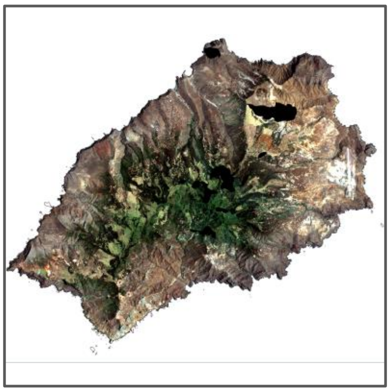
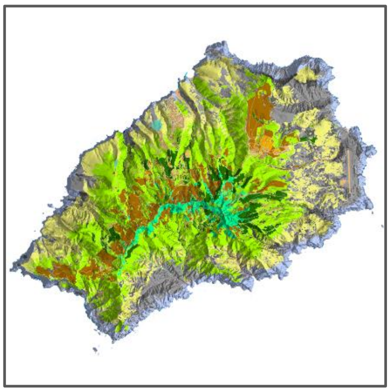
DPLUS052: Mapping St Helena's Biodiversity and Natural Environment

Remote sensing, monitoring & ecosystem service mapping

Final report





July 2018
Version No. 1.02

Version	Comment	Date
1.01	First issue	06. 07.2018
1.02	Re-issue, following comments from ENRD and project partners.	23.07.2018

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Acknowledgements
The project team would like to thank Samantha Cherrett and Elizabeth Cairns-Wicks for providing data, ongoing support and feedback on both business, ecological and administration aspects of the project as it progressed. Acknowledgements go to those members of the stakeholders, including; St Helena Government, Environment and Natural Resources Directorate (ENRD), Environmental Management Division (EMD) and Agricultural and Natural Resources Division (ANRD), the Landscape and Ecological Mitigation Programme (LEMP), St Helena National Trust and the St Helena Nature Conservation Group, Connect St Helena Ltd, SAERI (for putting the data on the website), Ascension Island Government and also independent contributors to the project. Finally, we also grateful to all those that participated in the workshops and data gathering.

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Executive summary

Aims

The major aims of this project were:

- Understand and promote the significance of the land-based environment and build this knowledge into policies and land management actions, including land resource planning and management of invasive species.
- Understand the relationship between the St Helena's habitats and soil characteristics in order to ensure conservation and land management actions have the best possible outcomes.
- Show how the habitats and soil interact and identify where and how the natural ecosystem can best be used to maintain resilience and ensure long term wellbeing, to help mitigate the effects of climate change.

Methods

To achieve these aims the project team employed the following methodology:

- The use of Earth observation (EO) techniques and understanding, combined with field survey and validation, to produce a detailed habitat map of the island with a three-tier classification system.
- An intensive soil surveying programme to represent habitat and soil type combinations across the island.
- Training of island staff in field habitat surveying and soil sampling techniques to enable work to be carried out in the future.
- Integration of the remote sensing and soil survey data to create maps that describe the island's soil characteristics relevant to ecosystem services.
- Use Earth observation to design a monitoring programme for the island to develop a 'Living Map'.
- Investigate how the soil and remote sensing data can be used in case studies of ecosystem service monitoring.

Outcomes & conclusions

The project has achieved the following outcomes:

- A ground-truthed and detailed habitat map based on EO data and targeted ecological surveys. This map is also a 'Living Map' in that it can reflect habitat changes as new EO data are received.
- A detailed soil survey that has resulted in soil maps showing values for pH, electrical conductivity, hydraulic conductivity, stability, carbon concentration and carbon stocks to 15 cm. Data are available to extend the carbon stocks to 30 cm.
- Combining maps of different soil parameters the project has produced a map indicating areas of low to high productivity.
- St Helena government staff have been trained in ecological and soil surveying so can develop the maps in the future.
- Example ecosystem services maps have been produced combining soil and remote sensing data

This project has shown that remote sensing has been a useful tool for St Helena, with difficult terrain and a very complex ecology. Combining remote sensing with ecological surveying to ground-truth the results, leads to increased accuracy. The rule-based methodology means that the map can be updated as new remote sensing data are available, reflecting changes to the habitat on the island.

Soil maps have identified areas where remedial action may be required especially to grazing land. The maps will also feed into decisions regarding conservation, to determine areas that will give the greatest chance of restoration success.

