LEFT: Local Ecological Footprint Tool v2

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October 6, 2016

Title	Isle of Skye
Description	The beautiful west coast of Scotland.
Date	10/06/2016 11:02:11
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Job ID	01579952D32A_3A0069FDE125355CD2DAD1C3

1 Introduction

The Local Ecological Footprinting Tool (LEFT) was developed to provide a simple-to-use tool for industries and landowners who have to make quick preliminary decisions about land-use change, and to assist in minimising the environmental impact of their operations.

The tool processes a series of high-quality open-access environmental datasets using standardised algorithms to produce maps at 30m resolution of land cover class, number of globally threatened terrestrial vertebrate and plant species, biodiversity of terrestrial vertebrates and plants, habitat intactness, wetland habitat connectivity, number of migratory species, and vegetation resilience. These results are aggregated in a single summary map showing the pattern of relative ecological value.

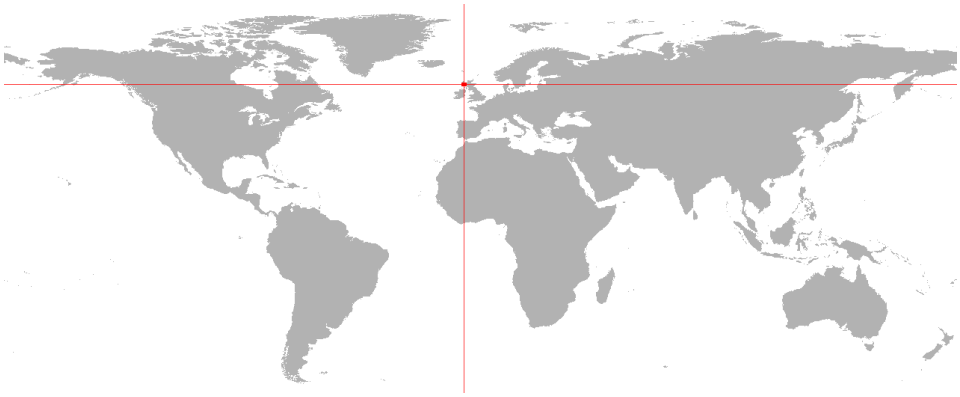
This report briefly describes the methods and datasets used to generate the maps for the specified area of interest. Further details on the modelling approach, datasets, and choice of ecological variables can be found in Willis et al., (2012; 2014; 2015) and Long et al., (2016 – in press)

Please note that this report was generated automatically. If you have any questions about LEFT or this output, please email support@left.zoo.ox.ac.uk.

Area of Interest

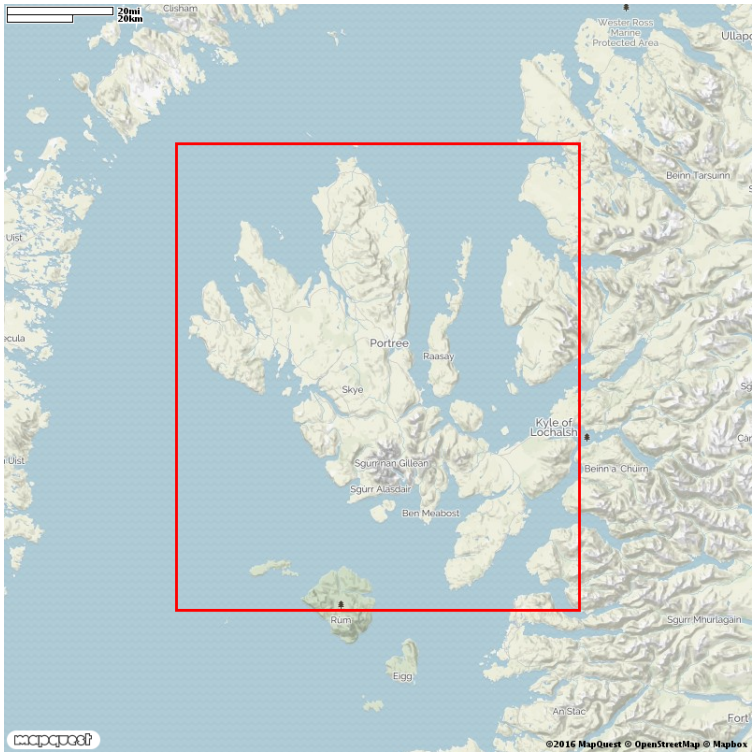
The specified area of interest for this analysis has the following bounding co-ordinates:

