

LEFT: Local Ecological Footprint Tool

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SUMMARY

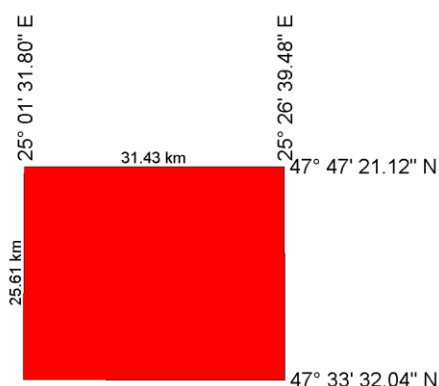
A LEFT analysis aims to systematically assess the ecological value of parcels of land across a landscape. The analysis is provided as a preliminary step in estimating the potential ecological impact, or footprint, of proposed development.

The analysis provides maps for the following derived measures of ecological value: 1) biodiversity, 2) vulnerability, 3) fragmentation, 4) connectivity, and 5) resilience. The final result of the analysis is a summary map of these measures where the values for each derived measure have been standardised across the study site to the interval [0, 1] and then summed. The summation provides an overall measure of relative ecological value across the study area. The summary ecological value map is the highlight result of the LEFT analysis and is shown in Figure 11. All analyses and output maps are produced at a resolution of 1/360 (0.0028) degrees, or approximately 300 m.

STUDY SITE

The study area for this LEFT analysis consists of an inner zone, 31.43 km east-west by 25.61 km north-south. This inner zone is nested within an outer zone which has a 300 km wide border that is added automatically during analysis. Figure 1a below shows the dimensions of the inner zone. Figure 1b shows the global location and the extent of the outer zone. Data sampled from the outer zone are used to inform the analysis about ecological patterns and processes within the inner zone.

(a)



(b)

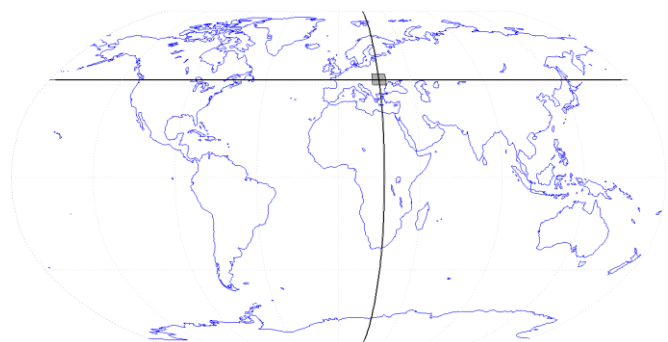


Figure 1. (a) Dimensions, and (b) location of the study site.

“STREET” MAP

To provide location and feature information a “street” map of the area is provided from OpenStreetMap.

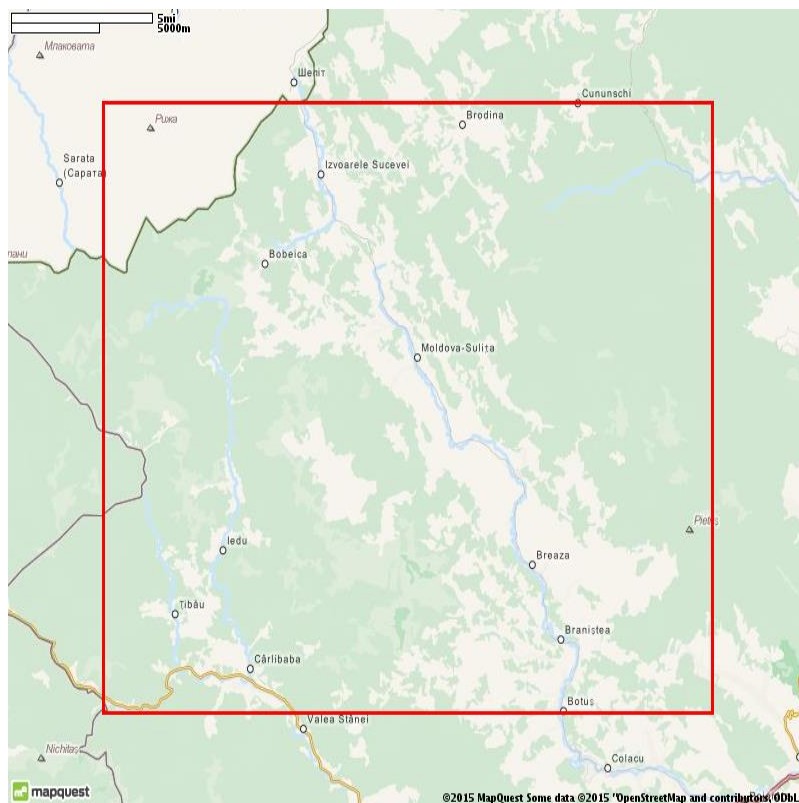


Figure 1c. “Street” map of the study site. (Copyright © [OpenStreetMap](#) contributors, [CC BY-SA](#)).

BASE MAP

A base map for the study site is derived from the GlobCover 2009 Global Land Cover Map (Copyright © ESA GlobCover Project, led by MEDIAS-France).

