Summary Report: Climate Change Risk-Based Assessment for Notifiable Features in Scotland

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December 2014

1. Key Points

- This report describes an analytical procedure aimed at ranking Notifiable Features in Scotland according to the risk posed to them by climate change.
- As well as discussing the results of this ranking process, it looks at potential adaptive management approaches for the most highly ranked features within that list.
- Different analytical approaches were necessary for Earth Science and Biodiversity Features, and each are reported separately
- Further work is underway to discuss the results with relevant experts, to develop new analytical procedures, and to explore the adaptation actions that might be applied

2. Introduction

1a. Defining the Problem

There is little doubt that climate change represents one of the major challenges to nature conservation. Climate is a critical factor in determining species' distributions. Climate change will lead to the rearrangement of species distributions, which in any one area – be it a nature reserve, county or country – will lead to the loss of some species, and gain of others. Even without losses and gains, species abundances may rise or fall as the climate changes. In addition, other components of our natural systems, our geodiversity, will be impacted by the changing climate in ways that can be both positive and negative.

Two general types of general management responses to climate change are possible. Mitigation management actions aim to limit the extent of climate change, for example by limiting greenhouse gas emissions. The work described in this report is not focussed on developing *mitigation* actions. Instead it considers the development of *adaptation* actions. These are activities that help systems adapt to the expected impacts of climate change. In terms of nature conservation this is based on the assumption that change will happen, and consequently that conservation management needs to help natural systems adapt to that change so as to promote the conservation of biodiversity and geodiversity as that change takes place.

Given the scale of climate change this represents a considerable challenge. As resources for conservation management are finite, it makes sense to target adaptation management action on those elements of our natural systems that are already a focus for conservation effort, and that are likely to suffer the greatest impacts of climate change.

But targeting adaptation action is not straightforward. The expected impacts of climate change vary from place-to-place. In addition different elements of our natural systems are likely to be more or less sensitive to different elements of climate change. Any prioritisation process must try to take account of this complexity.

A number of prioritisation analyses for nature conservation have been undertaken in the last few years. In many cases these have been based on climate envelope models (for example the MONARCH[1] and CHAINSPAN[2] projects). These are models that link the current distribution of a species to key climate parameters (i.e. defining a species' "climate envelope") and then use future projections of climate to determine the possible location of that envelope, and assess, for example, whether the range of the species will increase or decrease or whether it will map onto the current protected areas network.

Of necessity these studies have tended to focus on those species where good distribution data exist, for example the better-studied groups such as birds or vascular plants. But the distribution data for many components of biodiversity is often quite poor, not least because of the difficulty in identifying the members of certain groups such as lichens, fungi, and soil invertebrates. In addition the elements of our natural environment covered by conservation legislation also include geodiversity features. Climate envelope analyses are not relevant to assessing the likely impacts of climate change on features of this type, nor for prioritising climate change adaptation action.

The challenge, then, is to develop a prioritisation process to target conservation adaptation actions irrespective of the type of feature or the quality of data that we currently have concerning existing national-level distributions.

1b. This Project

This report summarises a project being undertaken by ClimateXChange researchers in collaboration with staff from Scottish Natural Heritage (SNH). The purpose of the project is to develop an analytical procedure resulting in a ranked list of **Notifiable Features in Scotland** according to the risk posed to them by climate change, and then to look at potential adaptive management approaches for the most highly ranked features within that list. This is to help SNH identify the consequences of climate change for protected areas and put in place climate change adaption measures, which is a priority for SNH, and a goal within the Scottish Climate Change Adaptation Programme.

To date, the work has had 2 main phases. **Phase 1** of the work was undertaken between April 2012 and March 2013. The aim of phase 1 was to develop a simple analytical procedure and to apply it to the full list of Notifiable Features in Scotland.

During Phase 1 a number of possible improvements to the analytical approach were suggested, as well as avenues for developing the work to make the outputs more readily accessible and useful. Some of these proposals were the focus of **Phase 2** of the project, which ran from April 2013 to March 2014.

Reports on the analytical approaches adopted, and the results of the analyses, were provided by the ClimateXChange team to SNH. These were substantial documents which recorded all of the detail of the work undertaken, making them unsuitable for widespread circulation beyond the project team. However, it is important that the existence, aims and outcomes of the work are easily accessible, and to this end we have produced this **Summary Report**.

[1] MONARCH – http://www.eci.ox.ac.uk/research/biodiversity/monarch.php

[2] CHAINSPAN - http://www.bto.org/science/climate-change/informing-adaptation/climate-change-impacts-avian-interests-protected-area-networks-chainspan

In this Summary Report we briefly describe the analytical approach which – after exploring numerous possibilities during Phases 1 and 2 of this work (and as fully detailed in the reports for these phases of work) – we have finally adopted. We then summarise the outcome of our analyses. For reasons explained later, we use a different analytical approach for Earth Science and for Biodiversity Notifiable Features, and so we present details of the approach and results separately for these two sets of feature types. Finally we outline the next steps in this work. This report is therefore broken down into three main sections:

- Data analysis and results – Biodiversity Features
- Data analysis and results – Earth Science Features
- Next steps

We have also attached a series of Appendices which describe in more detail some of the analyses and results files. These are referred to where appropriate throughout this Summary Report. It is not necessary to read all of the Appendices to understand the analytical process or its headline results – the Appendices are provided for information if required.

1c. Definitions

Initial project discussions demonstrated that having clear definitions of various key terms, and a clear purpose for the assessment, were critical. Definitions of terms can differ between studies, but for our purposes we have worked to the following:

Vulnerability is a combination of a system's sensitivity to climate change and its adaptive capacity. It is an intrinsic property of the system.

Risk is a combination of vulnerability of the system and its climate-related exposure.

The term "system" is replaced here with "notifiable feature"

We are aiming to assess the risk to the status of the *feature*. However, this is not assessed against some form of standardised reporting categorisation such as is used in Site Condition Monitoring (SCM[3]) reporting - the assessment is broader than that, i.e. <u>any</u> impact on the feature.

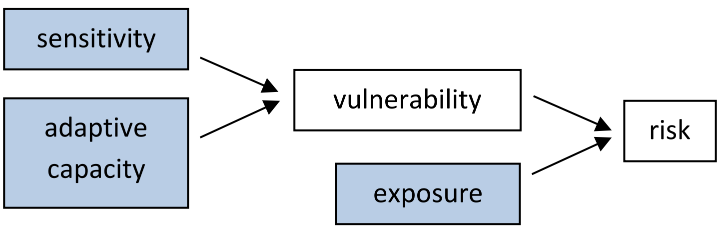
2. Data Analysis and Results – Biodiversity features

2a. Data sources – Biodiversity Features

Biodiversity Features from the Site Condition Monitoring (SCM) database include individual species, habitats, assemblages and aggregates.

For the Biodiversity Features we utilised an index-based approach to assessing risk. Briefly, the approach is derived from that applied in the ADAS assessment of protected sites in Wales[4].

It assumes a certain hierarchy of elements in producing a final risk score:



"Raw" data (a combination of expert knowledge, and measured and predicted parameters) are assigned to these various categories (shaded in blue). Vulnerability and risk scores are derived values calculated from this "raw" data.

[3] http://www.snh.gov.uk/protecting-scotlands-nature/protected-areas/site-condition-monitoring/
[4] To access this report in pdf format click here.

We used a range of data sources to provide information within each of the three categories.

Sensitivity

Sensitivity is the inherent sensitivity of the feature to changes in climate. Features of the same type (for example birds or plants of a given species) will have similar levels of sensitivity. However their exposure to climate change will vary depending on their location.

Biodiversity sensitivity scores - The sensitivity assessment for Biodiversity Features was based around the compilation of expert knowledge on habitat and/or species sensitivity. These data were gathered through a questionnaire process, followed by moderation of the questionnaire scores. Full details of this process are given in Appendix 1. [5]

Adaptive capacity

Adaptive capacity is the ability of a feature to adapt to climate change.

Site condition monitoring status - From the Site Condition Monitoring Database we used the "Reporting Condition to Scottish Government" data to assign a "risk" score using a methodology adapted from the ADAS 2011 approach. For more details see Appendix 2.

Connectivity - We produced a simple analysis of fragmentation risk for biodiversity (habitats and species) features in Scotland based on the spatial configuration of the protected area network. For more details see Appendix 3.

Site size - Shapefiles of the protected sites were downloaded from the SNH website (SSSI, SAC, SAP, RAMSAR), and then combined in to one shapefile. The area of each protected site was calculated using GIS software, and then site areas were assigned to features. The absolute site size value was then converted to a normalised value, which was incorporated into the overall score for adaptive capacity.

Exposure

Exposure is the projected change in climate that a particular feature will experience. This will depend on where the feature is located in Scotland.

Two sets of climate projection data were combined in the exposure calculations, one set provided by Andrew Harding, University of Edinburgh (referred to here and in the Excel spreadsheet as "Andrew's" climate data), and the other based on previous work at the James Hutton Institute relating to the Birse bioclimatic zones (referred to here as the Birse climate data).

"Birse" climate data - Maps have been produced for other projects - focussing on the Birse bioclimatic zones - that are based on the UKCIP09 projection at 50% probability level with emission scenario a1b, and for the time period 2040-2069. The data in these maps show projected changes in a number of climate parameters: PPTSUMMER – summer precipitation; PPTWINTER – winter precipitation; TSUMMER – summer temperature; TWINTER – winter temperature.

The spatial resolution of the maps is approx. 25km^2. The maps were used to assign a climate values to each protected site. Although protected sites are often composed of multiple polygons, the analyses are carried out on the whole area. Each site was given the climate value that covered the majority of its area. If a site is completely outside the climate map, the spatially closest value was given to the whole site. Site values were then assigned to features.