Latitude: 56.99°N to 57.73°N
Longitude: 6.82°W to 5.64°W



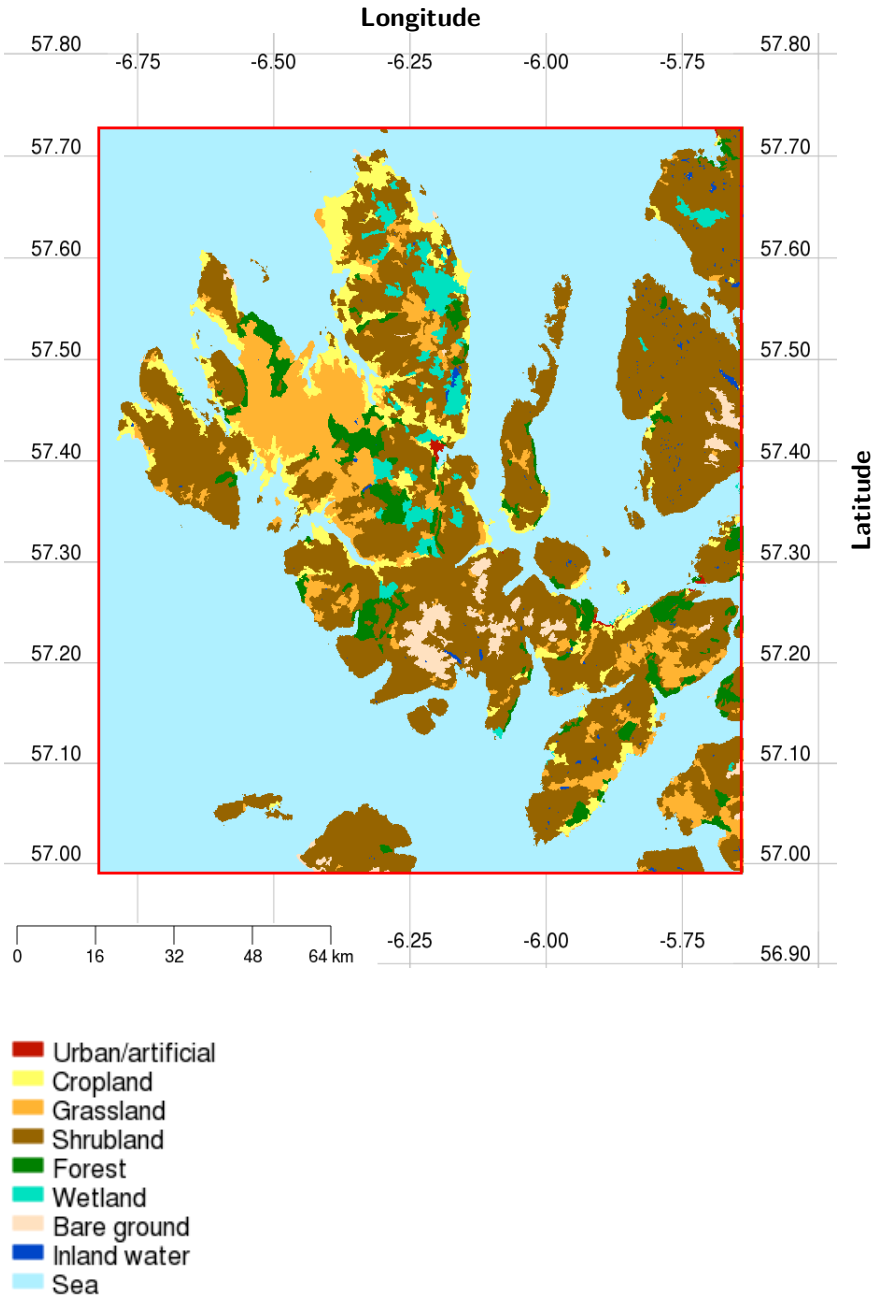
2 Street map

To provide context for the specified area of interest, a map showing features such as roads and the names of settlements was created from OpenStreetMap data.



3 Land cover

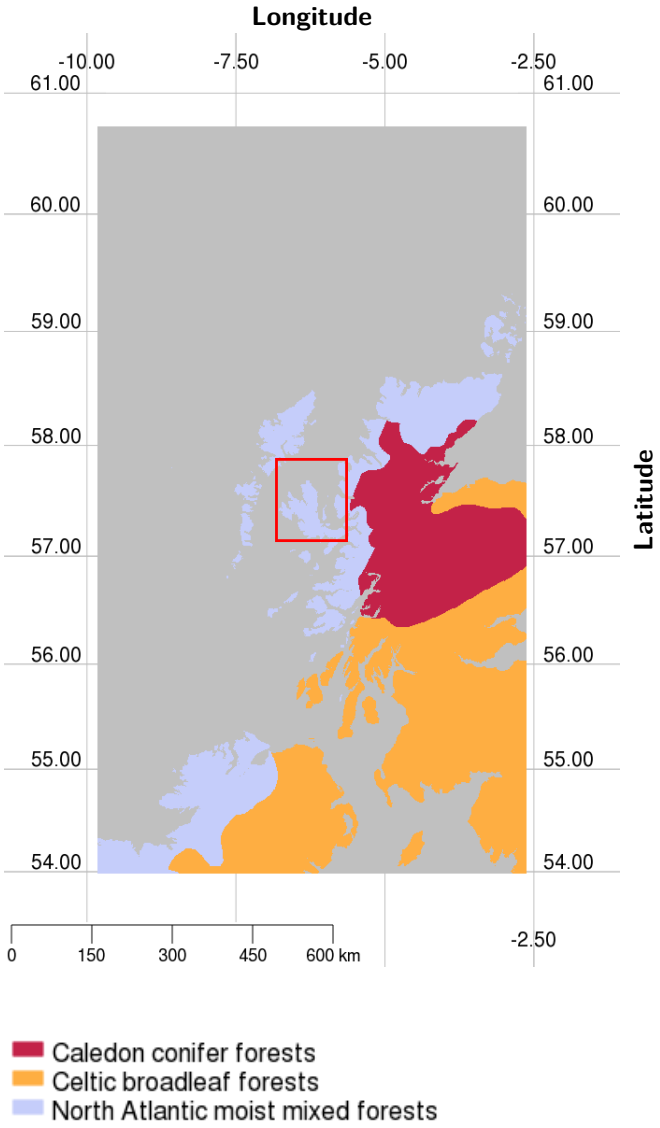
A map showing land cover in the year 2010 was derived from the GlobeLand30 data set (Copyright National Geomatics Center of China, DOI:10.11769/GlobeLand30.2010.db). Pixels were classified to land cover categories from multispectral Landsat and HJ-1 images, plus auxiliary data. In isolated areas without GlobeLand30 coverage, GlobCover 2009 land cover was used instead (Copyright ESA GlobCover Project, led by MEDIAS-France). OpenStreetMap land polygons were used to mask sea pixels.



Land cover map of the specified area of interest. Spatial resolution is 1 arcsec, or approximately 30 metres.

4 Ecoregions

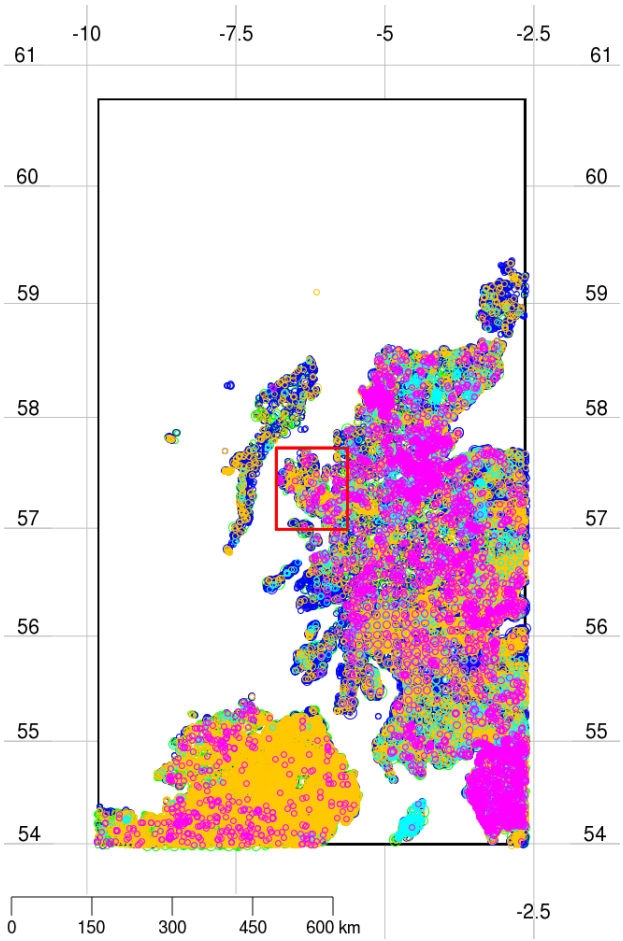
The WWF Terrestrial Ecoregion Classification (Olson et al. 2001) was used to identify the ecoregion(s) containing the specified area of interest. Relevant georeferenced biodiversity records were retrieved for this area from the Global Biodiversity Information Facility (GBIF, www.gbif.org). In addition, species occurrence data in the same ecoregions, up to a 3-degree buffer, were obtained to ensure a maximum number of records for modelling.