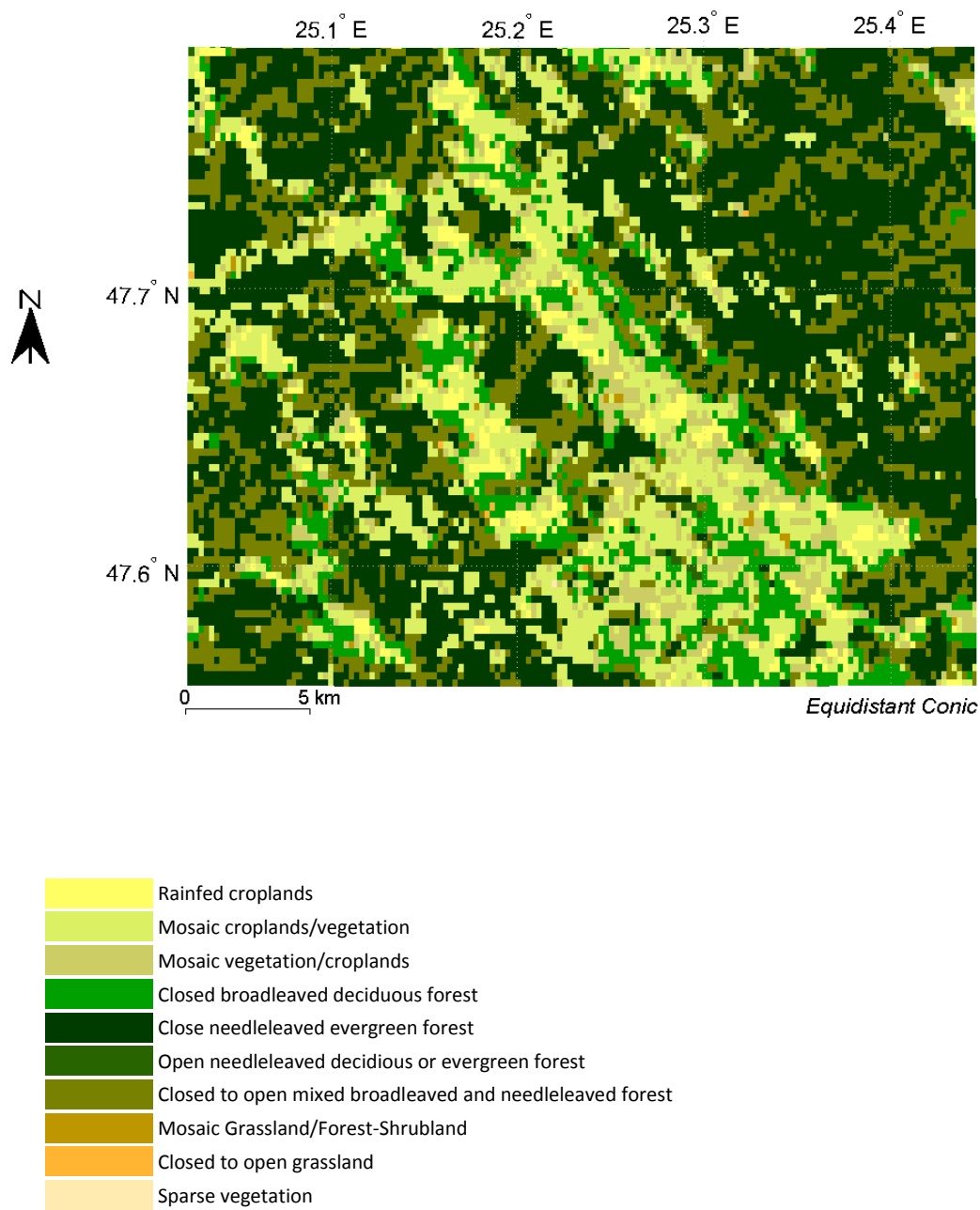


Figure 2. Land cover map of the inner zone of the study site. The resolution is 1/360 (0.0028) degrees, or approximately 300m.

1. BIODIVERSITY

Data on species occurrence are mined in real time from the Global Biodiversity Information Facility (GBIF) Data Portal (<http://data.gbif.org>) that provides online access to more than 300 million records of species occurrences worldwide.

The WWF Ecoregion classification (Olson, Dinerstein et al. 2001) is used to decide which of the available species occurrence records should be included in the analysis. Occurrence records are collected from the entire outer extent of the study site, but only those records found within ecoregions that also intersect with the inner zone are retained for further analysis.

Figure 3 shows the extent of ecoregions within the outer zone and highlights those intersecting with the inner zone. This allows a visual interpretation of the complexity of the greater region surrounding the study site.

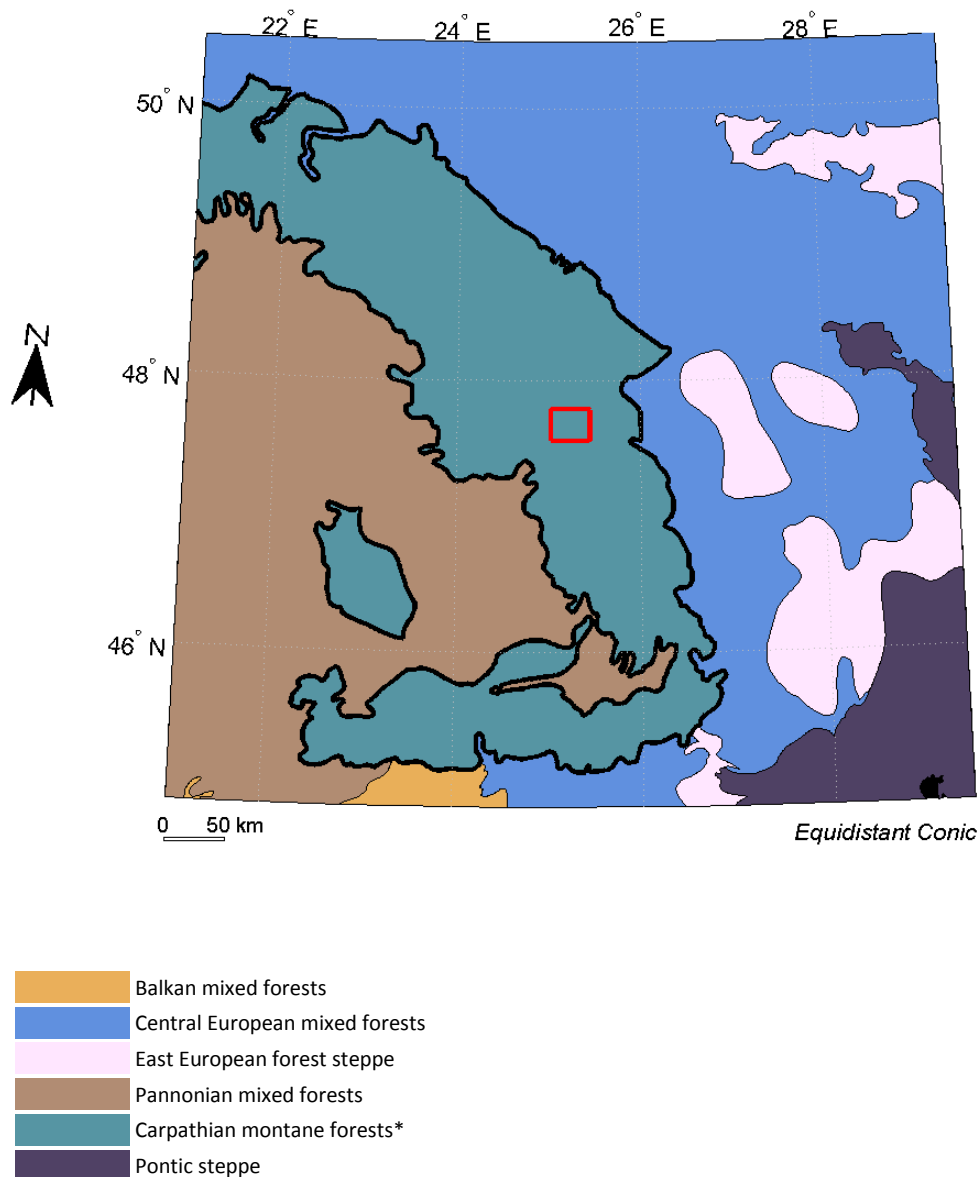


Figure 3. Ecoregion classification map showing the extent of ecoregions in the outer zone of the study site. Those ecoregions that also intersect with the inner zone (shown here as a red rectangle) are indicated in the legend with a star ().*

Of the total records retrieved, only terrestrial species that are identified to species level are retained and these are further divided into five groups (amphibians, reptiles, mammals, birds and plants) for analysis. Analysis is limited to those groups for which there are occurrence records for ten or more different species. Duplicate records (i.e. where the same species was recorded multiple times in the same location) are also removed.