"Andrew's" climate data - Climate data has been provided for 11 regional climate model (RCM) members with varying climate sensitivity. Climate projection data have been provided for all sites for 2050 model run end points. More information on these data can be found in Appendix 4.

[5] It should be noted that a slightly different weighting process has been used in the analyses for this report compared to that used for the Phase 2 Report, resulting in small differences in final rankings for some features. Further information is provided in Appendix 1.

2b. Data analysis – Biodiversity Features

The data and calculations used in this analysis can be found in the file *Simplified results_bio features.xlsx*. A full description of the calculations and an explanation of the content of this file can be found in Appendix 5.

It is worth noting here a couple of points concerning the Biodiversity Features analysis. First, our index-based analytical approach *does not assess uncertainty*; according to widely-used convention it cannot then be considered a risk assessment. Consequently this analysis is best described as a "risk-based" assessment. Integration of an assessment of uncertainty – using a Bayesian modelling approach - is a separate ongoing activity.

Second, the approach *cannot identify features that are likely to benefit from climate change.* This is because it is not based on projections of change in feature status, but instead is based on static measures of current status, and assumptions that link these to climate projections. For example, we assume that an unfavourable SCM status represents a high risk of an impact of climate change, and that a greater degree of climate change will have a greater negative impact on that feature, multiplying up to give a very high risk score. In order to assess which features might specifically benefit from climate change, we would need much better information enabling us to link "ideal" conditions for the feature (e.g. the optimum temperature conditions for a species) to the projected climate conditions. From this we could assess whether the projected climatic conditions for the feature move towards or away from this climatic optimum. This might be possible for some species features, but would involve considerable detailed modelling linking existing ranges to climate. In addition, such relationships can be spurious and driven by habitat loss (weakening the link between distribution and climate), and can also be very hard to assess for rare species with highly fragmented distributions. Our approach is therefore pragmatic – given available data – but we need to realise that the assessed risk is that climate change *will have an impact* on the feature but that the impact *could be positive or negative*: feature-by-feature assessment of the most highly ranked features might then indicate whether the features are likely to be winners or losers.

Comparison with ADAS analytical approach

Although our approach is similar to that adopted by ADAS (2011), particularly with respect to the way in which we combine different types of data using the arithmetic mean of their log +1 normalised scores (see Appendix 5 for detail), our approach differs from that adopted by ADAS (2011) in a number of ways.

First, we use a particular conceptual framework for building up the final risk score. This "cascade" is not adopted in the ADAS assessment.

Second, in some cases we utilise different raw data in the analysis. This is a consequence of expediency: we have utilised those data that were most immediately available to us, and in some cases assessments used in the ADAS report have only been undertaken for designated sites in Wales.

Third, and perhaps most importantly, our approach is focussed at the feature level. In contrast the ADAS analysis was focussed on delivering assessments at the site level, and site-level summary statistics were calculated based on combined scores for features within a site. Obviously, because we are working on a feature-by-feature basis, we do not calculate these site-level summary statistics, but instead calculate single risk scores for each feature.

2c. Results – Biodiversity Features

The following table shows the fifty Biodiversity Features that the analysis identifies as being most "at risk" based on the final Risk scores. It also shows the relative rankings of these features with respect to the component values that make up the final Risk score (e.g. sensitivity, adaptive capacity).

Site Code	Feature id	Site name	Feature	Sensitivity	Adaptive capacity	Vulnerability	Exposure	Risk
771	11056	Hells Glen	Lichen assemblage	86	133	5	8	1
1172	11860	Moffat Hills	Upland assemblage	1	503	10	59	2
1168	11850	Minto Craigs	Lichen assemblage	86	17	1	883	3
771	11055	Hells Glen	Bryophyte assemblage	86	313	20	8	4
717	15187	Glen Nant	Lichen assemblage	86	358	26	12	5
1334	12234	Ravenshall Wood	Lichen assemblage	86	266	17	465	6
208	16541	Birks of Aberfeldy	Lichen assemblage	86	81	2	1631	7
487	10446	Dalkeith Oakwood	Lichen assemblage	86	391	42	34	8
1573	12811	Tweedsmuir Hills	Upland assemblage	1	543	14	848	9
169	9780	Beinn Iadain and Beinn na h-Uamha	Upland assemblage	1	484	8	1064	10
736	10978	Glenkinnon Burn	Lichen assemblage	86	213	15	788	11
8158	13181	Knapdale Woods	Lichen assemblage	86	362	28	246	12
8161	13188	North Lowther Uplands	Upland assemblage	1	540	13	1047	13
520	10499	Doire Dhonn	Lichen assemblage	86	315	21	403	14
432	10313	Craighall Gorge	Lichen assemblage	86	216	16	1142	15
816	11164	Inverneil Burn	Lichen assemblage	86	305	19	437	16
1597	12880	Water of Ken Woods	Lichen assemblage	86	329	23	496	17
1160	11837	Milton Loch	Beetle assemblage	230	50	29	496	18
420	16596	Craig Leith and Myreton Hill	Upland assemblage	1	1079	55	131	19
764	11041	Hannaston Wood	Lichen assemblage	86	390	41	496	20
4	9476	Abbey St Bathans Woodlands	Lichen assemblage	86	326	22	867	21
1168	11851	Minto Craigs	Beetle assemblage	230	17	27	883	22
228	9932	Blar na Caillich Buidhe	Lichen assemblage	86	429	47	621	23
11	9499	Ach an Todhair	Upland assemblage	1	432	6	2070	24
699	10914	Glen Barisdale	Lichen assemblage	86	880	83	19	25
209	16485	Bishop Hill	Upland assemblage	1	818	30	958	26
436	10321	Craighoyle Woodland	Lichen assemblage	86	806	79	24	27
1168	15144	Minto Craigs	Vascular plant assemblage	396	17	40	883	28
120	9678	Balerno Common	Bryophyte assemblage	86	705	76	161	29
738	10982	Glentrool Oakwoods	Lichen assemblage	86	416	46	990	30
74	9585	Ardmeanach	Montane assemblage	1	511	12	2367	31
1289	12165	Pinbain Burn to Cairn Hill	Upland assemblage	1	854	32	1395	32
1332	16607	Rassal	Bryophyte assemblage	86	92	3	2851	33
1332	16608	Rassal	Lichen assemblage	86	92	3	2851	33
154	9738	Barry Links	Bryophyte assemblage	86	476	54	1318	35

190	9852	Ben More - Stob Binnein	Lichen assemblage	86	516	60	1183	36
1163	11843	Milton Wood	Lichen assemblage	86	623	69	1053	37
667	10851	Gannochy Gorge	Bryophyte assemblage	86	407	43	1449	38
667	10852	Gannochy Gorge	Lichen assemblage	86	407	43	1449	38
282	10021	Caenlochan	Montane assemblage	1	962	38	1718	40
1356	12294	River Ayr Gorge	Beetle assemblage	230	141	67	1312	41
719	10944	Glen Ralloch to Baravalla Woods	Lichen assemblage	86	348	25	2009	42
786	11083	Hill of Towanreef	Upland assemblage	1	488	9	2726	43
714	10937	Glen Lyon Woods	Lichen assemblage	86	410	45	1631	44
1053	11608	Loch Shiel	Bryophyte assemblage	86	773	77	648	45
751	11015	Gruinart Flats	Lichen assemblage	86	513	57	1523	46
186	14940	Ben Lomond	Snowbed	222	495	73	1009	47
836	11214	Kentra Bay and Moss	Bryophyte assemblage	86	474	53	1755	48
731	10971	Glen Coe	Upland assemblage	1	940	36	1946	49
1379	12358	Ross Park	Lichen assemblage	86	633	70	1367	50

It is worth noting that a low score in this table indicates a high ranking, i.e. a feature that is considered to be "at risk"; and that this relates to the likelihood of an impact of climate change without that impact being assessed as either positive or negative.

It is also worth noting that fifty features is a relatively arbitrary cut-off point, and is used here for illustration only. Many of the features just outside this list of fifty have similar – or more "risky" – scores for some of the underlying components.

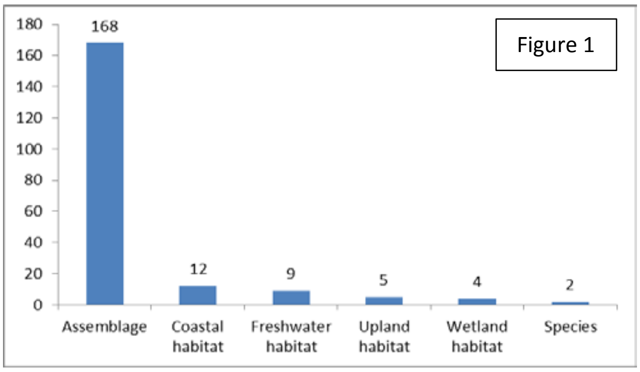


Figure 1. *Distribution of the top 200 most highly ranked biodiversity features within feature types (Assemblage, Coastal habitat, etc.).*

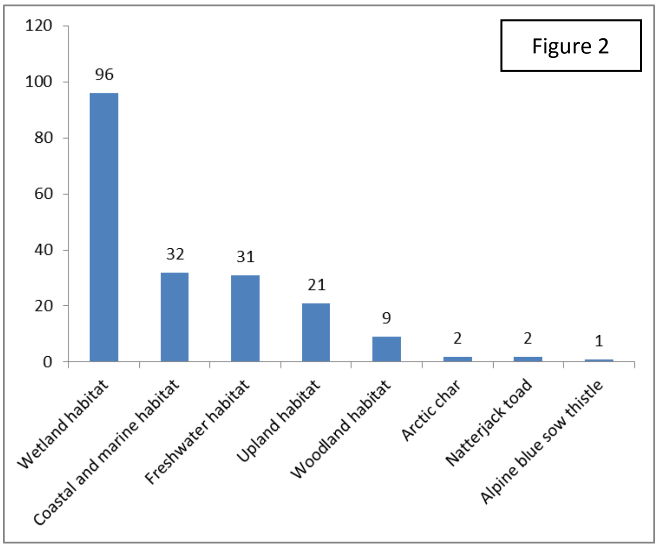


Figure 2. *Distribution (within feature types) of those features remaining from the top 500 most highly ranked biodiversity features following the exclusion of assemblages.*

Nonetheless, this table illustrates some important points. The first is that many of the features ranked as being at high risk are assemblages. This is likely to reflect the high sensitivity scores (and associated high confidence scores) given to these feature types. The second is that a final high Risk score need not be related to a high Exposure score (i.e. a high projected level of climate change) – some relatively low exposure scores are found within this list (e.g. for the sites Rassal and Ardmeanach). The high risk ranking results instead from their highly ranked vulnerability scores.