Terrestrial Ecoregions in the specified area of interest and in a surrounding 3-degree buffer.

5 Species occurrence data

The map below indicates the distribution of the georeferenced GBIF species occurrence records of amphibians, reptiles, birds, mammals, and plants for the specified area of interest plus a 3-degree buffer zone. Any duplicate records (of the same species recorded more than once in the same location) were removed. Text files containing these records are available in the output zip file (see Appendix 1: Output Files).

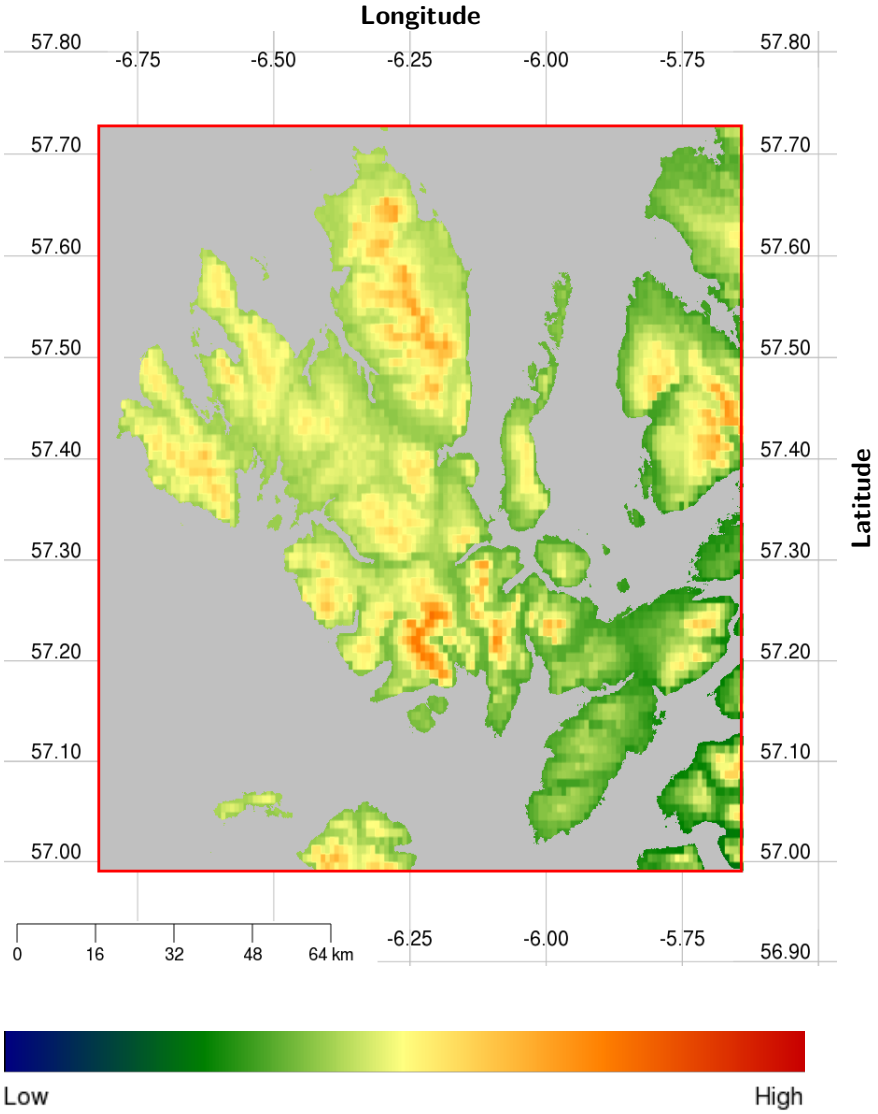


Taxon	Number of species	Number of Records	Colour
Amphibians	7	7140	
Reptiles	10	3583	
Mammals	74	36135	
Birds	279	34955	
Plants	2187	39181	
Total	2557	120994	

The table above indicates the number of species occurence records retrieved from GBIF for the specified area of interest plus buffer zone. Circles on the map are colour coded by taxonomic group (Amphibians – pink; Reptiles – light blue; Mammals – orange; Birds – dark blue; Plants – green).

6 Spatial pattern of biodiversity

The species records retrieved from GBIF (above) were combined with environmental covariates to express the pattern of biodiversity (beta-diversity, i.e. spatial turnover in species) across the area of interest. To do this, a Generalised Dissimilarity Model (GDM; Ferrier et al 2002) was run. The environmental covariates used in the model were annual mean temperature, annual mean precipitation, temperature seasonality, precipitation seasonality (Hijmans et al 2005), soil nitrogen, soil water holding capacity (Land and Water Development Division, FAO 2003), and land cover class (GlobCover 2009).



Beta-diversity in the specified area of interest. High values of beta-diversity (in red) represent greater spatial heterogenity in the set of species present compared to other parts of the area of interest. Low beta-diversity values (in blue) indicate a relatively homogeneous set of species.