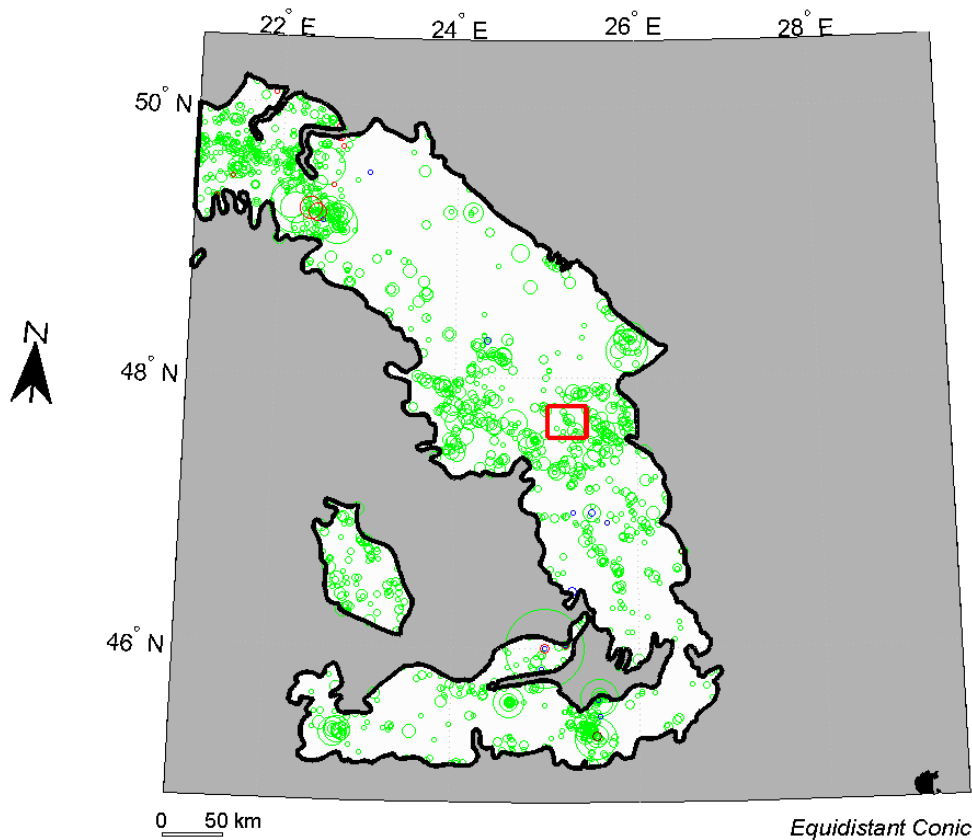


Figure 4. Map showing the potential area for species occurrence sampling (white). The unsampled area (grey) is made up of ecoregions that do not intersect with the inner zone of the study site (shown here as a red rectangle). Circle size represents the number of occurrence records co-located at each point.

Taxon	Number of species	Number of records	Colour
Amphibians	9	17	
Reptiles	5	6	
Mammals	30	48	
Birds	15	16	
Plants	1757	4486	
Totals	1816	4573	

These data are analysed using a generalized dissimilarity model (GDM, Ferrier, Drielsma et al. 2002) to determine the compositional turnover with respect to selected environmental variables (Figure 5). For plant species, the covariates include: annual mean temperature, annual mean precipitation, temperature and precipitation seasonality (from Worldclim, Hijmans, Cameron et al. 2005), % nitrogen in soil and soil water holding capacity (Land and Water Development Division, FAO, 2003). For amphibians, birds, mammals and reptiles, the covariates are: distance to water bodies (based on the Global Lakes and Wetlands Database (Lehner and Döll 2004) and Hydrosheds (Lehner, Verdin et al. 2008)), and the same climatic indicators as used for plant species. For each of the five groups, the GDM analysis predicts compositional dissimilarity between pairs of sites within the study area. Due to memory limitations related to the use of the GDM algorithm, the site-by-species matrix for each group is limited to 2,000 sites (i.e. if a group consists of more than 2,000 sites, it is randomly reduced to this maximum size). From an original GDM projection on 300 randomly selected pixels within the study site, a Delaunay triangulation (Nearest Neighbour) interpolation is implemented to calculate the compositional dissimilarity value for each 300 m pixel. Where multiple biological groups are analysed, the highest value of compositional dissimilarity for each pixel is retained. This process is iterated 10 times, and the median dissimilarity value among the 10 runs is taken. Due to this procedure, a

small degree of variability is possible when running this layer more than once.

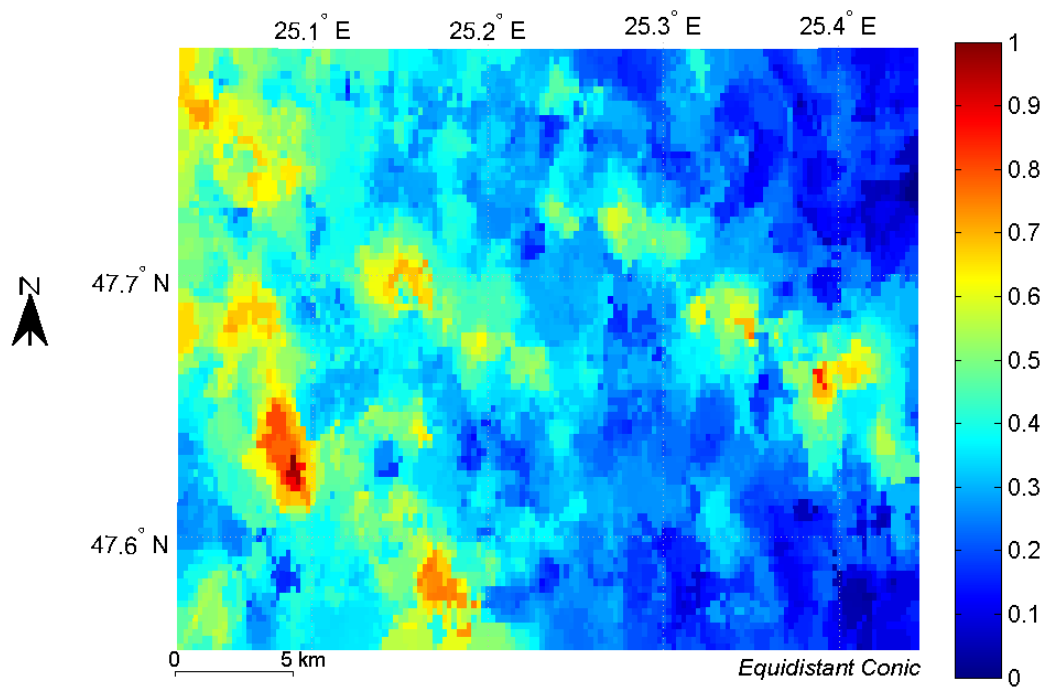


Figure 5. Beta diversity map based on the distance weighted averaged compositional dissimilarity between all pairs of sites.