The predominance of assemblages is further highlighted by an assessment of the types of Feature that compose the top 200 most highly ranked (Fig. 1). There are six broad groups of feature types present: assemblages, coastal habitats, freshwater habitats, upland habitats, wetland habitats, and two species (Natterjack Toad and Arctic Char)

If we take the top 500 most highly ranked features, and then exclude assemblages (note that this can be done in the Excel results file using the "Feature category" filter in the *Rankings* sheet), we get the distribution among feature types as shown in Fig. 2.

Now we can see that wetland habitats dominate the list. For many of the high ranking features, the drivers are a combination of high sensitivity, poor current status, low connectivity and small site size – all of which contribute to a high vulnerability score. In some cases these are then also linked with high impacts of some climate parameters - in particular projected maximum summer temperatures and the number of dry days – leading to a high exposure score.

This combination of factors is reflected in the distribution of highly ranked freshwater and wetland features (Fig. 3): these tend to be located in central and eastern lowland areas, and their distribution overlaps with areas of either intensive agriculture or high levels of urbanisation. Pollution may be responsible for poor SCM scores, and at the same time these sites are relatively small, isolated, and in areas with substantial projected changes in climate parameters, particularly summer rainfall and temperatures.

The characteristics of these features provides some indication as to the actions that might be taken to reduce the risk from climate change, for example improving their SCM status and – if possible – increasing site size.

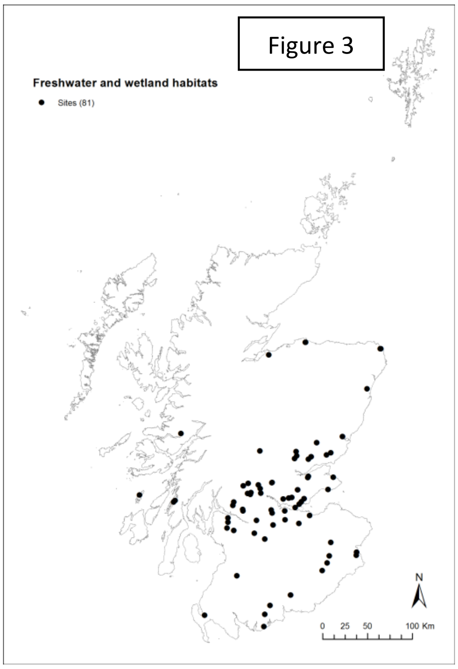


Figure 3. *Location of the (81) most highly ranked freshwater and wetland features.*

The results presented here are only illustrative, i.e. they have been extracted from the results file to give a flavour of the outcome of the analysis. A better understanding of the results can be achieved by manipulating the data in the results file[6], which in turn should be aided by the guidance provided in Appendix 5.

3. Data Analysis and Results – Earth Science Features

3a. Data sources and analysis – Earth Science Features

As with the Biodiversity Features, we took an index-based approach to assessing risk from climate change for Earth Science Features. Initially we applied exactly the same analytical process to both Earth Science and Biodiversity Features. However, in follow-up discussions with Earth Science specialists from both SNH and ClimateXChange, there was considerable concern about the adoption of a "single analysis" approach. This was not least because of the inclusion of data into the assessment of Earth Science Features (in particular site size) which may have limited bearing on the risk posed by climate change to these features, and the absence of other data relating to habitat isolation such that Earth Science Features may have been relatively down-weighted in the risk assessment process.

Consequently a separate analysis was developed and undertaken for the Earth Science Features. The overall approach and rationale is given in Appendix 6. To summarise the main differences between the approaches used for the Earth Science and Biodiversity Features, the Earth Science Features analysis:

1. Does not combine sensitivity and adaptive capacity data to give a vulnerability score. Instead both factors are accounted for in a single scoring process.

[6] The results sheets for the analyses of both the Earth Science and Biodiversity features are available on request from Rob Brooker, James Hutton Institute. Please e-mail rob.brooker@hutton.ac.uk

2. Does not combine vulnerability and exposure data to give a final risk ranking. Instead the exposure (i.e. climate) data are only used to provide a relative ranking within 5 main ranking categories.

The main steps in the Earth Science Features analysis were:

1. Application of the Earth Science Feature assessment procedure to all features in the Earth Science Sites (ESS) Database.
2. Linking these scores from the ESS Database to the features as listed in the Site Condition Monitoring (SCM) Database, based on a combination of SSSI codes and feature types.
3. Where multiple features from the ESS Database linked to only a single feature in the SCM Database, allocating the highest risk score based on the Earth Science Features assessment.
4. Combining climate data to give a single Exposure score.
5. Allocating Earth Science Features first to 5 main risk categories, and then within categories ranking them according to their Exposure scores.
6. Adding relative rankings to the full list of 656 Earth Science Features.

Finally it is worth noting that the ES assessment procedure, because of the methodology adopted by the assessment team, focusses on the probability of a *negative* impact of climate change on a given feature. This is in contrast to the assessment for Biodiversity features which assesses the likelihood of *any* impact of climate change on a feature, as described above.

The data and calculations used in this analysis can be found in the file *Simplified results_ES features.xlsx*. A full description of the content of this file can be found in Appendix 6.

3b. Results – Earth Science Features

Figure 4 shows the number of features within each risk category. This equates to 9.1% (High), 10.1% (Medium-High), 26.4% (Medium), 32.0% (Medium-Low), and 22.4% (Low) of the features assessed.

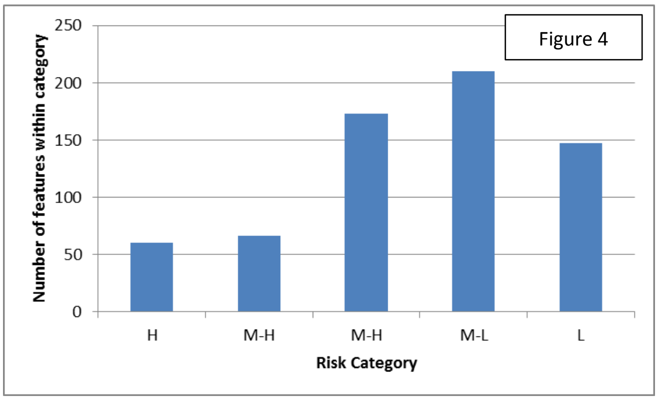


Figure 4. *The number of the 656 Earth Science features within risk categories (H=High, M-H=Medium-High, M=Medium, M-L=Medium-Low, L=Low.*

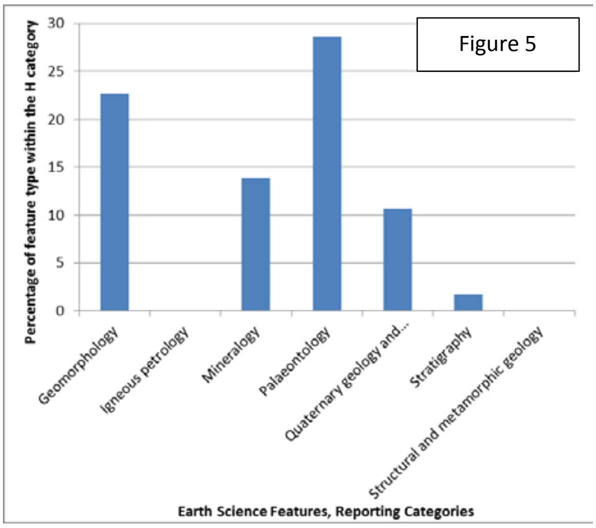


Figure 5. *Percentage of features within the high risk (H) category that belong to particular Earth Science feature types.*

In terms of the relative contribution to the H category, some feature types (classified using the Earth Science features reporting categories) are more common than we might expect if all features types contributed equally (approx. 9%).

In particular the Geomorphology and Palaeontology features are more common in the H group, with 23% and 29% of features from these feature types, respectively, being classified as H (Fig. 5).