Recommendations

The project has led to a number of positive outcomes, but could be considered a beginning for the cataloguing and valuing the stock of St Helena's natural capital. It is recommended that these maps and data feed into an exercise, which will identify and value natural capital accounts for areas such as, tourism, erosion prevention, biodiversity, flood prevention and carbon sequestration.

Limitations

The production of maps from sample point data, such as soils, using computer models will inevitably lead to situations where there is a disconnect between the prediction and the actual conditions. Some manual correction will be necessary in such situations and additional surveying will improve the accuracy of these maps.

1 St Helena habitat mapping

1.1 Introduction

St Helena is one of the most isolated islands on Earth; a volcanic tropical island in the South Atlantic Ocean with environmental landscapes ranging from deserts to cloud forests. The island's habitats consist of barren coastal fringes, dry and rocky wastelands on the outer part. Moving inland, scrub and woodland and wetlands, together with agricultural habitats occur. At the centre of the island on the highest ground are densely vegetated cloud forest. Urban areas occur scattered throughout the most accessible land on the island.

The sensitive ecosystems have been modified and exploited since the island's discovery in 1502; resulting in the loss of endemic species and the fragmentation of habitats. The flora today supports 45 native endemic species, up to 43 native species, 276 naturalised and forestry species, and at least 100 planted and adventive species (Lambdon, 2012). It is thought that up to 88 % of the species have been introduced, now account for more than 99 % of the island's biomass (Lambdon, 2012). The islands biodiversity is increasingly threatened by the effects of climate change, tourism and development pressures and invasive species.

St Helena aims to become more self-sufficient, but this requires careful land management practises whilst restoring habitats and protecting rare species. For this, accurate island-wide detailed vegetation, soil mapping, and derived datasets are urgently required; to better understand the island's biodiversity, species geographic distribution, to protect and restore native habitats, control invasive species, aid sustainable agriculture, and manage the island's land and water resources.

Habitat and soil information exists from 35-year old maps, localised and targeted data collection, disparate datasets, and historical paper reports. This project aims to update and build new knowledge around these maps. Remote sensing technologies and methods together with field-based surveying, and ancillary data (such as up-to-date road networks and buildings) were used to provide a detailed, geographic quantification of the current habitats and soils. The final maps give robust evidence for policy decision making. Using this data will help the island find solutions that benefit the island's society, economy and environment through the ecosystem approach.

The habitat map created forms the basis of a 'Living Map' which can be updated as new information becomes available. This also will help provide a cost-effect approach to the implementation of an island-wide monitoring program.

The outputs from this project are available through web map services for St Helena (*http://www.sainthelena.gov.sh/*) which have been developed by the South Atlantic Environmental Research Institute (SAERI). This will allow anyone to access the data to incorporate it in the planning for policies and land management decisions.

1.1.1 Aims and objectives

This project aims to:

- Understand and promote the significance of the land-based environment and build this knowledge in to policies and land management actions including land resource planning and management of invasive species.

- Understand the relationship between the St Helena's habitats and soil characteristics in order to ensure conservation and land management actions have the best possible outcomes.
- Show how the habitats and soil interact and identify where and how the natural ecosystem can best be used to maintain resilience and ensure long term well-being.

There are three main objectives to achieving this outcome:

- Use Earth observation techniques and understanding to produce a Living Map of the island.
- Integrate remote sensing and soil survey data to create maps that describe the islands soil characteristics.
- Use Earth observation to design a monitoring program for the island.
- Investigate how the data can be used in case studies ecosystem service monitoring.

1.1.2 Earth observation and its core considerations

Earth observation (EO) is the use of remote sensing data from satellite and airborne systems for mapping and monitoring the Earth. It provides an accurate and repeatable methodology for mapping a range of land features.

It is recognised that, increasingly, applications of EO form an integral element of operational chains and policy decision making processes within natural resource management. Over the past 50 years there have been progressive improvements in the spatial, temporal, and spectral resolution of EO sensors; making them a valuable resource across a range of mapping scales and for a variety of mapping requirements.

EO imagery lends itself particularly well to St Helena due to the island's remote location and size; allowing analysists to survey the entire island, including those areas that are hard to access (or even dangerous), from a single image without the need to physically be on-island. This can make it a very cost-effective solution, especially when combined with locally-based field work, to provide timely, efficient and potentially near real-time information.