2. VULNERABILITY

The map of vulnerable species distribution (Figure 6) is derived from the IUCN Red List of Threatened Species (IUCN 2012). The list was downloaded on 14 August 2012 (permalink <http://www.iucnredlist.org/search/link/502a1f85-b6ddd064>) and all terrestrial mammals, birds, reptiles, amphibians and plants in four threat categories: critically endangered (CR), endangered (EN), vulnerable (VU) and near threatened (NT) were extracted. For each species the list of countries making up the geographic range of the species was compiled from the individual species pages on the IUCN web site, excluding only countries in which the species is listed as vagrant or introduced. For each species a list of locality observations was obtained from GBIF and filtered by boundary polygons of the countries in the geographic range. Next, for each species we modelled the potential distribution using MaxEnt (Phillips, Anderson et al. 2006) and six environmental and geo-physical variables (bio1, bio4, bio12 and bio15 from Worldclim, Hijmans, Cameron et al. 2005; and aspect and slope). Only models with AUC ≥ 0.7 were retained. For each LEFT analysis, the models for those species whose native geographic range is included in the study area are projected using the same environmental and geo-physical variables and the projected probability values hardened to [0,1] at a cut value of 0.5. The hardened probability values are then summed across all modelled species. The resulting map represents the relative numbers of threatened species potentially present across the study area. All species included in the map are tabulated in Appendix I.

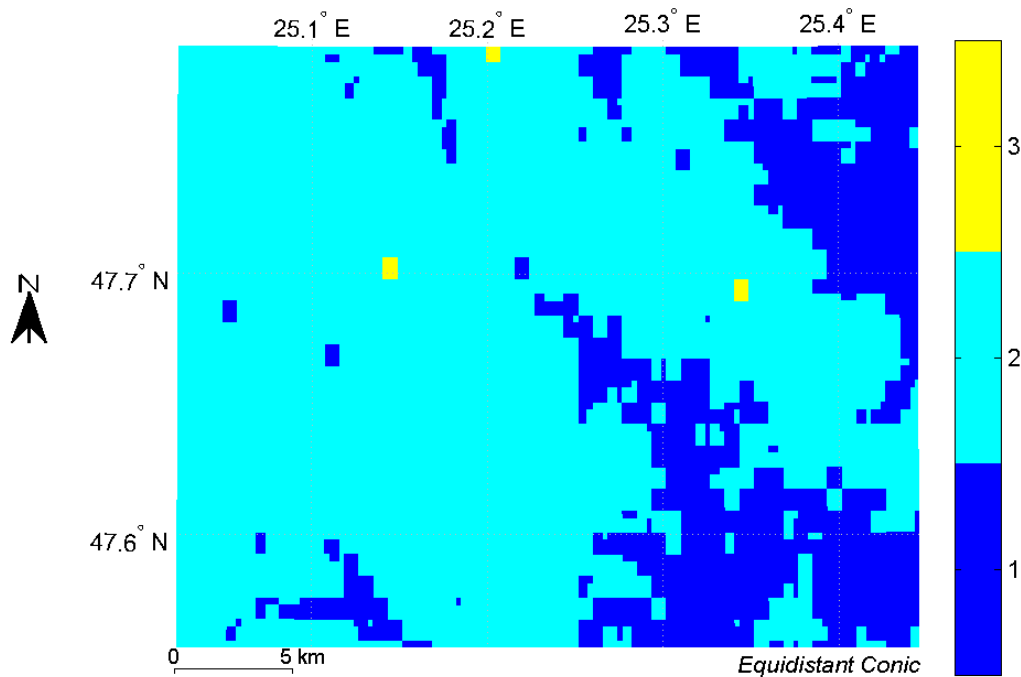


Figure 6. Vulnerability map of estimated number of globally threatened (CR, EN, VU) and near threatened (NT) terrestrial mammals, birds, reptiles, amphibians and plants. See Appendix I for a table of species names.

3. FRAGMENTATION

The extent of fragmentation in the landscape is calculated from GlobCover vegetation data (Copyright © ESA GlobCover Project, led by MEDIAS-France) by identifying the vegetation patch to which each pixel belongs and measuring the size of each patch (Figure 7). We reclassified the GlobCover vegetation categories into the following groups: closed forest, open forest, shrubland, grassland, sparse vegetation, flooded vegetation, and other. The other class includes agriculture, mosaics of agriculture and natural vegetation, urban areas, bare surfaces, water and snow/ice. Land in the class 'other' was assigned a patch size of zero.