The fifty most highly ranked Earth Science Features are:

Site Code	Feature id	Rank	Site	Feature type

1176	11868	1	Mollands	Quaternary of Scotland
1575	12814	2	Tynaspirit	Quaternary of Scotland
8163	13203	3	Firth of Forth	Mineralogy of Scotland
8163	13204	4	Firth of Forth	Arthropoda (excluding insects and trilobites)
8163	13205	5	Firth of Forth	Palaeozoic Palaeobotany
8163	13206	6	Firth of Forth	Permian - Carboniferous Fish/Amphibia
1276	12146	7	Pease Bay Coast	Silurian - Devonian Chordata
1540	12726	8	Tinto Hills	Quaternary of Scotland
512	16577	9	Din Moss and Hoselaw Loch	Quaternary of Scotland
751	11016	10	Gruinart Flats	Coastal Geomorphology of Scotland
1354	12285	11	Rinns of Islay	Coastal Geomorphology of Scotland
1636	12985	12	Whitlaw Mosses	Quaternary of Scotland
1474	12571	13	St Michael's Wood Marshes	Quaternary of Scotland
1583	12844	14	Upper Solway Flats and Marshes	Coastal Geomorphology of Scotland
1351	16530	15	Rickle Craig - Scurdie Ness	Mineralogy of Scotland
461	16517	16	Cree Estuary	Coastal Geomorphology of Scotland
282	16480	17	Caenlochan	Quaternary of Scotland
602	10694	18	Eigg - Laig to Kildonnan	Jurassic - Cretaceous Reptilia
1376	16394	19	Rosemarkie to Shandwick Coast	Mesozoic Palaeobotany
854	11239	20	Kingshouse	Quaternary of Scotland
1212	11967	21	Muir of Dinnet	Quaternary of Scotland
674	16428	22	Garron Point	Silurian - Devonian Chordata
74	9589	23	Ardmeanach	Hettangian, Sinemurian, Pliensbachian
1453	12514	24	South Kerrera and Gallanach	Silurian - Devonian Chordata
478	10426	25	Culbin Sands, Culbin Forest and Findhorn Bay	Coastal Geomorphology of Scotland
1190	16636	26	Morrone Birkwood	Quaternary of Scotland
893	11298	27	Laggan	Palaeozoic Palaeobotany
1238	12039	28	North Newton Shore	Non-marine Devonian
812	11152	29	Inverbrora	Mesozoic Palaeobotany
81	9599	30	Ardtun Leaf Beds	Palaeoentomology
81	9600	31	Ardtun Leaf Beds	Tertiary Palaeobotany
1455	12519	32	South Mull Coast	Mineralogy of Scotland
1188	11918	33	Morrich More	Coastal Geomorphology of Scotland
627	10758	34	Fannich Hills	Quaternary of Scotland
1285	12158	35	Philorth Valley	Quaternary of Scotland
606	10705	36	Elgol Coast	Mesozoic Mammalia
772	16569	37	Helmsdale Coast	Mesozoic Palaeobotany
611	10729	38	Eoligarry	Coastal Geomorphology of

				Scotland
965	11422	39	Loch Bee	Coastal Geomorphology of Scotland
966	11426	40	Loch Bee Machair	Coastal Geomorphology of Scotland
1267	12129	41	Papa Stour	Silurian - Devonian Chordata
1323	12201	42	Quoys of Garth	Quaternary of Scotland
580	16497	43	Durness	Coastal Geomorphology of Scotland
1278	12150	44	Pennylands	Silurian - Devonian Chordata
827	11195	45	Keen of Hamar	Mineralogy of Scotland
1126	11780	46	Mangersta Sands	Coastal Geomorphology of Scotland
620	10742	47	Fair Isle	Palaeozoic Palaeobotany
1508	12643	48	Sumburgh Head	Silurian - Devonian Chordata
1475	12572	49	St Ninian's Tombolo	Coastal Geomorphology of Scotland
1530	12705	50	The Cletts, Exnaboe	Silurian - Devonian Chordata

As with the biodiversity features, this selection of fifty features is purely illustrative. In contrast to the Biodiversity features, there is no real need to unpick these results – these features receive a high final risk score because of the assumptions made in the Earth Science features assessment procedure about the likely impacts of climate change on features of this type (as described in Appendix 6).

In terms of the spatial distribution of these features, Fig. 6 indicates the location of all Earth Science features, with features being colour-coded according to their assigned risk score.

Because climate data are applied to the scoring process after the main categorisation has been undertaken, the distribution is not clearly related to future climate change projections (in contrast, see the results for the biodiversity features). As recommended, exposure data have been used only to refine rankings within these major groups.

One site - the Firth of Forth - has multiple features within this top 50. This probably reflects the application of the same climate data to all features within a single site (hence all high-ranked features from the Firth get the same final risk score), and a lack of refinement in the link between particular changes in climate (i.e. temperature, precipitation) and the likely impact on different types of Earth Science features.

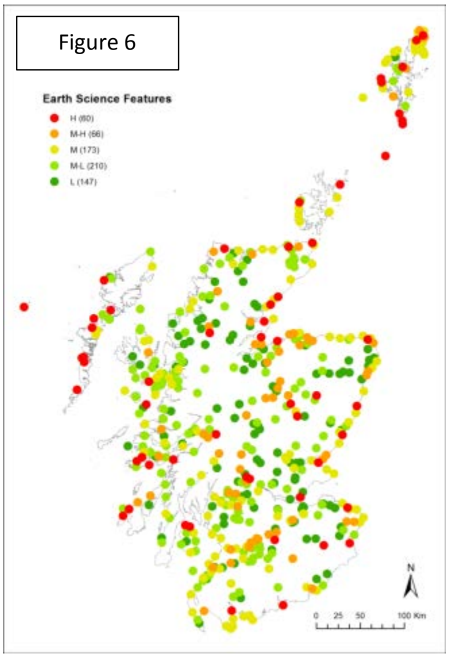


Figure 6. *Location of Earth Science features. Colour coding indicates the risk category to which a given feature has been assigned.*

Notably the Earth Science Sites Database contains data on nationally and internationally important geo features that are not protected by SSSI legislation (unnotified GCR sites) as well as the data on those that are (notified GCR sites). This data is not being used in the current analysis; however, similar analyses could easily be run for this data, highlighting the level of potential climate change threats to currently un-protected geo features. This could potentially assist with prioritising features for future protection.

4. Conclusions and Next Steps

4a. What are the main conclusions from our analyses?

Earth Science features

- Geomorphology and Palaeontology features dominate the "high risk" category, and this follows directly from the scores given to these features in the Earth Sciences feature assessment process.
- Because climate data are applied to the scoring process after the main categorisation has been calculated, the distribution is not related to future climate change projections, but reflects instead historic processes.

Biodiversity features

- Assemblages make up a large proportion of the most "at risk" features. This is driven by their allocated sensitivity scores. Whether the blanket application of a high sensitivity score is reasonable may need further consideration.
- Beyond assemblages, freshwater/wetland habitats generally rank highly, and this may result from the combined contributions of a range of parameters including high sensitivity, poor current status, low connectivity and site size, and the high impacts of some climate parameters.
- Highly ranked features – for example freshwater features - tend to be located in the central belt and eastern lowland areas.

4b. Possible adaptation management options

Given the list of the most highly ranked features in the Biodiversity feature analysis, certain recommendations seem to be sensible, specifically (and with increasing difficulty of implementation):

1. Address the situations that lead to poor site condition monitoring status.

2. Increase the size of the site on which the feature is located.

3. If possible, and relevant, increase the level of connectivity for the feature.

However, further consideration needs to be given to the application of adaptation management options to the high risk Earth Science features. In terms of the eight Adaptation Principles published by SNH (2012[7]), the focus of these principles seems very much to be on the conservation of biodiversity features. Below we have listed these principles, but have shaded out those that seem less relevant to the conservation of Earth Science features.

> 1. Reduce other pressures on ecosystems, habitats and species – e.g. pollution, unsustainable use, grazing, habitat fragmentation and invasive non-native species.
>
> 2. Make space for natural processes including geomorphological, water and soil processes, and species interactions.
>
> 3. Enhance opportunities for species to disperse by reducing fragmentation and increasing the amount of habitat available.
>
> 4. Improve habitat management where activities such as grazing, burning or drainage cause declines in diversity or size of species populations, or where modifying management or increasing habitat diversity could improve resilience to climate change.
>
> 5. Enhance habitat diversity, e.g. by varying grazing or plant cutting management on grassland or moorland, or creating new habitats on farms.
>
> 6. Take an adaptive approach to land and conservation management e.g. by changing objectives and management measures in response to new information.

[7] http://www.snh.gov.uk/docs/A1218771.pdf

7. Plan for habitat change where assessments indicate losses of habitats or species are inevitable, for example as a result of sea-level rise.

8. Consider translocation of species in circumstances where assessments indicate the likely loss of a species despite new management measures, and where there are suitable areas for nature to adapt.

Although the four highlighted principles may cover actions that help conserve Earth Science features, there may be other actions – not covered by this list – that need to be considered.

4c. Next Steps

We do not propose that our analyses or results represent a final answer as to which Notifiable Features are most at risk from climate change; they should not be taken as the sole basis for prioritising climate change adaptation action. This analysis represents only one part of a process aimed at identifying "at risk" features and then targeting adaptation action.

The next step for this project is to discuss the results of these analyses with experts to assess:

1. Whether – despite the acknowledged caveats associated with various sets of data – the overall pattern of results seem sensible.

2. If the results do seem sensible, what climate change adaptation actions might be applied.

The answer to this second question will involve "drilling down" through the data for individual features to assess the reasons for a high risk score. This in itself can help to give an indication as to whether any action is needed, and what type of action might be appropriate. For example, if a feature is ranked as high risk because of its SCM score, i.e. because it is considered to be in poor condition, the exact reason for this SCM score can then be explored and assessed with respect to whether it really represents a risk from climate change.

At the same time as discussing our results in more detail with experts, we are undertaking a parallel piece of work aiming to convert the analytical process into a Bayesian network analysis. The aim of this work is:

1. To make it easier to incorporate a measure of uncertainty with respect to final risk scores. This in turn could impact on the adaptation action chosen: for example if a Feature obtained a high risk score, but with very low certainty, detailed monitoring might be more appropriate than more interventionist management.

2. To make it possible to incorporate new datasets as they become available.

There is always a risk that action is postponed whilst analyses are continually refined. We are now at the stage in this project where we need to move from analysis to action, accepting the fact that at the same time we try to improve our analytical approach.

Acknowledgements

We would like to thank Brian Eardley for his help in accessing (and understanding) the Site Condition Monitoring data.

Appendix 1

Biodiversity Feature Sensitivity Assessment Process

The sensitivity assessment for Biodiversity Features was based around the compilation of expert knowledge on habitat and/or species sensitivity. This was data was gathered through a questionnaire process, followed by moderation of the questionnaire scores.