Some satellite programmes have been systematically capturing the same area since the 1970's (e.g., the Landsat program), with others planned for launch after 2023 (e.g., Sentinel-2D). Using this technology, we can gather information for the same location backward and forward in time.

A summary of the wider EO contexts; its main considerations, available data and opportunities to deliver the core benefits of EO to the operational, technical and financial components of St Helena's natural resource management, is provided in Appendix A and Appendix A.

1.2 Method

1.2.1 Defining the habitat classification

Creating a strong, dependable classification for St Helena was an important part of the project. It was vital that the system developed was consistent and allowed everyone (environmental professionals, land managers and policy makers) to understand and to provide evidence about the ecological communities recorded.

The habitat classification needed to be robust enough to be used as evidence when considering any land related activity.

Two main criteria were considered when designing the classification. The first was that it should fit within the overall context of the internationally recognised IUCN habitat types (*http://www.iucnredlist.org/technical-documents/classification-schemes/habitats-classification-scheme-ver3*). St Helena has a number of unique habitats types but these were grouped within the main classification units. The second criteria was to enable as many of the habitat types of possible to be identified using remote sensing and field validation.

Defining and agreeing the classification took place on Island over a number of workshops. Three levels of classification were agreed. Level 1 being the broadest and Level 3 the most detailed. The majority of habitats on St Helena can be identified using remote sensing to Level 2. Level 3 often requires knowledge of understory species or rarer components of a habitat which will require fieldwork to validate.

One of the main successes of the project has been the development of this robust, island specific, hierarchical, habitat classification. The classification works well for remote sensing for field validation and gives the island the robust evidence base it needs.

1.2.2 Field survey

Throughout January to September 2017, survey work was undertaken by ENRD, following on-island training on habitat surveying specifically for EO-based projects. In total 1630 habitats were evaluated across the island, through both on-site field visits, and aerial photographic interpretation (API) (Figure 1.1). This process involved using the image segmentation created as part of the remote sensing classification (Section 1.2.6), and characterising it with correct IUCN Level 3 habitat.

It was important to understand the limitations of remote sensing, API, and fieldwork when acquiring any survey outputs:

- Survey points should not be collected in areas where there are areas of cloud, heavy cloud shadow, or topographic shadow in the imagery.
- If there was a substantial time difference between the acquired imagery and the survey dates, there may be some discrepancies in the habitats observed by both surveyors and EO analysists. This is also true if there is a difference in climatic variations, for example if the imagery was captured during a period of drought but the survey was not.
- The inability for API or EO to identify the ground through a tree canopy can lead to instances of habitat misclassification, or disagreements between the surveyors and the API/EO analysts.
- A segmented polygon may not always delineate a single habitat type, and instead 'bleed' into adjacent areas. In these cases, the most abundant class was selected.
- An EO classification cannot map those habitats that have not been included in the survey work, or if there are too few occurrences of that habitat. These may have been added manually at a later date.