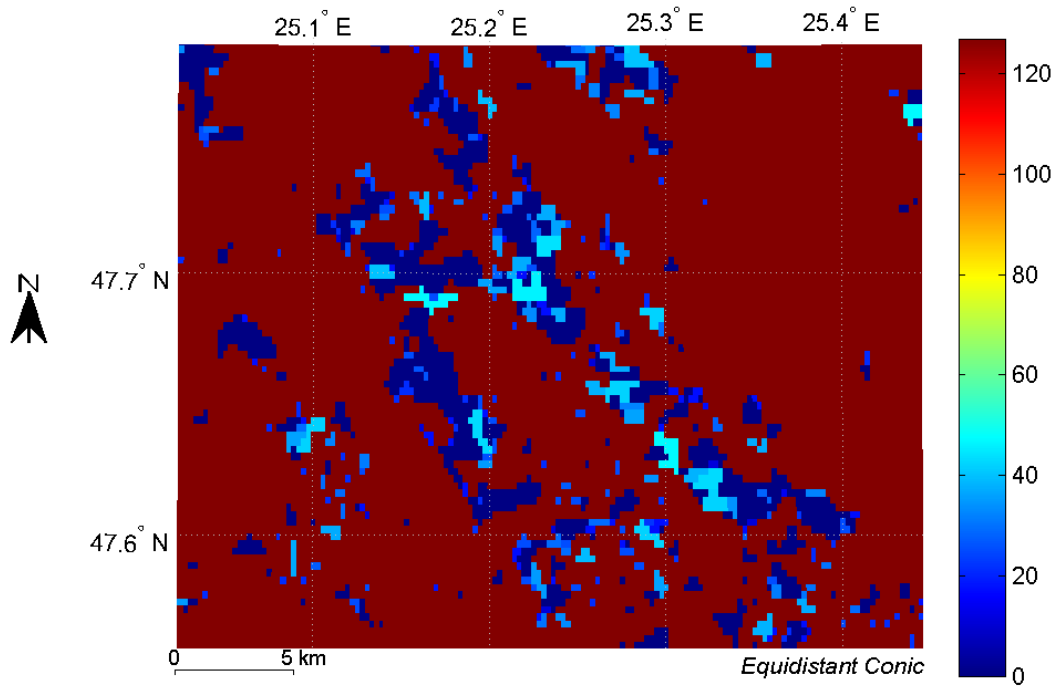


Figure 7. Fragmentation map of natural vegetation. The colour of each pixel indicates the size of the patch to which it belongs ($\ln(\text{patch area in ha}) \times 10$).

4. CONNECTIVITY

There are two measures of connectivity included in the LEFT: the relative number of migratory species estimated to be present and identification of the landscape features that support migration. All available species range polygon shapefiles for birds, terrestrial mammals and turtles identified as migratory species in the Global Register of Migratory Species (GROMS, Riede 2004) were summed to estimate the relative number of migratory species potentially present across the study area. All species included in this response are listed in Appendix II.

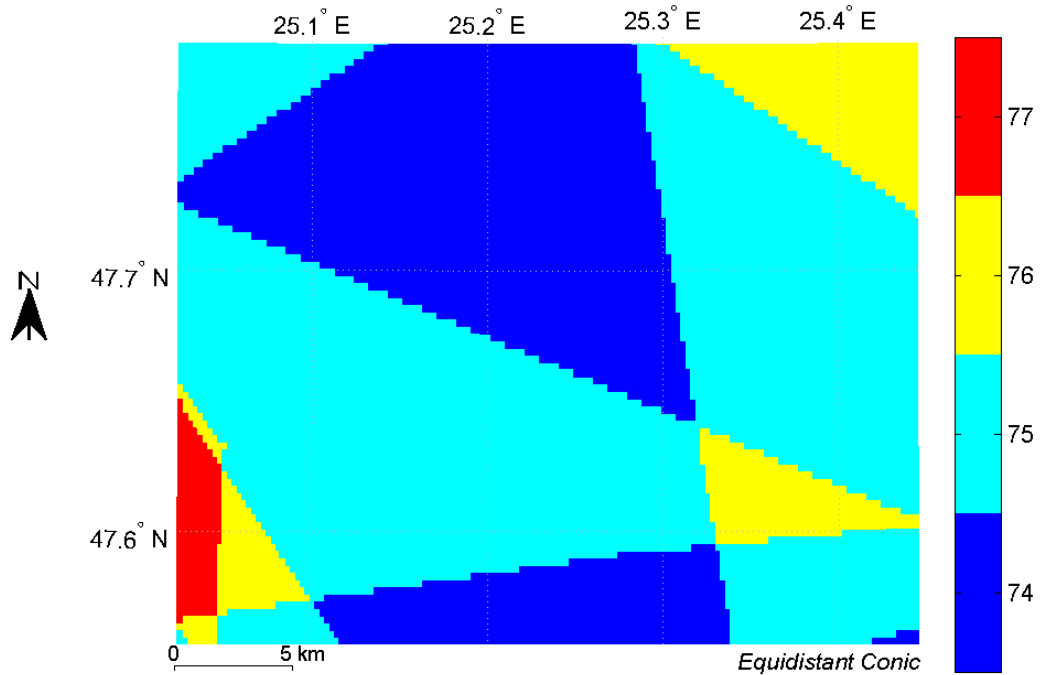


Figure 8. Connectivity map of estimated number of migratory species (birds, terrestrial mammals, turtles) identified by GROMS. See Appendix II for a table of species names.

Rivers, lakes and wetlands support migration for many species. The Global Lakes and Wetlands Database (GLWD; Lehner and Doll 2004) and Hydrosheds database (Lehner, Verdin et al. 2008) are used to identify these features within the study area.

All pixels identified by the GLWD as a lake, river, freshwater marsh/floodplain, swamp forest/flooded forest, coastal wetland, pan/brackish/saline wetland, bog/fen/mire, intermediate wetland/lake or wetland mosaic and the pixels immediately adjacent to these features are given a value of one. All pixels containing a polyline in the Hydrosheds 15 arc second resolution global rivers shapefile, which represents drainage channels with an upslope contributing area greater than about 100 km², and all pixels immediately adjacent to these features were given a value of one. Finally the connectivity measures derived from GLWD and hydrosheds were added together and reclassified such that all pixels containing or adjacent to a GLWD wetland or containing or adjacent to a hydrosheds channel took a value of one and all other pixels are given a value of zero for this measure of connectivity.