The questionnaire process

There are 4713 Biodiversity Features but only 366 unique Biodiversity Feature types. To produce the questionnaire, the habitat and species Feature types (excluding assemblages) were subdivided into groups based on broad habitats or species groupings, e.g. farmland habitats, coastal and marine habitats, birds, and amphibians and reptiles. Experts for each of these habitat types or species groups were then asked to provide data on both the sensitivity of the feature to climate change and their certainty with respect to that assessment.

This approach is summarised in the introduction to the questionnaire:

> Thank you for agreeing to take part in this survey. This survey is part of a larger project being undertaken through ClimateXChange, for Scottish Natural Heritage, which is trying to develop an assessment of the threat posed by climate change to Notifiable Features of protected areas in Scotland.
>
> In order to do this we need to assess the relative sensitivity of different types of Feature to climate change. Getting predictive modelling data for the wide range of species and habitats that are included in the list of Notifiable Features is not possible. To plug this gap we want to find out which of the species and habitats experts believe to be most sensitive to climate change.
>
> In this survey we would like you to score species and habitats depending on how sensitive you think they are to the projected impacts of climate change. In Scotland these include warmer, wetter winters, with increasing rainfall particularly on the west coast, and hotter drier summers, particularly in the east. They also include increases in sea level. More information on projected climate change impacts in Scotland can be found at http://ukclimateprojections.defra.gov.uk/21721
>
> We want you to consider the **sensitivity** of each species or habitat to climate change in Scotland. We realise that exposure to climate change and threats from other factors such as habitat fragmentation or management vary from place-to-place. However, these **local factors are accounted for elsewhere** in our assessment process, and we would like you to concentrate here on the climate change sensitivity of each habitat and feature. This sensitivity includes sensitivity to the direct effects of changes in climate (changes in temperature and precipitation), and to indirect effects such as sea level rise and loss of habitat.
>
> In this survey, as some of you will realise, **we have not included assemblages**. In some cases assemblages are composed of species with quite different ecologies. This makes it even harder to assess the climate change sensitivity of the assemblage overall. However, on the basis that each assemblage contains multiple species, the probability that an assemblage will respond in some way to projected climate change is likely to be high. We will therefore give all assemblage features a "high" sensitivity score in our analyses: we think this is both realistic and a sensible conservative approach.
>
> For those of you that have been asked to complete this survey as a **habitat expert**, it is worth noting that the names of the habitats are taken directly from the Site Condition Monitoring database. They do not therefore link up directly with other habitat classification schemes such as NVC. In addition, in some tables you may find two features with different names but which in practice might refer to the same habitat. Please don't worry about this, and try to score each feature separately (irrespective of whether you've already assigned a score to a habitat feature that you believe to be very similar). We need you to do this in order to be able to link your scores directly to the features in our assessment tables.

Scorers were then asked to provide scores for the habitat or species group for which they were an expert:

> Please assign a score to these habitats by placing an "X" in the appropriate box. Please provide one score for each Feature.
>
> Scores range from 1 (low or no sensitivity to climate change) to 5 (highly sensitive to climate change). When assigning these scores it does not matter whether you think the impacts of climate change on the habitat will be "good" or "bad", simply the extent to which you think this habitat in Scotland will respond to climate change.
>
> We would also like to you to give an assessment of your confidence in this score (L = Low, M = Medium, H = High). Following the approach adopted for the climate change impacts report cards (http://www.lwec.org.uk/resources/report-cards/biodiversity), confidence can be considered to increase "where there are multiple, consistent, independent lines of high-quality evidence."
>
> If a Feature is outside of the group that you have been asked to score, please mark NA (not applicable).

Scoring tables were produced for each species or habitat group, for example the following scoring table for amphibians and reptiles:

Amphibians and reptiles	Low				High	Confidence			
Species	1	2	3	4	5	L	M	H	NA
Great crested newt (Triturus cristatus)									
Natterjack toad (Epidalea calamita)									

In the first instance the features were scored by SNH habitat or species experts. These experts then recommended additional scorers.

Where possible we attempted to get at least 3 scores per feature type. However, despite considerable effort this was not possible in some cases, in particular:

1. Birds – the "birds" group contained 121 feature types, which may have deterred some scorers from engaging in the process. However, a joint RSPB-BTO team provided scores for many of the bird species based on a wide-ranging risk assessment analysis the utilised CEMs and the methodology of Thomas *et al.* 2011[8]. However, even with this contribution there were still a number of "bird" features that received only 1 score, specifically:

   Black-tailed godwit (Limosa limosa), non-breeding

   Chough (Pyrrhocorax pyrrhocorax), non-breeding

   Common gull (Larus canus), non-breeding

   Fair Isle wren (Troglodytes troglodytes fridariensis), breeding

   Greenland Barnacle goose (Branta leucopsis), non-breeding

   Greenland white-fronted goose (Anser albifrons flavirostris), non-breeding

   Hen harrier (Circus cyaneus), non-breeding

   Ringed plover (Charadrius hiaticula), passage

   Sandwich tern (Sterna sandvicensis), passage

   Seabird assemblage, breeding

[8] Thomas, C.D., Hill, J.K., Anderson, B.J. *et al.* (2010) A framework for assessing threats and benefits to species responding to climate change. *Methods in Ecology and Evolution* **2**: 125–142.

Seabird colony, breeding

Svalbard Barnacle goose (Branta leucopsis), non-breeding

Taiga bean goose (Anser fabalis fabalis), non-breeding

Turnstone (Arenaria interpres), passage

Waterfowl assemblage, non-breeding

2. Lower plants, mosses and lichens – None of our expert scorers felt confident to provide scores for 2 of the species within this group:

Egg wrack (Ascophyllum nodosum ecad mackaii)

Foxtail stonewort (Lamprothamnium papulosum)

In all of these cases we took the decision to set the sensitivity score to 5 (i.e. high) and the confidence score to 1 (low). This was considered a conservative approach.

Once sensitivity and confidence scores had been acquired, mean values for these scores for each Biodiversity Feature type were calculated, and linked to data from the moderating procedure to provide final sensitivity scores, as outlined below.

As well as providing scores, some respondents to the questionnaires provided comments or raised queries or concerns about the procedure. Notably no one group of scorers all raised similar concerns, and some scorers provided data without any associated comments (although this does not necessarily indicate that they had either no concerns or queries).

Finally, assemblages were excluded from the questionnaire-based scoring process. It would be an extremely complex process to provide scores for these on the basis of scoring each of the multiple species that compose an assemblage at a given site. As a conservative approach to handling assemblages they were all assigned a high risk score (i.e. 5) and high confidence associated with this risk, on the basis that it is very likely that at least one of the species that comprises an assemblage would respond in some way to climate change.

Moderation procedure

Scorers for some species or habitat groups may provide higher sensitivity values than scorers of other groups simply on the basis that they are more aware of the risk to that group from climate change – perhaps because a larger body of research has been done on that group. To account for this possibility we asked moderators to score a semi-random selection of features covering all species groups.

In all, 5 moderators provided scores. Moderators were chosen on the basis of their having a wide knowledge of Scottish biodiversity including both habitats and species, giving them the ability to score a wide range of feature types. Each moderator provided scores for 2 features from each of the habitat or species groups. If a group contained enough features, each moderator was allocated 2 different features to score; if there were less than 10 features in a group, then feature type allocations overlapped between some moderators.

When all moderators had provided scores, the average sensitivity and confidence scores for each habitat or species group were calculated. These were then used to moderate the sensitivity scores provided by habitat or species group experts.

Compilation of expert and moderator scores to provide final biodiversity sensitivity scores

The availability of the moderator scores, and the confidence scores provided by the habitat and species experts, enabled a number of different sensitivity metrics to be calculated. Four main metrics were calculated during development of the final risk assessment procedure:

1. Average sensitivity score.

2. Average sensitivity score weighted by average confidence score = av. sensitivity score x av. confidence score.

3. Average sensitivity score weighted by moderator score = av. sensitivity x moderator score for that habitat or species group.

4. Average sensitivity score weighted by average confidence score and moderator score = av. sensitivity x av. confidence score x moderator score for that habitat or species group.

After discussions within the project team we decided to use option 4 for production of the results presented in this report, and in the accompanying Excel file *Simplified results_bio features.xlsx*[9].

The final scores for each Biodiversity Feature type were assigned to the full list of Biodiversity Features (using MS Access), and these data were then incorporated into the results sheet.

[9] Please note that this is in contrast to the results shown in the Phase 2 report, which uses option 3. The choice to use option 4 for *this* document was made after completion of the Phase 2 report.

Appendix 2

Site condition monitoring data

We used the SCM[10] "Reporting Condition to Scottish Government" data provided by SNH to assign a "risk" score using the following methodology (adapted from the ADAS 2011 approach).

Unfavourable, declining = high risk, H, 2

Unfavourable, no change = high-medium risk, H-M, 1.5

Unfavourable, un-classified = high risk, H, 2

Unfavourable, recovering = medium risk, M, 1

Favourable, maintained = Low risk, L, 0

Favourable, un-classified = Low risk, L, 0

The numerical values were then used in the calculation of the adaptive capacity score.

The ADAS 2011 approach did not assign a score to "Favourable, declining" or "Favourable, recovered" features. Here we have allocated risk scores of Medium risk, M, 1, and Low risk, L, 0, respectively.

Note that some features are marked as "not assessed" – these were not given a score.

[10] http://www.snh.gov.uk/protecting-scotlands-nature/protected-areas/site-condition-monitoring/

Appendix 3

Connectivity indices

Overview

We produced a simple analysis of fragmentation risk for biodiversity (habitats and species) features in Scotland based on the spatial configuration of the protected area network.