7 Vulnerability

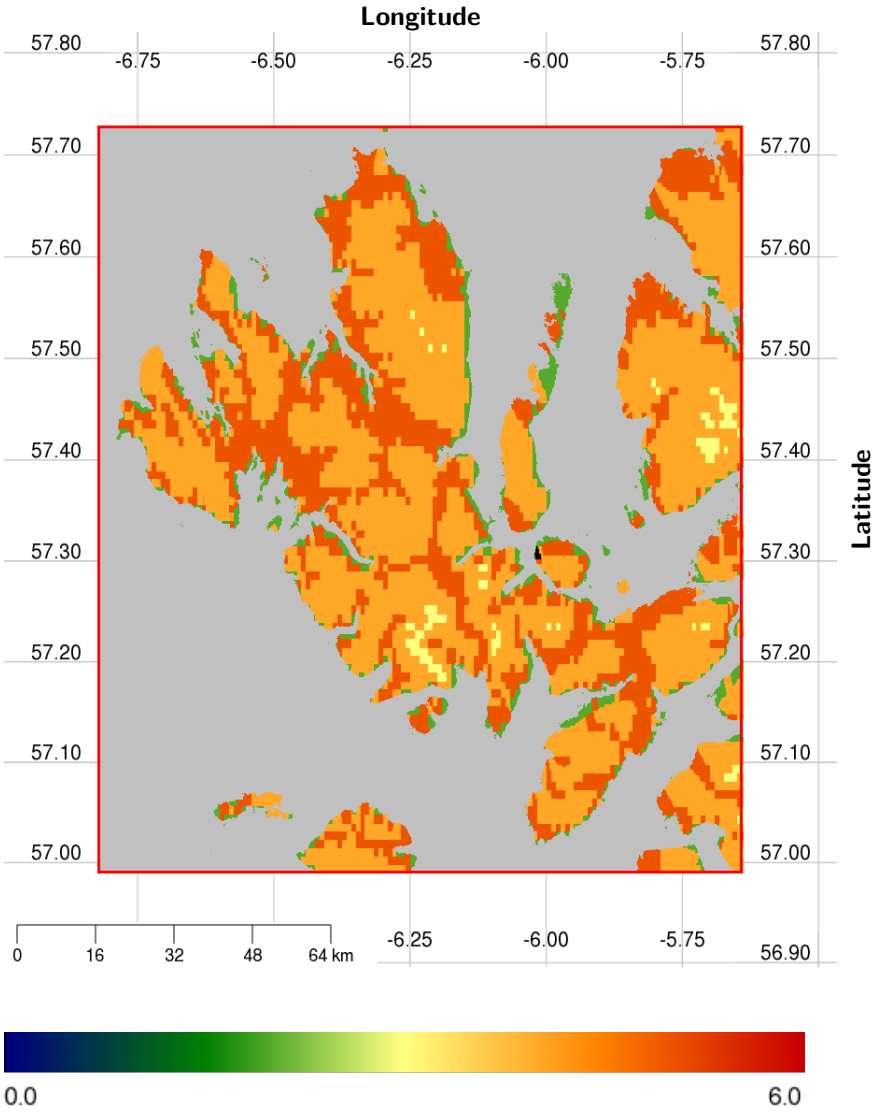
The IUCN Red List of Threatened Species (IUCN 2014) was queried to find the names of threatened species in the specified area of interest. All terrestrial amphibians, reptiles, birds, mammals, and plants determined by the IUCN to be either Critically endangered (CR), Endangered (EN), Vulnerable (VU), or Near Threatened (NT) were extracted. The Red List also identified the countries and sub-national administrative regions where each species is native (excluding areas where the species is vagrant or introduced).

The Global Administrative Areas database version 2.0 (www.gadm.org) was then used to create polygons comprising all the administrative regions in each species range defined by the IUCN. Each polygon represented the potential maximum extent of occurrence, within which a species distribution should be modelled. The same extent was used to sample background environmental variables for species distribution modelling.

For each threatened species, all unique geo-referenced records within the potential maximum extent were obtained from GBIF. A set of environmental covariates was then created for each location with a GBIF record. The covariates used were land cover from GlobCover 2009, mean annual temperature, temperature seasonality, total annual precipitation, and precipitation seasonality from Hijmans (2005), and elevation and slope from Farr (2007).

The potential distribution of each threatened species with more than 10 unique occurrence records was modelled using MaxEnt (Maximum Entropy Algorithm; Phillips et al., 2006). MaxEnt creates a climate-suitability model for each species, predicting where a species could potentially occur based on the habitat conditions where it is known to occur.

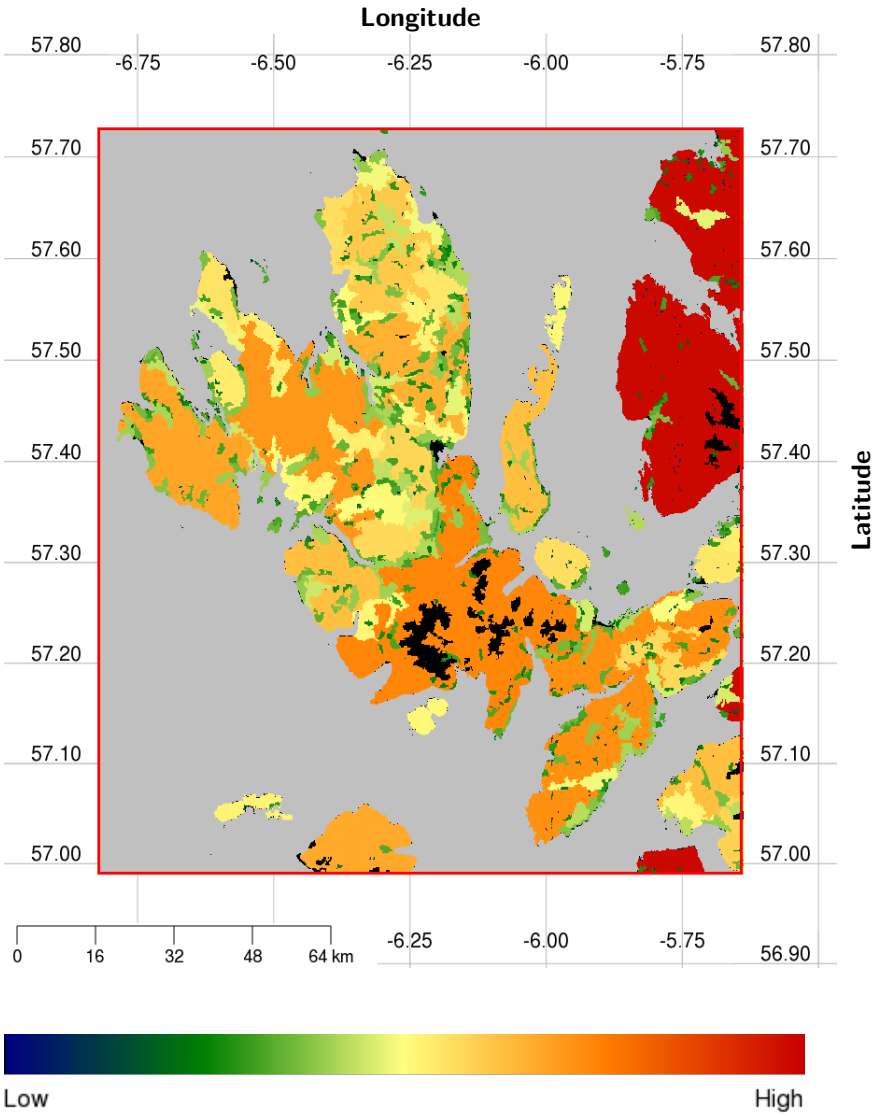
A list of the threatened vertebrate species included in modelling can be found in Appendix 2.



Vulnerability map showing the number of globally threatened (CR, EN, VU) and near-threatened (NT) terrestrial vertebrates and plants estimated to occur in the specified area of interest. Red indicates where the landscape contains the highest number of threatened species. See Appendix 2 for a list of species names.