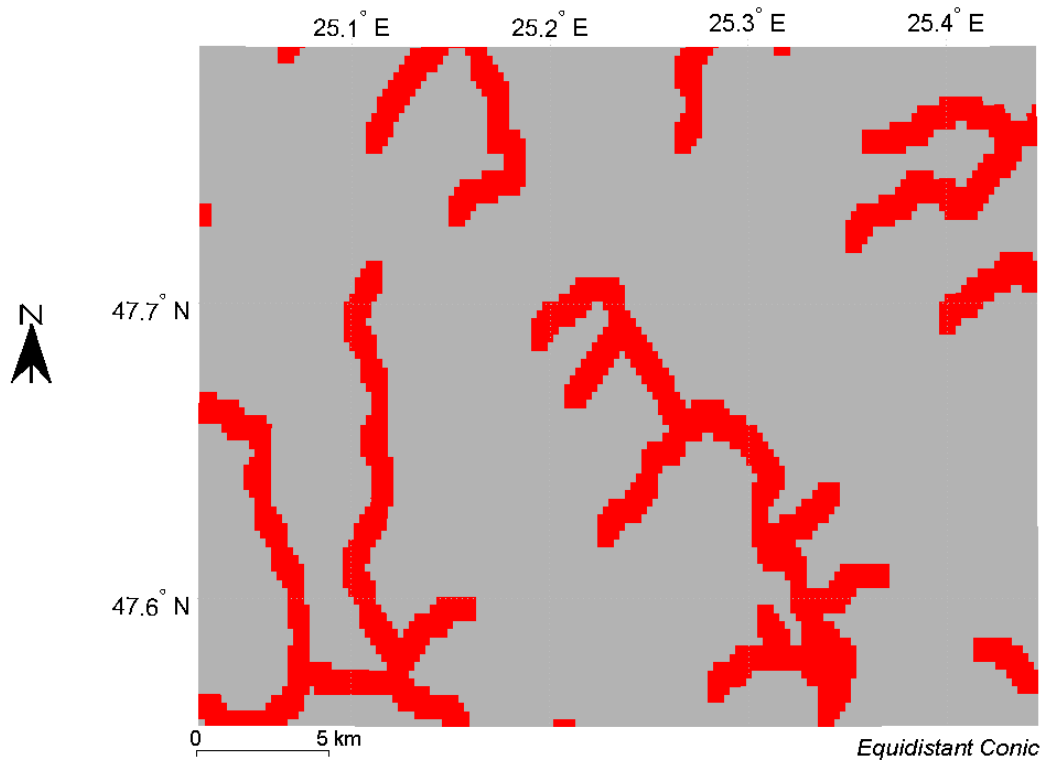


Figure 9. Connectivity map identifying areas that are wetlands or drainage channels as well as the pixels immediately adjacent to these features (red) and areas which are not wetlands, drainage channels or land adjacent to these (grey).

This product (Local Ecological Footprinting Tool) incorporates data from the HydroSHEDS database which is © World Wildlife Fund, Inc. (2006-2013) and has been used herein under license. WWF has not evaluated the data as altered and incorporated within [Local Ecological Footprinting Tool], and therefore gives no warranty regarding its accuracy, completeness, currency or suitability for any particular purpose. Portions of the HydroSHEDS database incorporate data which are the intellectual property rights of © USGS (2006-2008) (data available from U.S. Geological Survey, EROS Data Center, SD), NASA (2000–2005), ESRI (1992-1998), CIAT (2004-2006), UNEP-WCMC (1993), WWF (2004), Commonwealth of Australia (2007), and Her Royal Majesty and the British Crown and are used under license. The scientific citation for the HydroSHEDS database is: Lehner, B., Verdin, K., Jarvis, A. (2008): New global hydrography derived from spaceborne elevation data. Eos, Transactions, AGU, 89(10): 93-94.

5. RESILIENCE

Differences in resilience across the study area are indicated by the ability of vegetation to retain high productivity despite low rainfall conditions (Figure 10). Values of annual net primary productivity (NPP ($\text{kg m}^{-2} \text{yr}^{-1}$), Zhao et al. 2009) for the year 2005 per vegetation type (determined by GlobCover, also as of 2005) were overlaid with data of the historical mean total annual precipitation (mm) over 1950-2000 (from Worldclim, Hijmans et al. 2005) to identify patterns across space in the level of productivity of each vegetation type given spatial variations in rainfall. Quartiles of precipitation and NPP per vegetation type are calculated and used to identify areas that maintain maximum NPP during intervals of low precipitation. Areas that fall in the 4th quartile of NPP and the 1st quartile of precipitation are assigned a value of 1. Areas that fall in the 3rd quartile of NPP and the 1st quartile of precipitation are assigned a value of 0.5. All other areas are assigned a value of zero for resilience.

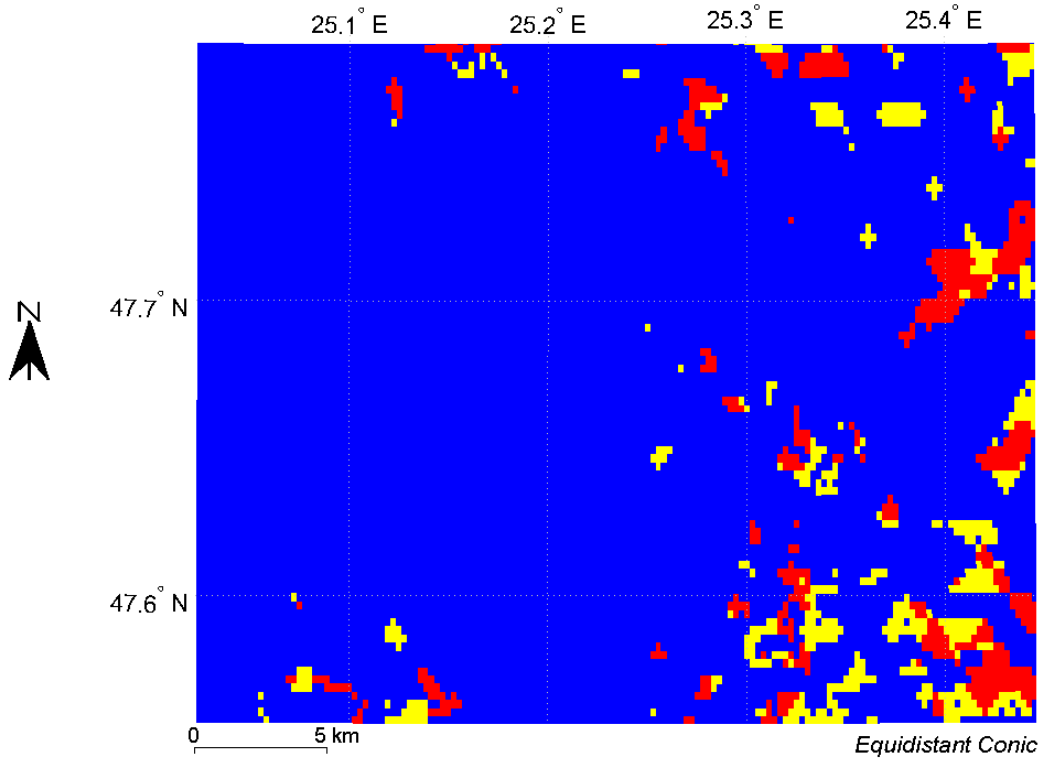


Figure 10. Resilience map identifying the areas in the 4th quartile of net primary productivity ($\text{kg m}^{-2} \text{yr}^{-1}$) and the 1st quartile of precipitation (mm) (red), or the 3rd quartile of net primary productivity and the 1st quartile of precipitation (yellow). All other areas are blue. Null data values are black.

SUMMARY ECOLOGICAL VALUE

The analysis above has provided maps for five derived measures of ecological value: 1) biodiversity, 2) vulnerability, 3) fragmentation, 4) connectivity, and 5) resilience. The final result of the analysis is a summary map of these measures where the values for each derived measure have been normalized across the study site to the interval [0, 1] and then summed. There are two distinct components to connectivity, so each of these contributes just half its value to the sum. The summation then has a maximum value of 5 and provides an overall estimate of relative ecological value across the study site.