Methods

Literally hundreds of measures have been proposed to quantify different aspects of fragmentation/connectivity (McGarigal & Marks 1995; Riitters *et al.* 1995; Gustafson 1998; Hargis *et al.* 1998; Calabrese & Fagan 2004). Generally a distinction is made between structural and functional measures (Kindlmann & Burel 2008): structural measures simply look at the spatial arrangement of patches whereas functional measures make a link to behaviour of organism, e.g. dispersal capacity. In this preliminary analysis we used simple structural measures that capture patch area and shape and patch isolation. We selected these indices as they make minimal assumptions about the organism or the landscape, they have an intuitive ecological interpretation, and they are as simple as possible from mathematical point of view.

The study area comprised Scotland plus a 10 km buffer zone to avoid edge effects. In order to derive the fragmentation metrics we assigned all features to habitat types, calculated the fragmentation measures separately for each habitat and then assigned these values back to the features. Initially we calculated 16 indices. Because many of the indices were correlated (all data available on request) we undertook a Principle Components Analysis (with scaling to unit variance) to identify the main uncorrelated components of all the different indices. This yielded three main components that combined explained 83% of the variation in the values of the 16 indices: the first component was representative of distances between patches, the second of the total area covered by the patches and patch shape (notably edges density), and the third component of the degree of division of the landscape (e.g. how many patches there are). To keep the analyses as simple and intuitive as possible we therefore selected only four indices for the final structural fragmentation risk assessment: total area, edge density, median nearest neighbour patch distance and landscape division, and assigned levels of risk according to the scale given in Table 1. Maps for all habitats are available if needed.

	High risk	Medium risk	Low risk
Area	<100 km^2	100-1000 km^2	>1000 km^2
Edge density	>1	0.75-1	<0.75
Nearest neighbour patch distance	Poor disp.: >5km High disp.: >50 km	Poor disp.: <5km High disp.: 20-50 km	Poor disp.: 0 km High disp.: <20 km
Landscape division	>0.75	0.25-0.75	<0.25

Table 1. *Assignment of risk scores to the different aspects of fragmentation. For nearest neighbour patch distances, we first categorised the features as not/poorly dispersed (e.g. beetles) and highly dispersed (e.g. birds), and then assigned risk levels differently to these.*

The final fragmentation risk score was the sum of the four individual scores, whereby high risk = 2, medium risk =1 and low risk = 0. In total we calculated fragmentation scores for 38 habitat types (excluding rivers as all freshwater habitat types) and assigned values to 162 features types.

All calculations were performed in R x64 2.15.0 using the libraries adehabitat, gdistance, gpclib, maptools, raster, SDMtools and vegan.

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Appendix 4

<u>"Andrew's" climate data</u>

Climate data has been provided for 11 regional climate model (RCM) members with varying climate sensitivity. Climate sensitivity differs from site sensitivity, in that it measures the sensitivity of a given model to a doubling of atmospheric carbon dioxide. In this case the model sensitivities range from 2.6 to 7.1, as shown in the table below.

Index	RCM Run	Sensitivity of driving model (K)
0	*Afixa*	2.6
1	Afixc	2.8
2	Afixh	3.4
3	Afgcx	3.5
4	Afixj	3.9
5	Afixi	4.4
6	Afixk	4.4
7	Afixm	4.5
8	Afixo	4.8
9	Afixl	4.9
10	Afixq	7.1

Climate projection data were provided for all sites for both 2050 and 2080 model run end points and were combined in a number of ways during their use in the Phase 1 and 2 analyses.

After discussions within the project team we decided to use the 2050 ensemble average for production of the results presented in this report, and in the accompanying Excel file *Simplified results_bio features.xlsx.*

Climate data are also used in the analysis of Earth Science Features. Again, only the average values for the 2050 data for the entire ensemble have been used.

Importantly, the normalisation procedure was slightly modified. Rather than using the maximum and minimum values from within a given data set, it used the maximum and minimum values from across the entire ensemble. This is to ensure that differences between members are not lost in post-processing, which would happen if the values from each separate data set were used to undertake normalising.

Appendix 5

Analyses and Results Files – Biodiversity Features

Data Analysis

In brief, the analytical procedure operates as follows:

1. All data is converted to give a numeric value such that greater negative effects have larger positive values.
2. Any categorical data is given a numeric ranking, e.g. Low impact (L) = 0, Medium impact (M) = 1, High impact (H) = 2.
3. Data are normalised such that they all fall between 0 (original minimum value) and 1 (original maximum value).
4. Single values for adaptive capacity and exposure scores are calculated as the arithmetic mean (average) of the log(n+1) values of the parameters within each category.
5. Sensitivity scores are imported following the calculations described in Appendix 1.
6. A vulnerability score is calculated as the arithmetic mean (average) of the sensitivity and adaptive capacity scores.
7. A final risk score is calculated as the arithmetic mean (average) of the vulnerability and exposure scores. We use an unweighted arithmetic mean approach. This is based on the results of preliminary analyses during Phase 1 that compared an unweighted mean approach to approaches that weighted the mean based on both the number of parameters used to calculate each score, and on expert opinion.
8. For ease of comparison, final risk scores are back-converted using antilog (final values)-1 to give scorings prior to ranking. Without undertaking this back calculation we would be trying to compare log values of the risk scores. By converting them back using the antilog we revert them to an average normalised value between 0 and 1, which is more intuitive to interpret (0 = lowest risk, 1 = greatest risk).
9. Rankings are applied to the final risk scores. Lower ranking numbers equate to higher calculated risk.

In terms of data transformations (i.e. calculations applied to the data before it is included in the analysis) relevant to particular data types:

- For the connectivity data, a summed risk score value was used as the basis for producing a normalised ranking - this is based on 4 separate connectivity indices (see Appendix 3).
- For the site size data, we first calculated the normalised value and then used (1- normalised value) to give a risk score: this was done because bigger sites are considered to have lower risk in terms of adaptive capacity (i.e. they have higher adaptive capacity).

The climate change projection data are projected change values between two time periods (current and future: see Appendix 4). Because change might be positive or negative, but we assume that a big change is bad, all climate change projection data were converted to absolute values prior to normalising.

Results sheet: *Simplified results_bio features.xlsx*

This file contains 8 separate sheets:

Metadata – A basic description of the content of the other sheets.

Sensitivity – Biodiversity Feature sensitivity data, i.e. the results of the separate sensitivity analysis as detailed in Appendix 1.

Adaptive capacity – Site Condition Monitoring, Connectivity and Site Size data, as well as the calculations used to provide a final Adaptive Capacity score for each Feature.

Exposure - Birse Climate Data and "Andrew's" Climate Data, as well as the calculations used to provide a final Exposure score for each Feature.

Calculations – The calculations used to combine the sensitivity, adaptive capacity and exposure scores in order to give a Vulnerability and final Risk score.

Results – Calculations used to summarise and analyse the data from the risk assessment, as described in more detail below.

Rankings – Rankings for features from the risk assessment, as described in more detail below.

Look-up sheet - Tables enabling searches for results for particular notifiable features using the feature ID number.

Following the calculations through the results file

Key sheets for understanding the calculations are the *Sensitivity*, *Adaptive capacity*, *Exposure*, and *Calculations* sheets. Within each of the first three sheets are the calculations that normalise the raw data and convert it to a log10(n+1) score, and then combine these data to give the sub-scores for each of the data types. These are then brought together in the *Calculations* sheet, where the final risk scores are calculated.

Results and Rankings sheets

Key sheets for looking at the results are the *Results* and *Rankings* sheets. Data from the Calculations sheet is used to automatically populate the *Results* sheet, where the final risk scores are then back converted to give a normalised ranking, and then converted into H (2), M (1) or L (0) categorical scorings.

In the *Results* sheet it is possible to alter the thresholds for the H, M and L categories using the purple cells AB4 to AC6. For example:

	Lower limit (>)	Upper limit (<=	**Check**
H (2)	0.75	1	**0.25**
M (1)	0.5	0.75	**0.25**
L (0)	0	0.5	**0.5**
			1

The sum of figures in the check column needs to equal 1. If it doesn't the bottom right cell of this table is highlighted in red.

The *Rankings* data enables features to be sorted according to their ranking based upon any of the score types (low ranking values = high risk features; high ranking values = low risk features). It also allows the sorting of features according to coarse feature categories, and through this filter the exclusion of assemblages. In addition this sheet contains the source data (normalised) from which the final risk scores were calculated.

Both the *Results* and *Rankings* sheets have data filters that enable sorting by a range of different variables. In all other sheets, feature data are ordered according to feature i.d. code as taken from the SCM database.

Appendix 6

Analyses and Results Files – Earth Science Features

Introduction

The 'risk' scores developed for Earth science features are a combination of 'sensitivity' and 'adaptive capacity' scores. These are then used to calculate an overall risk score for each feature. Both the 'sensitivity' and the 'adaptive capacity' elements are largely based on expert opinion; this is because other data as used in the Biodiversity Features analysis (e.g. site size and site condition) are irrelevant to an assessment of sensitivity or adaptive capacity for Earth Science Features.

For the purposes of the risk scoring exercise, Earth Science Features were divided into 'geo feature type' sub-divisions. Each Geological Conservation Review (GCR) site has a number of characterisations specified within the 'Earth Science Sites Database' (A57434). Five particular characterisations (water dependency classification - WDC, Earth Science Sites Classification - ESCC, Site Condition Monitoring Reporting Category - SCMRP, Site Condition Monitoring Feature Name- SCMFN, and Coastal type) can be used to divide all GCR sites (and hence all SSSI geo features) into a number of 'feature types' such that features within each 'geo feature type' are likely to respond to and be impacted by climate change in similar ways.