8 Intactness

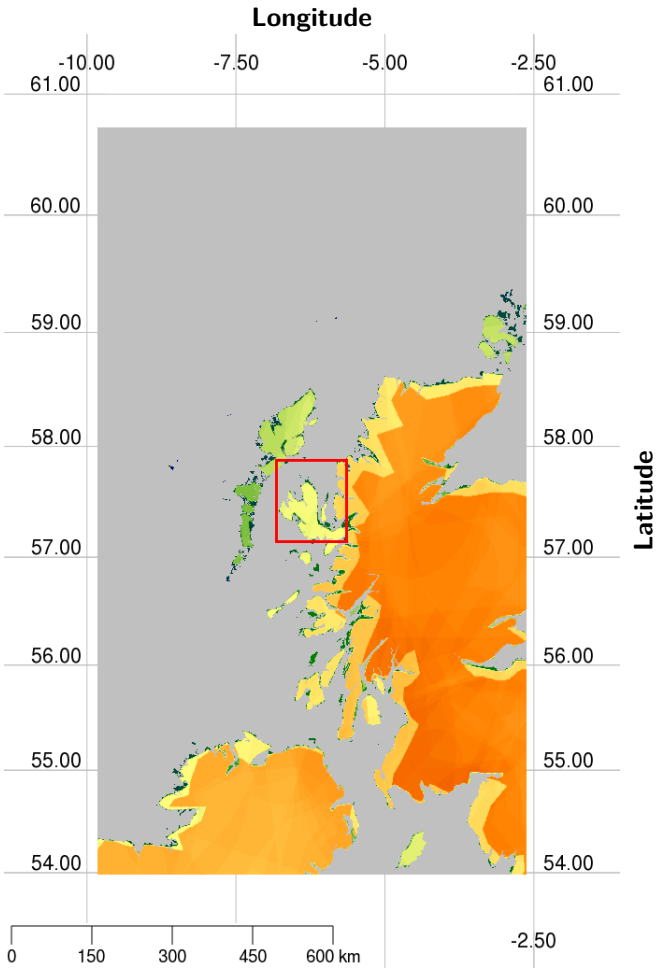
To identify patches of intact habitat in the specified area of interest, the land cover map described above was reclassified. Pixels in the urban/artificial, bare ground, and snow/ice categories were omitted from consideration. Every remaining pixel was assigned to a group of neighbouring pixels with the same land cover class, and the area of each group in hectares was calculated. In the resulting map those areas with a greater intact patch size are less fragmented, and carry a higher ecological value.



Intactness map. Values express the size of the land cover patch to which each pixel belongs (ln(patch area in ha) x 10). Urban, bare, and snow pixels were assigned an intactness value of 0. Resolution of the data is 1 arcsec, or about 30m.

9 Connectivity: Migratory species

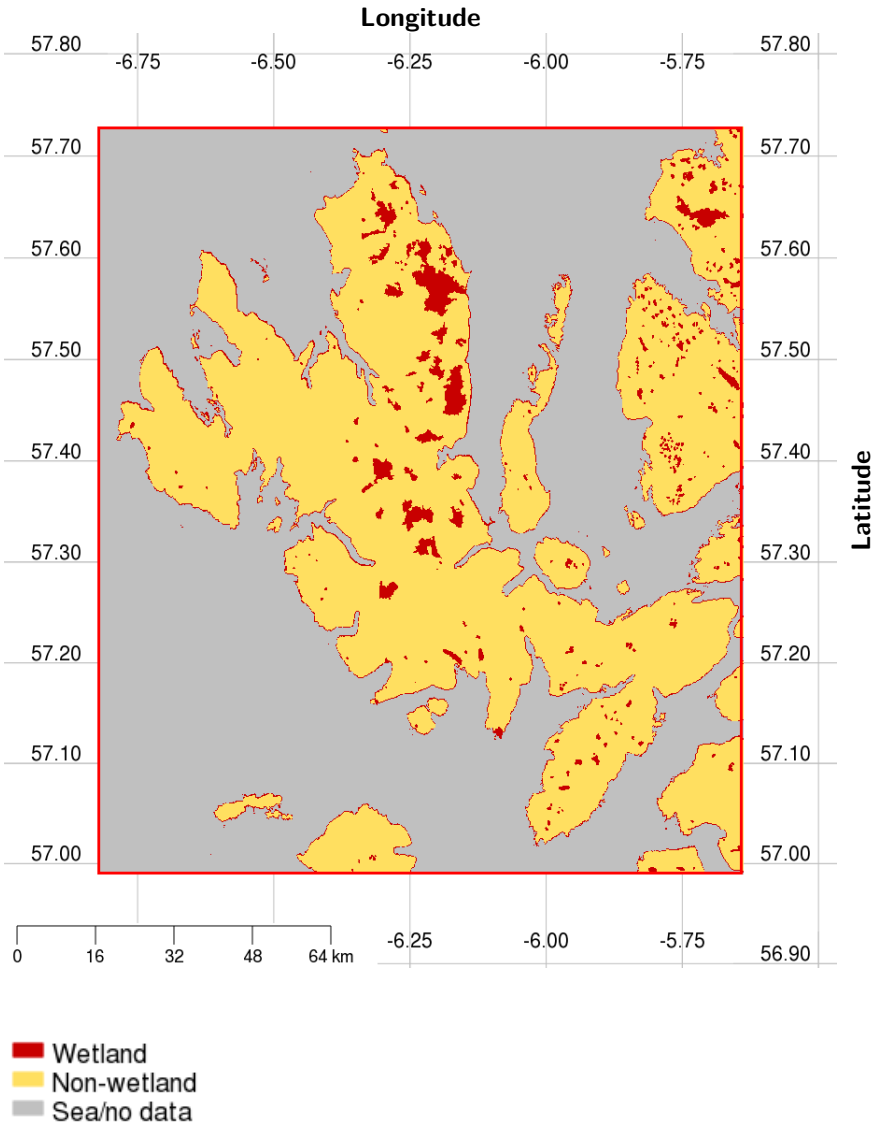
Habitat connectivity across a landscape is usually achieved through wetland corridors and/or other migratory routes. To remotely characterise important migratory routes, the Global Register of Migratory Species (GROMS; www.groms.de; Riede 2004) was queried. This database provided both a list of 4,430 migratory vertebrate species (terrestrial birds and mammals) and digital maps describing the migratory routes for >1,000 of those species. Grids for all species shown to have a migratory route across the area of interest were added together to yield an estimate of migratory species density.



Number of migration corridors overlapping the specified area of interest. A list of the migratory species potentially crossing this area can be found in Appendix 3.

10 Connectivity: Wetlands

A measure of wetland dispersal corridors across the specified area of interest was derived from the land cover map described previously. Pixels within 100 metres of water bodies were identified. Those buffer zones, along with pixels classed as Inland water or Wetland, were assigned a high ecological value of 1. All other land pixels were given a value of 0.