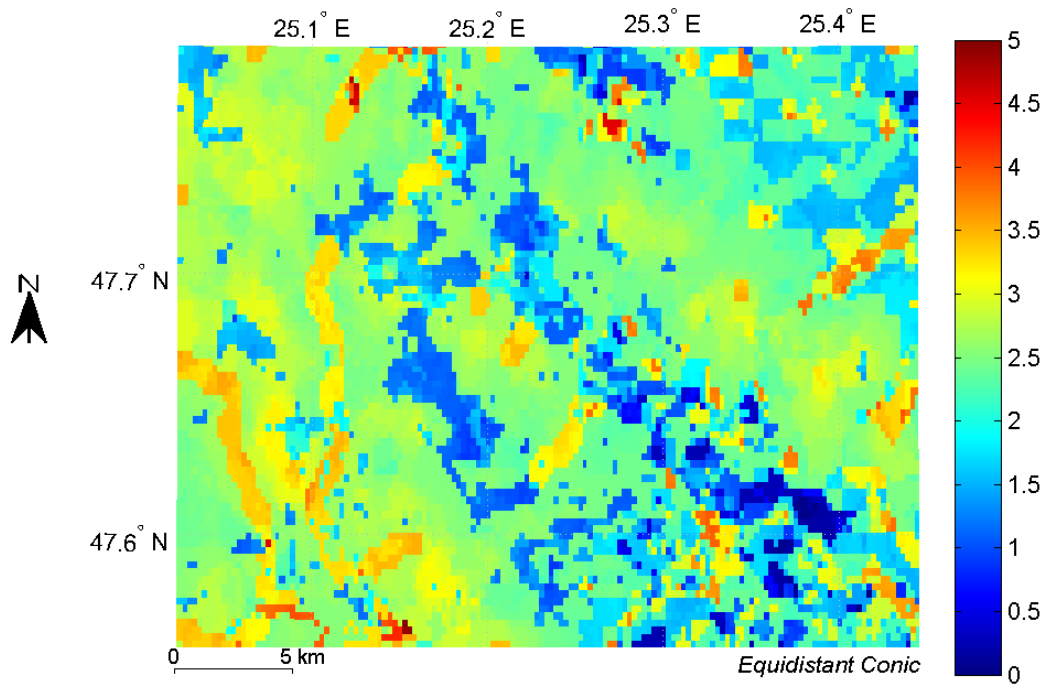


Figure 11. Summary ecological value of the study area. Red areas indicate high relative ecological value; blue areas indicate a lower relative ecological value.

OUTPUT FILES

The zip file distributed with this analysis ([01516BD795F2_ABBE4F3293145B2EADF838B2.zip](#)) contains several directories of ancillary files. The images directory contains all the images in this document as .png files. The data directory contains georeferenced .tif files of the six ecological measures, the final summary measure, and a data mask derived from the Globcover dataset. These files can be opened using appropriate GIS software.

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DATA SOURCES

Data obtained from GBIF 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 used in this analysis.

Academy of Natural Sciences, MAL (accessed through GBIF data portal, <http://gbif-mirror.zoo.ox.ac.uk:8080/gbif-portal/datasets/resource/2006>, 2015-12-06) Australian Museum, Australian Museum provider for OZCAM (accessed through GBIF data portal, <http://gbif-mirror.zoo.ox.ac.uk:8080/gbif-portal/datasets/resource/14113>, 2015-12-06) Australian National Herbarium (CANB), Australian National Herbarium (CANB) (accessed through GBIF data portal, <http://gbif-mirror.zoo.ox.ac.uk:8080/gbif-portal/datasets/resource/47>, 2015-12-06) Bioversity International, EURISCO, The European Genetic Resources Search Catalogue (accessed through GBIF data portal, <http://gbif-mirror.zoo.ox.ac.uk:8080/gbif-portal/datasets/resource/1905>, 2015-12-06) Botanic Garden and Botanical Museum Berlin-Dahlem, Herbarium Berolinense (accessed through GBIF data portal, <http://gbif-mirror.zoo.ox.ac.uk:8080/gbif-portal/datasets/resource/1095>, 2015-12-06) Botanic Garden and Botanical Museum Berlin-Dahlem, Lichen Herbarium Berlin (accessed through GBIF data portal, <http://gbif-mirror.zoo.ox.ac.uk:8080/gbif-portal/datasets/resource/1097>, 2015-12-06) Botanic Garden and Botanical Museum Berlin-Dahlem, Naturhistorisches Museum Mainz, Botanical Collection (accessed through GBIF data portal, <http://gbif-mirror.zoo.ox.ac.uk:8080/gbif-portal/datasets/resource/12677>, 2015-12-06) Botanic Garden and Botanical Museum Berlin-Dahlem, Naturhistorisches Museum Mainz, Zoological Collection (accessed through GBIF data portal, <http://gbif-mirror.zoo.ox.ac.uk:8080/gbif-portal/datasets/resource/12678>, 2015-12-06) California Academy of Sciences, CAS Herpetology (HERP) (accessed through GBIF data portal, <http://gbif-mirror.zoo.ox.ac.uk:8080/gbif-portal/datasets/resource/14129>, 2015-12-06) Carnegie Museums, CM Birds Collection (accessed through GBIF data portal, <http://gbif-mirror.zoo.ox.ac.uk:8080/gbif-portal/datasets/resource/14930>, 2015-12-06) Carnegie Museums, CM Herps Collection (accessed through GBIF data portal, <http://gbif-mirror.zoo.ox.ac.uk:8080/gbif-portal/datasets/resource/14929>, 2015-12-06) Cornell University Museum of Vertebrates, CUMV Reptile Collection (accessed through GBIF data portal, <http://gbif-mirror.zoo.ox.ac.uk:8080/gbif-portal/datasets/resource/14899>, 2015-12-06) Discover Life, Therevid PEET Project (accessed through GBIF data portal, <http://gbif-mirror.zoo.ox.ac.uk:8080/gbif-portal/datasets/resource/7933>, 2015-12-06) Field Museum, Field Museum of Natural History (Botany) Bryophyte Collection (accessed through GBIF data portal, <http://gbif-mirror.zoo.ox.ac.uk:8080/gbif-portal/datasets/resource/14352>, 2015-12-06) Finnish Museum of Natural History, William Nylander lichen collection (accessed through GBIF data portal, <http://gbif-mirror.zoo.ox.ac.uk:8080/gbif-portal/datasets/resource/13713>, 2015-12-06) FishBase, Fishbase (accessed through GBIF data portal, <http://gbif-mirror.zoo.ox.ac.uk:8080/gbif-portal/datasets/resource/1602>, 2015-12-06) Forest Research Institute, Department of Natural Forests, Coleoptera of Kozienice Forest (accessed through GBIF data portal, <http://gbif-mirror.zoo.ox.ac.uk:8080/gbif-portal/datasets/resource/1481>, 2015-12-06) Forest Research Institute, Department of Natural Forests, Herbarium of the Department of Natural Forests (Forest Research Institute) (accessed through GBIF data portal, <http://gbif-mirror.zoo.ox.ac.uk:8080/gbif-portal/datasets/resource/1486>, 2015-12-06) Forest Research Institute, European Centre for Natural Forests, Fungi Collection (accessed through GBIF data portal, <http://gbif-mirror.zoo.ox.ac.uk:8080/gbif-portal/datasets/resource/2590>, 2015-12-06) GBIF-Spain, Herbario de la Universidad de Salamanca: SALA (accessed through GBIF data portal, <http://gbif-mirror.zoo.ox.ac.uk:8080/gbif-portal/datasets/resource/239>, 2015-12-06) GBIF-Spain, Real Jardin Botanico, Madrid: MA-Fungi (accessed through GBIF data portal, <http://gbif-mirror.zoo.ox.ac.uk:8080/gbif-portal/datasets/resource/1518>, 2015-12-06) GBIF-Spain, Universidad de Murcia, Dpto. Biología Vegetal (Botánica), Murcia: MUB-MUSCI (accessed through GBIF data portal, <http://gbif-mirror.zoo.ox.ac.uk:8080/gbif-portal/datasets/resource/2398>, 2015-12-06) GBIF-Sweden, Gothenburg Herbarium - General (GBIF:IH:GB:Herbarium) (accessed through GBIF data portal, <http://gbif-mirror.zoo.ox.ac.uk:8080/gbif-portal/datasets/resource/1765>, 2015-12-06) INSTITUTE OF BOTANY S.A.S., Dataflos (accessed through GBIF data portal, <http://gbif-mirror.zoo.ox.ac.uk:8080/gbif-portal/datasets/resource/13502>, 2015-12-06) Illinois Natural History Survey, Illinois Natural History Survey (accessed through GBIF data portal, <http://gbif-mirror.zoo.ox.ac.uk:8080/gbif-portal/datasets/resource/13517>, 2015-12-06) Institute of Dendrology PAS, Institute of Dendrology PAS, Flora of Sudety Mountains (accessed through GBIF data portal, <http://gbif->