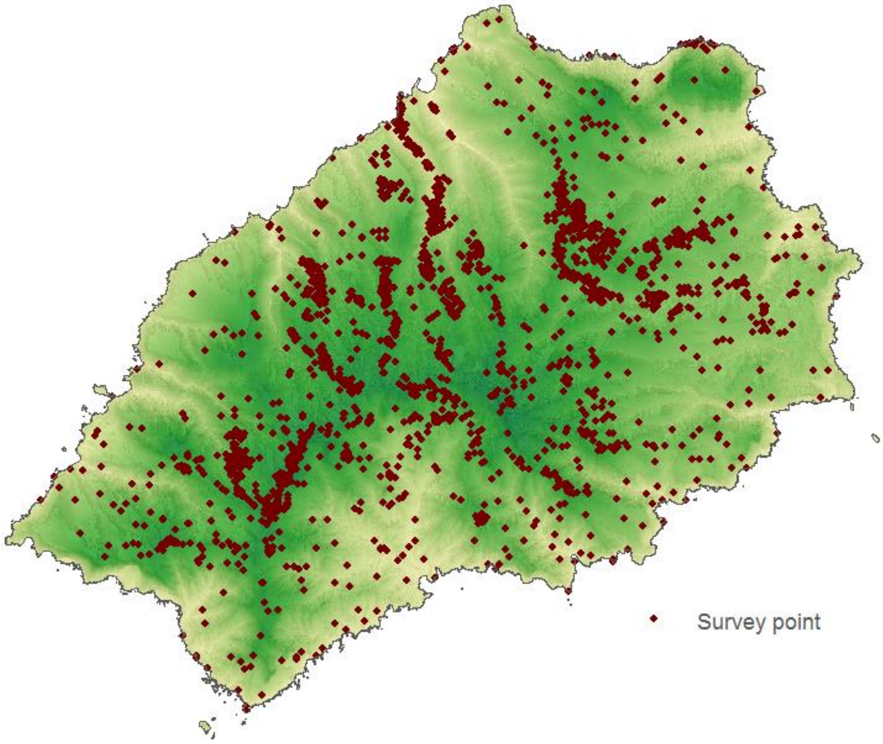


Figure 1.1: Location of all points and polygons collected as survey work by ENRD

This survey work took place throughout the classification period, enabling the analyst to adjust the ruleset, to take into account any new survey information.

Table 1.1 shows the number of survey observations for IUCN Level 1, identified by ENRD. The IUCN Level 3 habitats, and their survey abundance, is available in Appendix B.

Table 1.1: IUCN Level 1 habitats and survey observations

IUCN Level 1	*Number of observations*
1. Forest & Woodland	553
3. Shrubland	371
4. Native Grassland	3
5. Wetlands	35
6. Inland Barren Areas	141
8. Desert	85
12. Marine - Intertidal	30
13. Marine - Coastal/Supratidal	11
14. Artificial - Terrestrial	371
15. Artificial - Aquatic	18
17. Other Vegetated	12

1.2.3 Earth observation data

Three Pléiades imagery were acquired for this project; two archive and one specifically tasked (Figure 1.2). Despite using three separate images that each cover the entire island, there were some areas that contained elements of cloud cover across all the datasets. Table 1.2 shows the basic characteristics of these multi-spectral datasets.

Table 1.2: Satellite imagery characteristics

Sensor	*Bands*	*Resolution*	*Date*	*Notes*
Pléiades	Blue, Green, Red, NIR	2 metres	05/11/2014	Cloud-masked
Pléiades	Blue, Green, Red, NIR	2 metres	07/12/2014	Cloud-masked
Pléiades	Blue, Green, Red, NIR	2 metres	25/01/2017	Tasked, cloud-masked

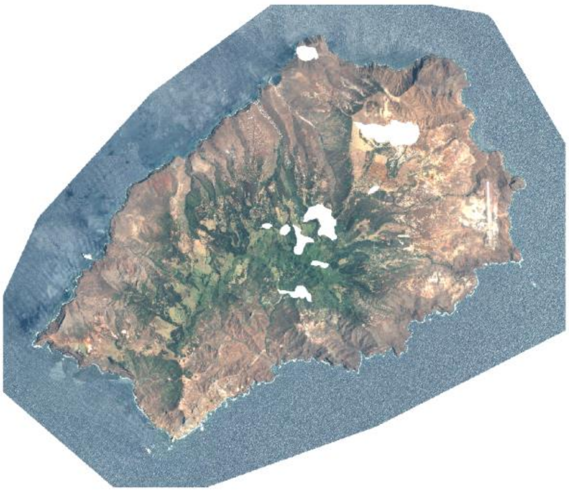


Figure 1.2: A mosaic of the three Pléiades imagery acquired for the classification, shown as RGB. Note the areas of white indicate those areas that cloud-cover existed in every image.

On each image, analysis-ready datasets were created in order to extract as much meaningful information for the classification. A list of the analysis-ready data products are detailed in Table 1.3.

Table 1.3: Image analysis-ready data

Principle components analysis (PCA)	*Chlorophyll vegetation index (CVI)*
Normalized difference vegetation index (NDVI)	Green normalized difference vegetation index (GNDVI)
Soil-adjusted vegetation index (SAVI)	Shade/water
Photosynthetic vegetation (PV)	Non-photosynthetic vegetation (NPV)

Additionally, a digital terrain model (DTM) was supplied by St Helena Government, derived from very high resolution (VHR) stereo-imagery, and captured 05/11/2014. From this model, further analysis-ready datasets was created, specifically slope (the steepness of a surface), and aspect (the orientation of a slope to north) models, as shown in Figure 1.3.