Following preliminary analyses and discussions, some site types, were further split into a number of sub-categories. The final list of site types as used in this analysis is given below.

a1) SCMFN = 'Coastal Geomorphology of Scotland' or 'Coastal Geomorphology of Scotland (saltmarsh morphology)', Coastal type = 8. Sandspits and tombolos, 9 Machair, or 10 Saltmarsh (sensitive active coastal features)

a2) SCMFN = 'Coastal Geomorphology of Scotland', Coastal type = 6. Gravel and 'shingle' beaches, or 7. Sandy beaches and coastal dunes (moderate active coastal features)

a3) SCMFN = 'Coastal Geomorphology of Scotland', Coastal type = 3. Hard rock, or 11 Coastal assemblages (robust active coastal features)

b) WDC = 1, SCMPC = 'Geomorphology', SCMFN ≠ 'Coastal Geomorphology of Scotland' or 'Karst' (active rivers and cave features)

c) WDC = 1, SCMRP = 'Quaternary Geology and Geomorphology' (lake pollen record features)

d) WDC = 2, SCMRC = 'Quaternary Geology and Geomorphology' (peat bog pollen record features)

e) WDC = 9, ESCC = IA (freeze-thaw formed features)

f1) WDC = 3, SCMRP = 'Palaeontology' or 'Mineralogy', ESCC = EC or FM,EC (coastal-only water-exposed fossil and mineral features)

f2) WDC = 3, SCMRP = 'Palaeontology' or 'Mineralogy', ESCC = EW or FM,EW (river-only water-exposed fossil and mineral features)

f3) WDC = 3, SCMRP = 'Palaeontology' or 'Mineralogy', ESCC includes EC but ≠ EC or FM,EC (fossil and mineral features partly coastal-water-exposed and partly non-water-exposed)

f4) WDC = 3, SCMRP = 'Palaeontology' or 'Mineralogy', ESCC includes EW but ≠ EW or FM,EW (fossil and mineral features partly river-water-exposed and partly non-water-exposed)

g1) WDC = 3, SCMRP ≠ 'Palaeontology' or 'Mineralogy', ESCC = FM,EC (finite area, coastal-only non-fossil, non-mineral water-exposed features)

g2) WDC = 3, SCMRP ≠ 'Palaeontology' or 'Mineralogy', ESCC = EC or EC,EW (extensive, coastal-only and mostly coastal with some river non-fossil, non-mineral water-exposed features)

g3) WDC = 3, SCMRP ≠ 'Palaeontology' or 'Mineralogy', ESCC = FM,EW (finite area, river-only non-fossil, non-mineral water-exposed features)

g4) WDC = 3, SCMRP ≠ 'Palaeontology' or 'Mineralogy', ESCC = EW or EW,EC (extensive, river-only and mostly river with some coastal non-fossil, non-mineral water-exposed features) g5) WDC = 3, SCMRP ≠ 'Palaeontology' or 'Mineralogy', ESCC ≠ FM,EC or EC or EC,EW, or FM,EW or EW or EW,EC (non-fossil, non-mineral features partly water-exposed and partly non-water-exposed)

h1) WDC = 9, SCMRP = 'Palaeontology' or 'Mineralogy' (non-water dependent fossil and mineral features)

h2) WDC = 9, SCMRP ≠ 'Palaeontology' or 'Mineralogy', ESCC ≠ IA (non-water dependent features excepting fossil, mineral and freeze-thaw features)

i) SCMPN = 'Karst' (karst feature)

Note that the original 'h)' type sites were not sub-divided with respect to flood risk: comparing a number of example sites to flood risk areas on SEPAs flood risk maps showed no overlap, and this was thought likely to be the case for the majority if not all these sites. Instead small 'h)' type sites particularly vulnerable to vegetation changes were sub-divided using a proxy of 'SCMRP = 'Palaeontology' or 'Mineralogy'', as SCM shows that these are in general the sites most vulnerable to vegetation change.

Risk Scoring Method

The risk scores are assessed for different feature types with respect to five likely effects of climate change (five 'scenarios').

1) Coastal processes: rising sea level, increased storminess and coastal erosion
2) Rivers: increased flooding and erosion
3) Decrease in freeze-thaw processes due to warmer winters
4) Changes in rainfall patterns
5) Changes in vegetation cover

Each scenario was scored with respect to two components of climate change impacts:

A) Likelihood of this change affecting the feature of interest

B) Likely severity of detrimental impact if feature is affected

Scores were given for each scenario 1-5 for each site type with separate scores given for each of the two components A) and B).

Initial scores were based on a simple four level scoring system: No Risk, Low Risk, Medium Risk and High Risk. Scores for the two components (A and B) were then combined to give an aggregated risk score for each climate change 'scenario'. The risk scale for the aggregated risk score was sub-divided into six levels: No Risk, Low Risk, Low-Medium Risk, Medium Risk, Medium-High Risk and High Risk. The procedure for combining the two component scores to give the aggregated score is shown in the table below.

Aggregated Risk category	**NO RISK**	**LOW**	**MEDIUM-LOW**	**MEDIUM**	**MEDIUM-HIGH**	**HIGH**
Component score combinations aggregations	No	Low/Low	Low/Medium	Medium/Medium Low/High	Medium/High	High/High

The 6 aggregated risk categories for and how scores for the two components are combined such that they result in these aggregated scores.

The highest aggregated risk score calculated for any of the 5 climate change scenarios was then taken as the overall risk score for that geo feature type. This means that the risk score given is the highest likely risk from the climate change scenarios considered.

The following tables detail the classification of the site types with respect to each of the five 'scenarios'. Notes detailing the rationale behind the assigned classifications are also provided.

1) Coast: rising sea level, increased storminess and coastal erosion

Likelihood of this change effecting feature

None	Low	Medium	High
i) c) d) g3) g4)	b) e) f2) f4) h1) h2)	g5)	a1) a2) a3) f1) f3) g1) g2)

Likely severity of detrimental impact if feature effected

Low	Medium	High
a3) f4) g2) g5) h1) h2)	a2) b) f2) f3)	a1) e) f1) g1)

Combined risk score

None	Low/Low	Low/Medium	Medium/Medium Low/High	Medium/High	High/High
NO RISK	**LOW**	**MEDIUM-LOW**	**MEDIUM**	**MEDIUM-HIGH**	**HIGH**
c) d) i) g3) g4)	f4) h1) h2)	b) f2) g5)	a3) e) f3) g2)	a2) f3)	a1) f1) g1)

a) Active coastal features are clearly likely to be impacted by changes in sea-level, storminess and coastal erosion ('high' likelihood). In some cases impacts on the feature may be severe (e.g. entire soft sediment features could be eroded away); however in less sensitive sites types, changes may be relatively small or may not be detrimental to the interest feature, hence a lower impact score is assigned.

f) & g) Water-exposed features will be affected by sea-level rise etc. if they are coastally located. Features near low spring tide mark will be lost if sea-levels rise. As fossil and mineral sites are all 'finite' sites where loss of an area, even a very small area in many cases, is likely to be highly damaging to the feature, the chances of this having a big impact are high (so 'high' impact assigned). This is also the case for 'finite' non-fossil/mineral sites.

h) There is a possibility (low likelihood) that non-water dependent features i.e. those above current high tide level may be affected by coastal changes; however, if they are affected the impact on the feature is likely to be low as the affects will be reduced by distance from the sea. There may be some exceptions where risk is higher; but these would only be able to be determined on a site-by-site basis.

2) Rivers: increased flooding and erosion

Likelihood of this change effecting feature

None	Low	Medium	High
e) i)	a1) a2) a3) f1) f3) g1) g2) h1) h2)	c) d) f2) f4) g3) g4) g5)	b)

Likely severity of detrimental impact if feature effected

Low	Medium	High

a2) a3) c) d) f3) g2) g4) g5) h1) h2)	a1) b) f1) f2) f4) g1)	f2) g3)

Combined risk score

None	Low/Low	Low/Medium	Medium/Medium Low/High	Medium/High	High/High
NO RISK	**LOW**	**MEDIUM-LOW**	**MEDIUM**	**MEDIUM-HIGH**	**HIGH**
e) i)	a2) a3) f3) g2) h1) h2)	a1) c) d) f1) g1) g5)	f4) g4)	b) f2) f4) g3)	

b) Active river and cave features will be impacted by changes in river flow such as flooding and erosion hence a 'high' likelihood is assigned. Some changes will be detrimental to the features; however many will not be. Therefore a 'medium' impact score is assigned.

c) Changes in river flow, flooding and erosion may disturb lake pollen record features (medium 'likelihood'; but the impact is unlikely to be very great ('low' impact).

f) and g) Riverbank water-exposed features may be impacted by changes in flow and/or changes in river course or erosion, but many may not; therefore a 'medium' likelihood is assigned. Coastal water-exposed features are likely to be affected by changes in river flow etc in only a very few cases (e.g. near river mouths); so again it would be helpful to refine 'site-type' to distinguish between these coastal and non-coastal sites.

h) There is a possibility (low likelihood) that non-water dependent features i.e. those above current river levels may be affected by changes in river flow etc; however, if they are affected the impact on the feature is likely to be low as the affects will be reduced by distance from the river. There may be some exceptions where risk is higher; but these would only be able to be determined on a site-by-site basis.

3) Decrease in freeze-thaw processes due to warmer winters

Likelihood of this change effecting feature

None	Low	Medium	High
c) d) h1) h2)	a1) a2) a3) b) f1) f2) f3) f4) g1) g2) g3) g4) g5) i)		e)

Likely severity of detrimental impact if feature effected

Low	Medium	High
a1) a2) a3) b) f1) f2) f3) f4) g1) g2) g3) g4) g5) i)		e)

Combined risk score

None	Low/Low	Low/Medium	Medium/Medium Low/High	Medium/High	High/High
NO RISK	**LOW**	**MEDIUM – LOW**	**MEDIUM**	**MEDIUM-HIGH**	**HIGH**
c) d) h1) h2)	a1) a2) a3) b) f1) f2) f3) f4) g1) g2) g3) g4) g5) i)				e)

e) Active freeze-thaw features will clearly be affected by changes in freeze-thaw so a ‘high’ likelihood score is assigned. Current observations of the freeze-thaw feature in Tinto Hill SSSI suggests it is quite sensitive to changes in seasonal freeze-thaw patterns; so a ‘high’ impact score is also assigned.