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APPENDIX I

The IUCN Red List of Threatened Species (IUCN 2009) includes 4 species of globally threatened terrestrial mammals, birds, reptiles, amphibians and plants predicted to be present in the study area. Latin name, taxonomic class and IUCN threat category are tabulated below. (NT – near threatened, VU – vulnerable, EN – endangered, CR – critically endangered)

1	<i>Acrocephalus paludicola</i>	AVES	VU
2	<i>Betula oycoviensis</i>	MAGNOLIOPSIDA	VU
3	<i>Sorex alpinus</i>	MAMMALIA	NT
4	<i>Spermophilus suslicus</i>	MAMMALIA	NT

APPENDIX II

The Global Register of Migratory Species (GROMS, Riede 2004) includes 80 species predicted to be present in the study area. These names are tabulated below.

- 1 [Accipiter gentilis](#)
- 2 [Accipiter nisus](#)
- 3 [Alcedo atthis](#)
- 4 [Anas acuta](#)
- 5 [Anas clypeata](#)
- 6 [Anas crecca](#)
- 7 [Anas platyrhynchos](#)
- 8 [Anas strepera](#)
- 9 [Anser albifrons](#)
- 10 [Apus apus](#)
- 11 [Aquila chrysaetos](#)
- 12 [Aquila heliaca](#)
- 13 [Aquila pomarina](#)
- 14 [Asio flammeus](#)
- 15 [Asio otus](#)
- 16 [Athene noctua](#)
- 17 [Aythya ferina](#)
- 18 [Aythya nyroca](#)
- 19 [Barbastella barbastellus](#)
- 20 [Bucephala clangula](#)
- 21 [Buteo buteo](#)
- 22 [Buteo lagopus](#)
- 23 [Caprimulgus europaeus](#)
- 24 [Charadrius dubius](#)
- 25 [Chlidonias niger](#)
- 26 [Circaetus gallicus](#)
- 27 [Circus aeruginosus](#)
- 28 [Circus pygargus](#)
- 29 [Columba oenas](#)
- 30 [Columba palumbus](#)
- 31 [Coracias garrulus](#)
- 32 [Coturnix coturnix](#)
- 33 [Cuculus canorus](#)
- 34 [Eptesicus serotinus](#)
- 35 [Falco columbarius](#)
- 36 [Falco naumanni](#)
- 37 [Falco peregrinus](#)
- 38 [Falco subbuteo](#)
- 39 [Falco tinnunculus](#)
- 40 [Fulica atra](#)
- 41 [Glareola pratincola](#)

- 42 [*Haliaeetus albicilla*](#)
- 43 [*Himantopus himantopus*](#)
- 44 [*Hirundo rustica*](#)
- 45 [*Jynx torquilla*](#)
- 46 [*Limosa limosa*](#)
- 47 [*Merops apiaster*](#)
- 48 [*Milvus migrans*](#)
- 49 [*Milvus milvus*](#)
- 50 [*Miniopterus schreibersi*](#)
- 51 [*Myotis dasycneme*](#)
- 52 [*Myotis daubentoni*](#)
- 53 [*Myotis emarginatus*](#)
- 54 [*Myotis myotis*](#)
- 55 [*Myotis mystacinus*](#)
- 56 [*Myotis nattereri*](#)
- 57 [*Myotis oxygnathus*](#)
- 58 [*Numenius tenuirostris*](#)
- 59 [*Nyctalus noctula*](#)
- 60 [*Nycticorax nycticorax*](#)
- 61 [*Otus scops*](#)
- 62 [*Pelecanus crispus*](#)
- 63 [*Phalacrocorax pygmaeus*](#)
- 64 [*Phylloscopus collybita*](#)
- 65 [*Phylloscopus trochilus*](#)
- 66 [*Plecotus auritus*](#)
- 67 [*Porzana parva*](#)
- 68 [*Rallus aquaticus*](#)
- 69 [*Rhinolophus ferrumequinum*](#)
- 70 [*Riparia riparia*](#)
- 71 [*Scolopax rusticola*](#)
- 72 [*Sterna hirundo*](#)
- 73 [*Streptopelia decaocto*](#)
- 74 [*Streptopelia turtur*](#)
- 75 [*Sturnus vulgaris*](#)
- 76 [*Tachybaptus ruficollis*](#)
- 77 [*Tringa hypoleucos*](#)
- 78 [*Tringa totanus*](#)
- 79 [*Upupa epops*](#)
- 80 [*Vanellus vanellus*](#)