Sentinel-1 data was also considered. However, the volume of Sentinel-1 required during the project was limited, and reduced their effectiveness. The extreme topographical nature of St Helena also reduced the capabilities of this sensor; producing strong foreshortening and radar shadow, resulting in extreme bright/dark areas with very little useable data.

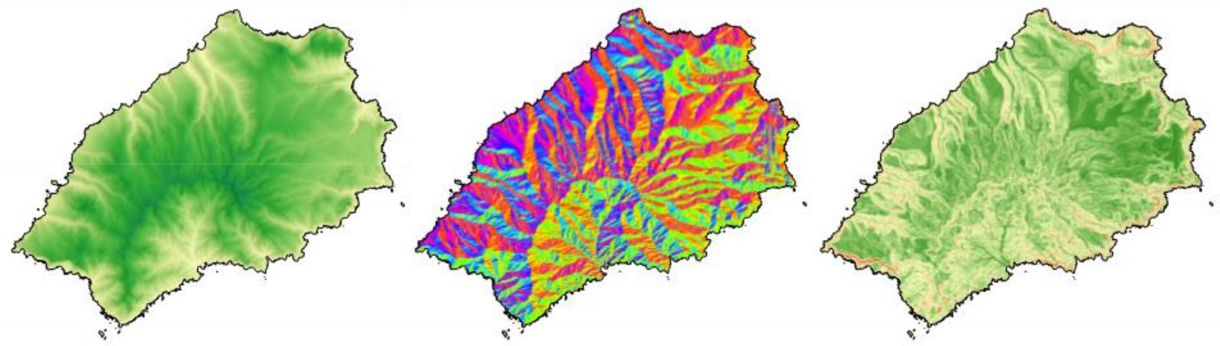


Figure 1.3: The DTM (left), aspect (centre), and slope (right) models

1.2.4 Additional datasets

Supplementary, thematic datasets were provided by St Helena Government in order to delineate specific land use features. These included urban areas (roads, buildings, and gardens), open water (valley guts, and reservoirs), forestry, as well as areas of agriculture, and commercial pastureland. These are displayed in Figure 1.4.