4) Changes in rainfall patterns

Likelihood of this change effecting feature

None	Low	Medium	High
h1) h2)	a1) a2) a3) c) e) f1) f2) f3) f4) g1) g2) g3) g4) g5)	b)	d) i)

Likely severity of detrimental impact if feature effected

Low	Medium	High
a1) a2) a3) b) c) e) f1) f2) f3) f4) g1) g2) g3) g4) g5)	i)	d)

Combined risk score

None	Low/Low	Low/Medium	Medium/Medium Low/High	Medium/High	High/High
NO RISK	**LOW**	**MEDIUM-LOW**	**MEDIUM**	**MEDIUM-HIGH**	**HIGH**
h1) h2)	a1) a2) a3) c) e) f1) f2) f3) f4) g1) g2) g3) g4) g5)	b)		i)	d)

d) Peat bogs are very likely to be affected by changes in rainfall hence a ‘high’ likelihood is assigned to ‘Peat bog pollen’ features. Drying out of a peat bog could destroy the pollen record so a ‘high’ impact is also assigned.

i) The formation of karst features will be affected by changes in rainfall so a ‘high’ likelihood is assigned. These changes could have a damaging effect on the karst (e.g. increased dissolution rates) or may not; hence a ‘medium’ impact is assigned. This is a fairly precautionary score.

5) Changes in vegetation cover

Likelihood of this change effecting feature

None	Low	Medium	High
c)	a1) a2) a3) b) d) e) f1) f2) f3) f4) g1) g2) g3) g4) g5) h1) h2) i)		

Likely severity of detrimental impact if feature effected

Low	Medium	High
a1) a2) a3) b) d) e) f1) f2) f3) f4) g1) g2) g3) g4) g5) h2)	i) h1)	d)

Combined risk score

None	Low/Low	Low/Medium	Medium/Medium Low/High	Medium/High	High/High
NO RISK	**LOW**	**MEDIUM-LOW**	**MEDIUM**	**MEDIUM-HIGH**	**HIGH**
c)	a1) a2) a3) b) d) e) f1) f2) f3) f4) g1) g2) g3) g4) g5) h2)	h1) i)	d)		

d) Changes from peat bog to any other type of vegetation cover would impact peat bog features; but climate changes may not cause changes in peat bog vegetation so only a 'medium' likelihood is assigned. If change occurred it could destroy the pollen record; therefore a 'high' impact is assigned.

h) & i) Vegetation changes resulting from climate change may affect almost all types of Earth science feature, including non-water dependent features of all types, by changing the visibility of the feature. However the likelihood of this occurring is probably relatively low. The most vulnerable sites are likely to be fossil and mineral sites h1) which tend to be small and could easily be obscured, and karst sites i) where vegetation changes could alter the dissolution patterns thus affecting the feature.

Summary of Results

The following table summarises the results of these analyses. It is colour coded according to the highest calculated risk score for each Earth Science feature site-type

Site type	Description	Definition codes	Highest risk score Method 2 (factor giving this score)	Approx.no. of GCR sites*
a1)	Sensitive active coastal features	SCMFN = 'Coastal Geomorphology of Scotland' or 'Coastal Geomorphology of Scotland (saltmarsh morphology)', Coastal type = 8, 9 or 10	HIGH (1)	16
a2)	Moderate active coastal features	SCMFN = 'Coastal Geomorphology of Scotland', Coastal type = 6 or 7	MEDIUM-HIGH (1)	13
a3)	Robust active coastal features	SCMFN = 'Coastal Geomorphology of Scotland', Coastal type = 3 or 11	MEDIUM (1)	14
b)	Active rivers and cave features	WDC = 1, SCMPC = 'Geomorphology', SCMFN ≠ 'Coastal Geomorphology of Scotland' or 'Karst'	MEDIUM-HIGH (2)	28
c)	Lake pollen record features	WDC = 1, SCMRP = 'Quaternary Geology and Geomorphology'	MEDIUM-LOW (2)	19
d)	Peat bog pollen record features	WDC = 2, SCMRC = 'Quaternary Geology and Geomorphology'	HIGH (4)	14
e)	Freeze-thaw	WDC = 9, ESCC = IA	HIGH (3)	2

	formed features			
f1)	Coastal-only water-exposed fossil and mineral features	WDC = 3, SCMRP = 'Palaeontology' or 'Mineralogy', ESCC = EC or FM,EC	HIGH (1)	38
f2)	River-only water-exposed fossil and mineral features	WDC = 3, SCMRP = 'Palaeontology' or 'Mineralogy', ESCC = EW or FM,EW	MEDIUM-HIGH (2)	22
f3)	Fossil and mineral features partly coastal-water-exposed and partly non-water-exposed	WDC = 3, SCMRP = 'Palaeontology' or 'Mineralogy', ESCC includes EC but ≠ EC or FM,EC	MEDIUM-HIGH (1)	6
f4)	Fossil and mineral features partly river-water-exposed and partly non-water-exposed	WDC = 3, SCMRP = 'Palaeontology' or 'Mineralogy', ESCC includes EW but ≠ EW or FM,EW	MEDIUM (2)	11
g1)	Finite area, coastal-only non-fossil, non-mineral water-exposed features	WDC = 3, SCMRP ≠ 'Palaeontology' or 'Mineralogy', ESCC = FM,EC	HIGH (1)	3
g2)	Extensive, coastal-only (and mostly coastal with some river) non-fossil, non-mineral water-exposed features	WDC = 3, SCMRP ≠ 'Palaeontology' or 'Mineralogy', ESCC = EC or EC,EW	MEDIUM (1)	178
g3)	Finite area, river-only, non-fossil, non-mineral water-exposed features	WDC = 3, SCMRP ≠ 'Palaeontology' or 'Mineralogy', ESCC = FM,EW	MEDIUM-HIGH (2)	4
g4)	Extensive, river-only (and mostly river with some coastal), non-fossil, non-mineral water-exposed features	WDC = 3, SCMRP ≠ 'Palaeontology' or 'Mineralogy', ESCC = EW or EW,EC	MEDIUM (2)	57
g5)	Non-fossil, non-mineral features partly water-exposed and partly non-water-exposed	WDC = 3, SCMRP ≠ 'Palaeontology' or 'Mineralogy', ESCC ≠ FM,EC or EC or EC,EW, or FM,EW or EW or EW,EC	MEDIUM-LOW (1,2)	225

h1)	Non-water dependent fossil and mineral features	WDC = 9, SCMRP = 'Palaeontology' or 'Mineralogy'	MEDIUM-LOW (5)	70
h2)	Non-water dependent features excepting fossil, mineral and freeze-thaw features	WDC = 9, SCMRP ≠ 'Palaeontology' or 'Mineralogy', ESCC ≠ IA	LOW (1, 2, 5)	248
i)	Karst feature	SCMPN = 'Karst'	MEDIUM-HIGH (4)	1

* Note that this is a rough count of notified and unnotified GCR sites (NOT SSSI features) from the Earth Science Sites Database A57434, not removing double or old entries.

When looking across the 5 final risk categories we see the following distribution of site types: High 73 (7%), Medium-High 74 (8%), Medium 260 (27%), Medium-Low 314 (32%), Low 248 (26%)

There are still some 'site types' with large numbers of features, notably g2), g5) and h2).

- 'Extensive coastal sites' (g2) is a large group because we have a lot of coast and a lot of coastal sites. There is no obvious grouping within this that would be more or less at risk, so there is no reason to sub-divide this site type.
- 'Partly water-exposed, non-fossil, non-mineral sites' (g5) could be sub-divided into those with part-coastal and those with part-river water-exposure; but these two sub-groups would receive the same overall risk score ('coastal sites' from factor/scenario 1 and 'river sites' from factor/scenario 2), so there seems little point in sub-dividing at this stage.
- The features in the 'h2' site type, are all features considered to be at low risk, and there is no reason to sub-divide this site type unless a group of features is identified that may be at higher risk from climate change.

Addition of Exposure Data

The additional element that needs to be added to give a final risk score for ES Features is a measure of 'exposure'. However, for Earth Science Features 'exposure' data is treated as a 'rough' measure of the degree of climate change impact, and is used to rank sites only *within* the risk score category (e.g. high, medium, low etc) defined by the scoring system detailed above. This means that a site that is considered low risk in the scoring system will never become high risk just because it has a relatively large predicted change in climate compared to other features; similarly one considered high risk will never become low risk.

The combination of the exposure data with the results of the risk scoring system is undertaken in the sheet *Simplified results_bio features.xlsx*.

Results sheet: *Simplified results_ES features.xlsx*

This file contains 5 separate sheets:

Metadata – A basic description of the content of the other sheets.

ES Feature scores – Includes the scores for the assessment undertaken for ES Features, as detailed above

Exposure - Birse Climate Data and "Andrew's" Climate Data, as well as the calculations used to provide a final Exposure score for each Feature.

Results – Combination of ES feature scores and Exposure scores to give a final risk ranking, as discussed in more detail below.

Look-up sheet - Table showing allocation of rankings and information on individual features.

Following the calculations through the results file

With only two underlying sets of data, it is much easier to follow the calculation of the final ES Features risk score through the results file *Simplified results_ES features.xlsx*. This calculation is undertaken in the *Results* sheet. First, features are sorted according to their ES Feature score, and then within these categories they are sorted according to their exposure score. An overall ranking is then applied.