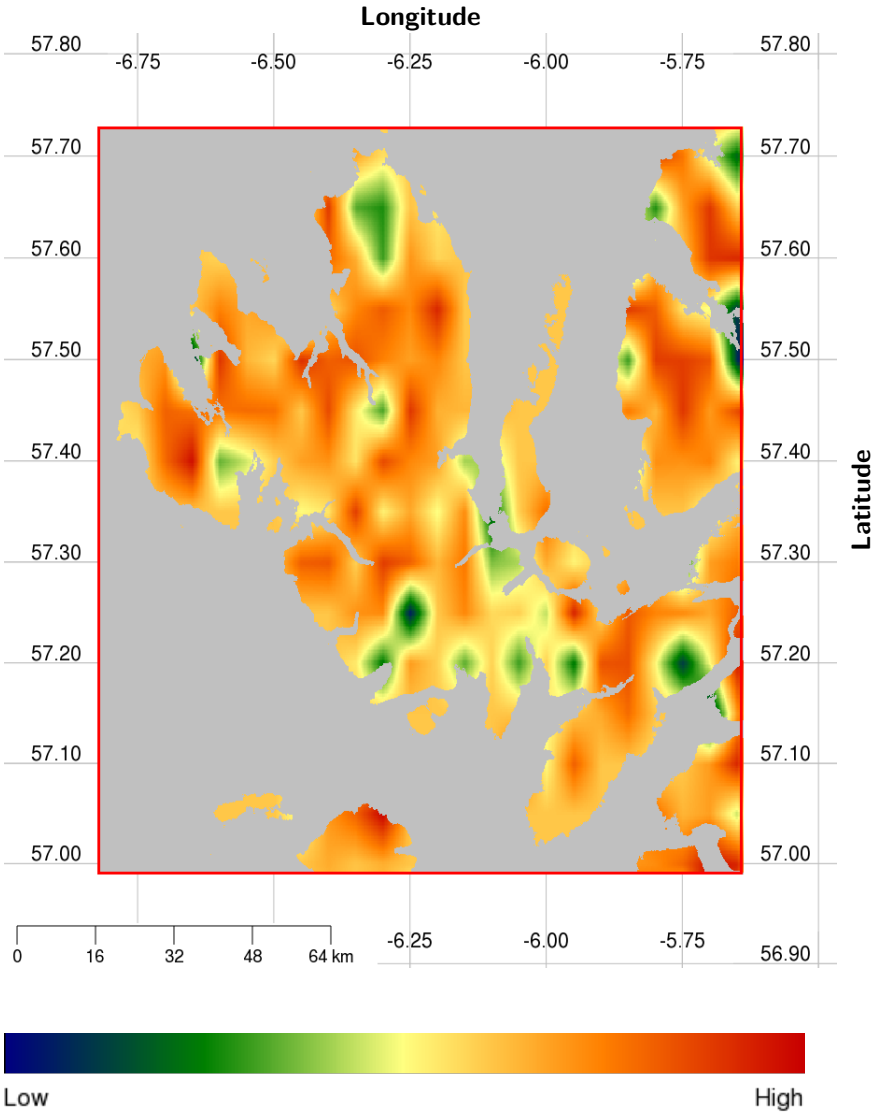
Wetland connectivity showing areas of open water, permanent wetland, or within 100m of water. The resolution of the data is 1 arcsec, approximately 30m.

11 Resilience

The resilience of vegetation to climate perturbations was estimated using monthly time series of Enhanced Vegetation Index (EVI) and three climate variables. A PCA regression was performed between EVI and air temperature, the ratio of actual to potential evapotranspiration, and cloud cover for the period 2000-2013. This identified the months when EVI is related to climate drivers and measured the strength of that relationship over 14 years.

Next the variability in EVI and in each climate variable was calculated. A measure of sensitivity to each climate variable was determined by dividing EVI variability by climate variability, thus measuring how much EVI varied per variation in climate (i.e. the nervousness of EVI to climate).

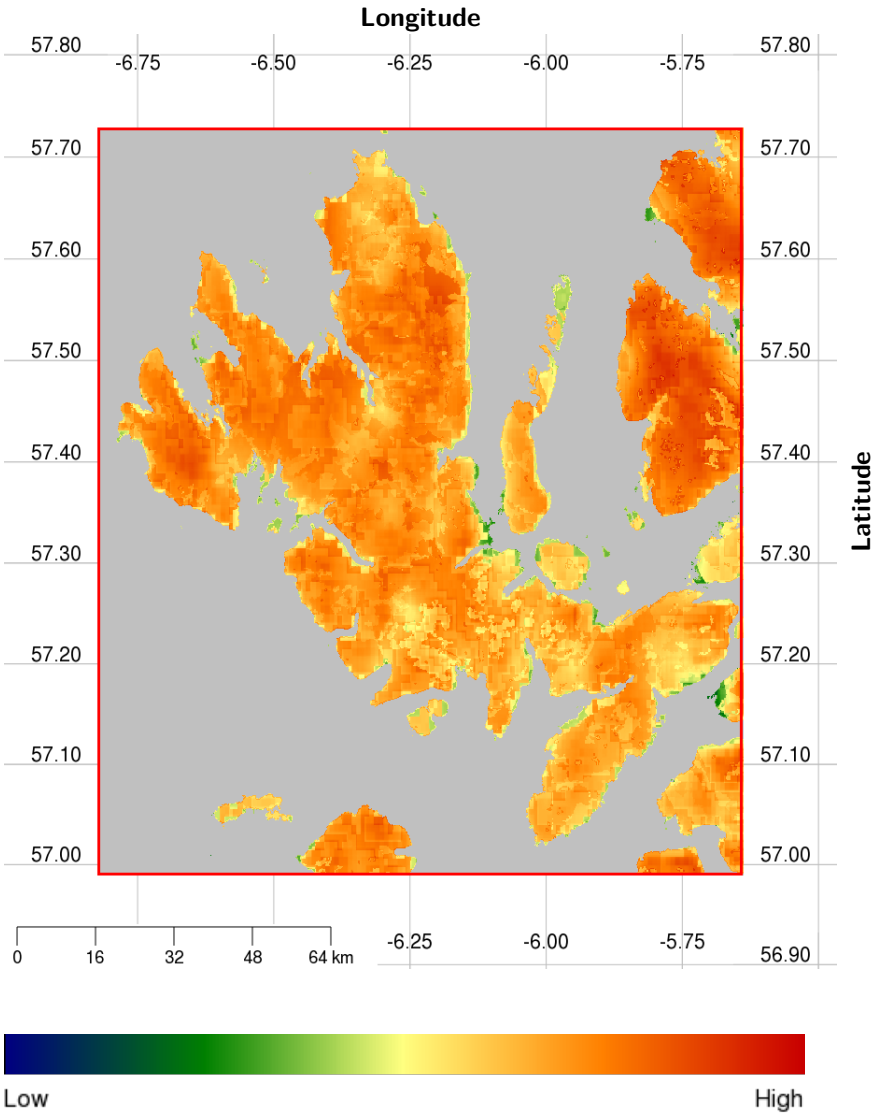
In the resultant resilience map, high values indicate areas where vegetation maintained greenness despite fluctuations in climate. Low resilience values reveal areas where photosynthetic activity changed when climate anomalies occurred.