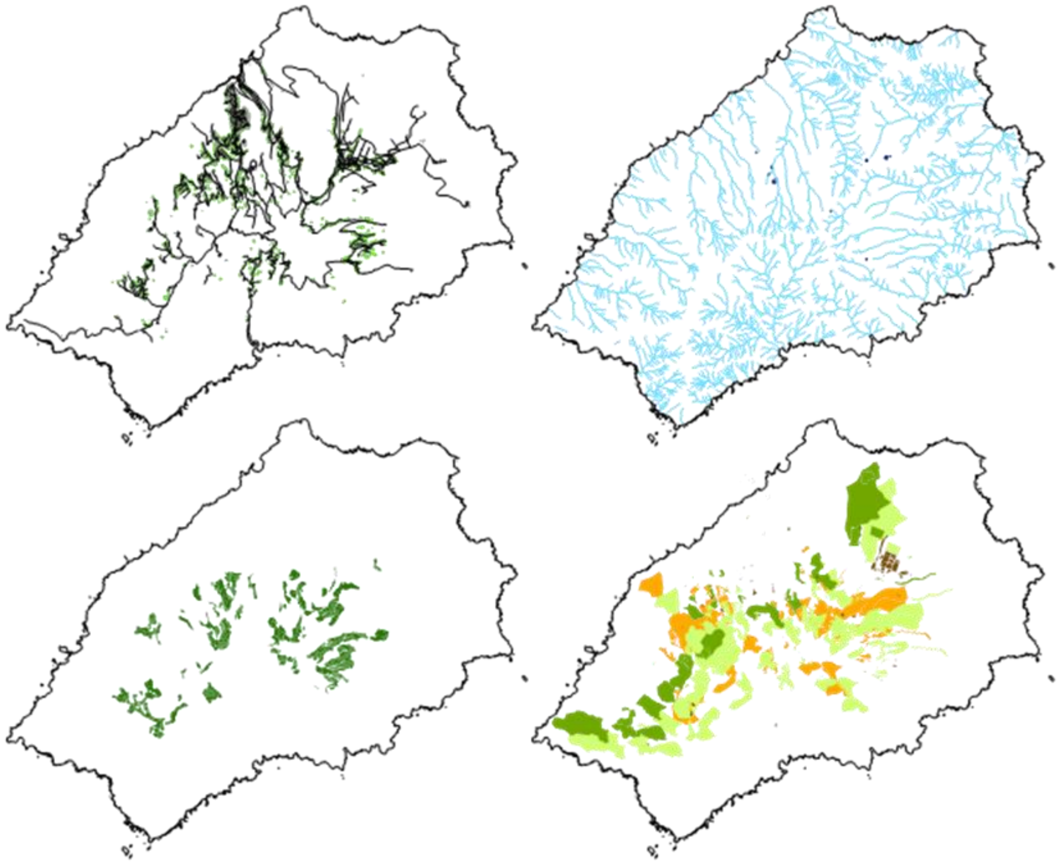


Figure 1.4: Additional datasets clockwise from top-left; urban, valley guts and reservoirs, forestry, agriculture and pastureland

1.2.5 The classification concepts

Since the launch of Landsat-1 in the early 1970's, image classification has been used to characterise land cover for agricultural and ecological purposes. Image classification is based on the assumption that different land covers have characteristic reflectance signatures that can be identified and separated to produce a thematic map. Initially, images were classified at the per-pixel scale, however this tended to produce noisy and often unreliable classification datasets due to the substantial variation in signatures seen between pixels. More recently, object-based classification has become the norm, whereby images are broken into objects of similar colour and texture and classified at this scale. In addition to producing maps that are more consistent in appearance, object-based methods are better at handling noisy image data such as SAR.

Figure 1.5 illustrates the step-by-step process followed for the habitat classification, with each of these process described in more detail in the following sections.

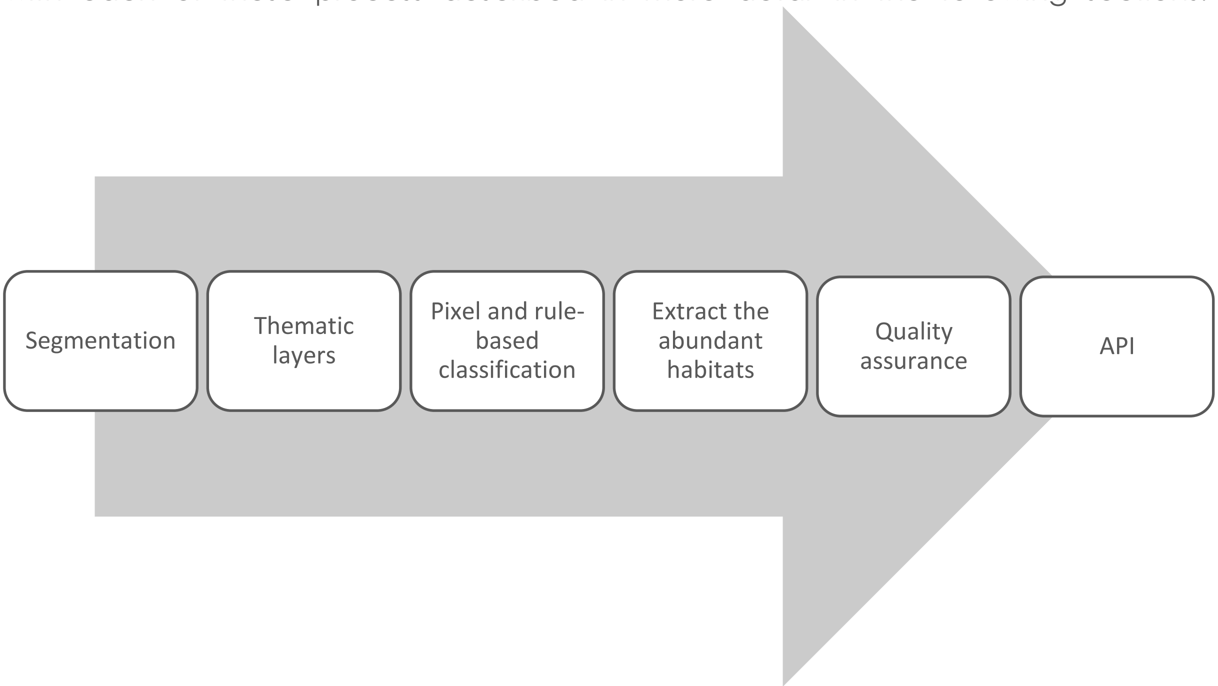


Figure 1.5: The classification process

1.2.6 Segmentation (object-based image analysis)

The object-based image analysis (OBIA) grouped pixels into those with similar spectral values. This allowed the whole object to be analysed. As the data values for these objects represented a combination of what was present within the object, it was necessary to understand the appearance of the dominant vegetation type and any effects on this of the sub-dominant vegetation type, shade and soil present. This additional knowledge was added during field work. Where objects such as rivers and buildings already had accurate outlines, these outlines were built into the segmentation so that the resulting map would align with existing information. A subset of the segmentation is illustrated in Figure 1.6.

