings and strandings records from the British Isles*. Bulletin de l'Institut Royal des Sciences Naturelles de Belgique, Biologie, **67**: (Supplement). 37–46.
- Frederiksen, R., Jensen, A., and Westerberg, H. (1992). *The distribution of the coral Lophelia pertusa around the Faroe Islands and the relation to internal tide mixing*. Sarsia, **77**: 157–171.
- Gage, J.D. (1986). *The benthic fauna of the Rockall Trough: regional distribution and bathymetric zonation*. Proceedings of the Royal Society of Edinburgh, **88**:159-74.
- Howell, K. (2010). *A benthic classification system to aid the implementation of marine protected area networks in the deep/high seas of the NE Atlantic*. Biological Conservation, **143**: 1041-56.

Data sources and bibliography

- Hughes, D.J., Nickell, T. and Gontarek, S. (2014). *Biotope analysis of archived stills from the SEA7 region of Scotland's seas (2011)*. JNCC Report 502.
- ICES. (2007). *Report of the Working Group on the Biology and Assessment of Deep-Sea Fisheries Resources (WGDEEP)*, 8–15 May 2007, ICES Headquarters. ICES CM 2007/ACFM. **20**.
- ICES. (2010). *ICES Advice 2010*, **book 9. 9.4.14**. 211–216.
- ICES. (2013). *Report of the ICES\NAFO Joint Working Group on Deep-water Ecology (WGDEC)*, 11-15TH March 2013, Floedevigen, Norway, ICES CM 2013\ACOM:28. 95pp
- Inall, M. and Sherwin, T.B (2006). *SEA7 Technical Report – Hydrography*. Department of Trade and Industry.
- Macleod, K., Simmonds, M.P. and Murray, E (2003). *Summer distributions and relative abundance of cetacean populations off north-west Scotland*. Journal of the Marine Biological Association of the UK, **83**: 1187–1192.
- Marine Scotland (2013). Features, Activities, Sensitivities Tool (FEAST) online resource. Available online from: www.marine.scotland.gov.uk/FEAST/. Version 1.0 (August 2013).
- OSPAR Commission. (2008a). *List of Threatened and/or Declining Species and Habitats*. Reference Number: 2008-6. <http://www.ospar.org/documents/DBASE/DECRECS/Agreements/08-06e_OSPAR%20List%20species%20and%20habitats.doc>.
- OSPAR Commission. (2008b). *Case Reports for the OSPAR List of Threatened and/or Declining Species and Habitats*. OSPAR Commission. Biodiversity Series. <http://qsr2010.ospar.org/media/assessments/p00358_case_reports_species_and_habitats_2008.pdf>.
- Shapiro, G.I. and Hill, A.E. (1997). *Dynamics of dense water cascades at the shelf edge*. Journal of Physical Oceanography, **27**: 2381–94.
- SNH & JNCC (2014). *Assessment of the adequacy of the Scottish MPA network for MPA search features: summary of the application of the stage 5 selection guidelines*. Final report produced by Scottish Natural Heritage, the Joint Nature Conservation Committee and Marine Scotland for the Scottish Marine Protected Areas Project.
- Sotheran, I., Benson, A, and Crawford-Avis, O. (2014). *Mapping habitats and biotopes to strengthen the information base of Marine Protected Areas in Scottish waters, Phase 2 (Barra Fan and Hebrides Terrace Seamount Area)*, JNCC Report No. 527
- Swift, R.J., Hastie, G.D., Barton, T.R., Clark, C.W., Tasker, M.L. and Thompson, P.M. (2002). *Studying the distribution and behaviour of cetaceans in the northeast Atlantic using passive acoustic techniques*. Report for the Atlantic Frontier Environmental Network.
- Weir, C.R., Pollock, C., Cronin, C. and Taylor, S. (2001). *Cetaceans of the Atlantic Frontier, north and west of Scotland*. Continental Shelf Research, **21**: 1047–1071.