Red indicates regions of greater vegetation resilience to climatic perturbations.

12 Summary Ecological Value

In addition to the preceding maps, a summary ecological valuation (SEV) was calculated for the specified area of interest. In this, each of the above layers was standardised into a map of Z-scores. Z-scores were then added together to show the landscape pattern of each layer on a scale comparable to all the other layers. For example, a pixel with the same value as the mean of its layer across the area of interest would have a Z-score of 0, while a pixel one standard deviation above the mean for that layer would have a Z-score of 1, and a pixel one standard deviation below the layer mean would have a Z-score of -1.



Summary ecological value of all LEFT layers in the area of interest. Areas with high SEV are relatively important across several measures of ecological value, while areas with low SEV are relatively less important. The resolution of the data is 1 arcsec, approximately 30m.

13 Data assurance information: Data Assurance Metric (DAM)

The output and validity of results will be significantly influenced by the availability or, conversely, the paucity, of data available in the databases for the selected region. The most critical data in this respect are the species occurrence records contained in GBIF. Due to sampling bias, GBIF coverage for some regions of the world is better than others (Gaiji et al., 2013). In order to provide a first estimate of the confidence that can be placed in the output from a region, a metric to assess the density of species occurrence records was devised. In this, the number of species records was obtained from GBIF for each taxonomic group (amphibians, reptiles, birds, mammals, plants) in the user-specified area of interest, as well as in a much larger reference area comprising the WWF ecoregions that intersect the area of interest. Species density was then calculated by dividing the number of different species in an area by the size of the area raised to an exponent of 0.2. Exponentiation is necessary in order to consistently control for the logarithmic form of species-area relationships and allow species densities from areas of different sizes to be directly comparable (Rosenweig 2012). The density of local species occurrence records for a taxonomic group can be compared to the density of records for the same group in the much larger reference area. This gives a first approximation of the degree to which the GBIF records available for a specified area of interest provide a good representation of the species expected in that area, based on wider biogeographical patterns and species-area relationships.

The table below shows species densities for the area of interest and the broader reference area, and the ratio of those densities. A representation score above 1.0 means that the number of species records retrieved was higher than expected, so the data are more reliable. Representation below 1.0 indicates poorer GBIF coverage and less reliable species data.

Taxon	Species density in area of interest	Species density in reference area	Representation
Amphibians	0.63	0.09	7.38
Reptiles	0.97	0.12	8.05
Birds	32.89	6.13	5.37
Mammals	6.32	0.83	7.62
Plants	335.09	30.13	11.12

14 Data assurance information: Compared to other regions (COAM)

To appreciate the importance of the ecological values obtained for the specified area of interest relative to other regions, a 'compared to other areas metric' (COAM) was calculated. This metric used the polygons of the WWF Terrestrial Ecoregion Classification (Olson et al, 2001) to identify zones ecologically similar to the area of interest. Zonal statistics were then used to assess the importance of each LEFT layer relative to the same measure over the entire ecoregion. For each layer, the difference in standard scores between the area of interest and the broader ecoregions is presented in the following chart. This shows whether a study area is relatively more or less ecologically valuable than other regions with similar biogeographic characterisitics.

List of ecoregions which intersect the region of interest:

North Atlantic moist mixed forests

Layer	Min	Max	Mean	SD	Ref. Mean	Ref. SD
Beta-diversity	0.55	0.60	0.57	0.01	0.74	0.09
Vulnerability	0.00	5.00	4.17	0.75	4.28	0.81
Intactness	0.00	137.00	87.26	31.55	64.00	75.00
Migratory	38.00	80.00	67.22	9.90	76.32	15.04
Wetland	0.00	1.00	0.09	0.29	0.10	0.30
Resilience	0.63	0.92	0.82	0.04	0.81	0.06

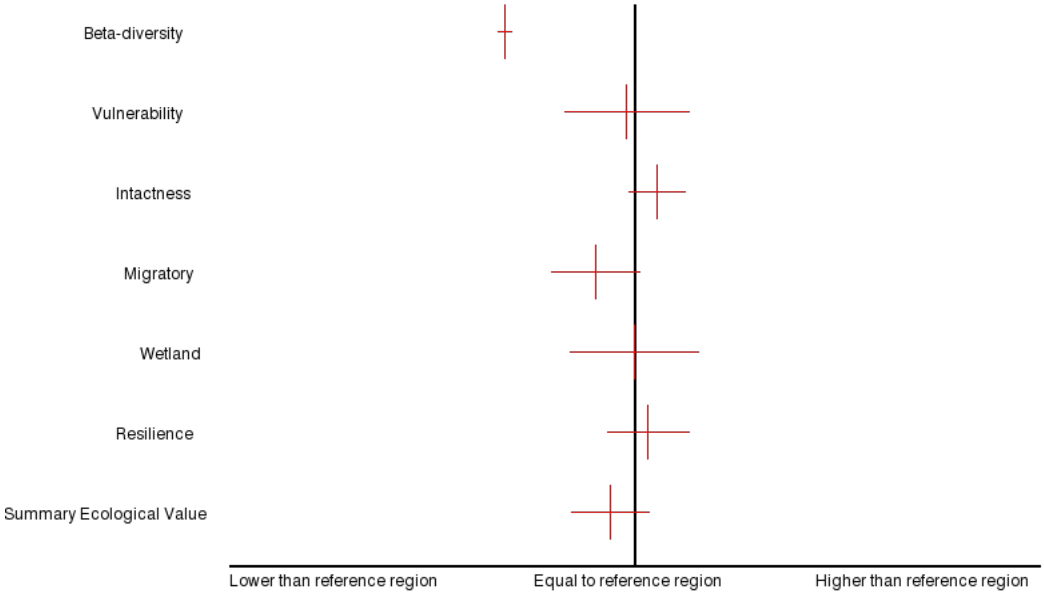


Table and chart indicating the importance of the area of interest relative to the reference region for each layer (standard scores +/- uncertainty in standard scores). If a layer has a positive standard score then the area of interest is more important than the reference region; a layer with a negative standard score is less important in the study area than in the reference region.

References

Ferrier S, Drielsma M et al. (2002) Extended statistical approaches to modelling spatial pattern in biodiversity in northeast New South Wales. II. Community-level modelling. Biodiversity and Conservation. 11: 2309-2338

Hijmans RJ, Cameron SE et al. (2005) Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology. 25: 1965-1978

IUCN (2014) Red list of threatened species, version 2014.1

Land and Water Development Division, FAO, Rome (2003) The digital soil map of the world.

National Geomatics Center of China (2014) 30-meter Global Land Cover Dataset (GlobeLand30). www.globallandcover.com, DOI:10.11769/GlobeLand30.2010.db

Olson DM, Dinerstein E et al. (2001) Terrestrial ecoregions of the world: a new map of life on earth. Bioscience 51: 933-938

Phillips SJ, Anderson RP et al. (2006) Maximum entropy modelling of species geographic distributions. Ecological Modelling 190: 231-259

Riede K (2004) Global register of migratory species: from global to regional scales. Final report of the R&D Project. Bonn, Federal Agency for Nature Conservation

Rosenzweig ML, Donoghue J, Li YM, Yuan C (2010) Estimating Species Density. In Magurran AE and McGill BJ (eds) Biological Diversity: Frontiers in Measurement and Assessment

Credits

The concept of LEFT was developed by Kathy Willis and Elizabeth Jeffers of the Zoology Department, University of Oxford and Randi Hagemann, Tone Karin Frost, Mathijs Smit, Christian Collin-Hansen, and Jurgen Weissenberger from Statoil ASA.

The algorithms in LEFT II were developed by Peter Long, David Benz, Marc Macias Fauria, and Alistair Seddon of the Zoology Department, University of Oxford. Spatial data processing for LEFT II was performed by Peter Long and David Benz.

Andrew Simpson, David Power, and Mark Slaymaker at the Department of Computer Science, University of Oxford developed the service-oriented interoperability framework (sif) middleware used to provide LEFT II as an automatic web-based tool. Richard Smith, of Tessella, and Philip Holland contributed to extending the functionality of the sif plugins in LEFT II.

The development of LEFT and LEFT II was funded by Statoil.

Appendix 1: Output Files

Clicking on the "ZIP" button for this analysis when logged in on the LEFT website will allow you to download a file named output.zip. This contains:

In the root,
A copy of this document: report.pdf

In the folder /data/
Folders for each LEFT layer containing a copy of the styled map for that layer presented in this report. The styled maps are in PNG format.

In the folder /data/biodiversity/output/result/
Text files for each taxonomic group containing all GBIF records retrieved during this analysis: aves.txt, amphibian.txt, mammalian.txt, reptilian.txt, and plantae.txt

Clicking on the "GeoTIFF ZIP" button for this analysis when logged in on the LEFT website will allow you to download a file named geotiffs.zip. This contains:

In the root,
Folders for each of the following LEFT layers: land cover class, beta-diversity, vulnerability, fragmentation, migratory species, wetlands, resilience, and summary ecological value

Each folder contains a single geoTIFF file. This is a copy of the image for that layer subset to the specified area of interest at full spatial resolution (1 arcsec, approximately 30m). Images are either 8-bit or 16-bit depth. Projection is latitutde/longitude on the WGS1984 datum. These geoTIFF files can be opened with standard desktop GIS software to perform further analyses.

Appendix 2: Vulnerable Species

The IUCN Redlist of Threatened Species (IUCN 2014) includes the following species of terrestrial mammals, birds, reptiles, and amphibians that have been modelled to be potentially present in the specified area of interest (NT = Near Threatened, VU = Vulnerable, EN = Endangered, CR = Critically Endangered):

Lutra lutra (mammal NT) (http://en.wikipedia.org/wiki/Lutra_lutra)
Numenius arquata (bird NT) (http://en.wikipedia.org/wiki/Numenius_arquata)
Puffinus griseus (bird NT) (http://en.wikipedia.org/wiki/Puffinus_griseus)
Puffinus mauretanicus (bird CR) (http://en.wikipedia.org/wiki/Puffinus_mauretanicus)

Appendix 3: Migratory Species

The following migratory species identified in the Global register of Migratory Species (GROMS; Riede et al 2004) have migration routes which intersect the specified area of interest:

Alca torda; Alcedo atthis; Alle alle; Anas acuta; Anas clypeata; Anas crecca; Anas penelope; Anas strepera; Anser albifrons; Anser brachyrhynchus; Ardea cinerea; Arenaria interpres; Asio flammeus; Asio otus; Aythya ferina; Aythya fuligula; Aythya marila; Branta canadensis; Branta leucopsis; Bucephala clangula; Buteo buteo; Calidris alba; Calidris alpina; Calidris canutus; Calidris maritima; Caprimulgus europaeus; Caretta caretta; Cepphus grylle; Charadrius hiaticula; Columba oenas; Columba palumbus; Crex crex; Cygnus cygnus; Cygnus olor; Dermochelys coriacea; Eudromias morinellus; Fratercula arctica; Fulica atra; Fulmarus glacialis; Gallinago gallinago; Gavia arctica; Gavia immer; Gavia stellata; Haliaeetus albicilla; Hirundo rustica; Histrionicus histrionicus; Hydrobates pelagicus; Jynx torquilla; Larus argentatus; Larus canus; Larus fuscus; Larus glaucoides; Larus hyperboreus; Larus marinus; Larus ridibundus; Lepidochelys kempii; Limosa lapponica; Melanitta nigra; Morus bassanus; Myotis mystacinus; Numenius arquata; Numenius phaeopus; Oceanodroma leucorhoa; Phalacrocorax carbo; Phylloscopus collybita; Phylloscopus trochilus; Plecotus auritus; Pluvialis apricaria; Pluvialis squatarola; Podiceps auritus; Podiceps nigricollis; Puffinus griseus; Puffinus puffinus; Puffinus yelkouan; Rallus aquaticus; Riparia riparia; Rissa tridactyla; Scolopax rusticola; Sterna hirundo; Sterna paradisaea; Streptopelia decaocto; Streptopelia turtur; Sturnus vulgaris; Tachybaptus ruficollis; Tadorna tadorna; Thalasseus sandvicensis; Tringa glareola; Tringa hypoleucos; Tringa nebularia; Tringa totanus; Uria aalge; Vanellus vanellus; larus minutus

Appendix 4: Data Sources

Georeferenced species records obtained from the GBIF occurrence API (http://www.gbif.org/occurrence) are shared according to the GBIF Data Use Agreement, which includes the provision that users of any data accessed through or retrieved via the GBIF Portal will always give credit to the original data publishers. The following table lists the data sources for all occurrence records which have been used in this analysis.

Antarctic Biodiversity Information Facility (ANTABIF)
Botanical Garden Meise
California Academy of Sciences
Cornell Lab of Ornithology
Council of Heads of Australasian Herbaria (CHAH)
European Molecular Biology Laboratory (EMBL)
Museum für Naturkunde Berlin
National Biodiversity Data Centre
National Herbarium of New South Wales
National Museum of Natural History, Smithsonian Institution
Natural History Museum
Natural History Museum, University of Oslo
Naturalis Biodiversity Center
Ocean Biogeographic Information System
Royal Botanic Garden Edinburgh
Royal Ontario Museum
South African National Biodiversity Institute
Tela Botanica
UK National Biodiversity Network
iNaturalist.org
naturgucker.de