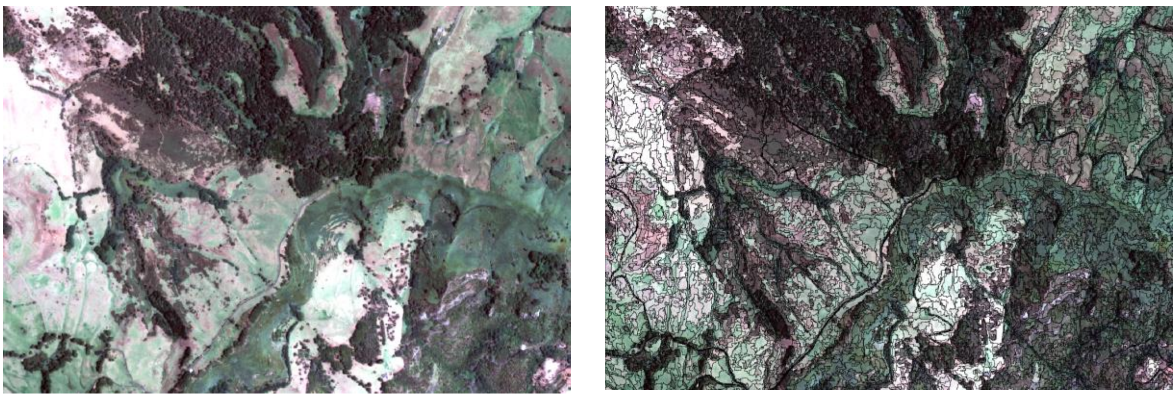


Figure 1.6: Subset of imagery (left) and the derived segmentation (right)

1.2.7 Thematic layers

During the segmentation process, it was possible to incorporate and classify the thematic datasets (i.e. the urban, gardens, open water, forestry, and agriculture) using the attributes within the shapefiles. This meant the analysts did not have to classify those objects that data already existed for (i.e. buildings and roads).

1.2.8 Pixels, and rule-based classification

Due to the strong heterogeneous nature of the vegetation within St Helena, it became apparent that the spectrally significant objects derived through the segmentation, though well-delineated and at an appropriate scale relative to the habitats being examined, could not adequately differentiate between all the different vegetated habitat classes. It was therefore decided to adapt to the heterogeneity and formulate the rule-base at the pixel scale. The pixel-based output could then be aggregate into the segmented objects at a later stage (see Section 1.2.9)

A rule-base was developed to incorporate the ecological and contextual knowledge into the classification to best separate vegetation assemblages with a similar look but occurring in very different settings. By combining knowledge of the island ecology, land management and vegetation reflectance within a rule-base, the likely presence of habitats within an area could be mapped. The first stage to understanding this relationship involved a questionnaire, which helped people consider the ecological parameters of each habitat type. The questionnaire was helpful as a starting point, but was not finally incorporated into the official project, due to the very disturbed nature of the island habitats and ecology.

The rule-based approach incorporates knowledge of both the imagery content within the classification process using numerically derived rules and ecological knowledge to establish noted differences and changes within the imagery, and thus used to progressively produce a classification (Lucas et al., 2007).

Rule-sets utilise a range of image and ancillary data available, examples including: Pléiades, Sentinel-1, Sentinel-2, digital elevation models (DEMs), cadastral data on roads and buildings etc. Multispectral image derived products including; endmembers (e.g., photosynthetic vegetation (PV), non-photosynthetic vegetation (NPV) and shade), band ratios and indices such as NDVI are used frequently. These allow more information about vegetation to be described by the imagery and be included in the rules. Elevation, slope and aspect layers were also used at a range of scales to provide important data to classify landscape setting (Medcalf et al., 2013).

1.2.9 Extract the abundant habitats

Once the rule-set is complete, the pixel-based classification was exported as a raster. Using zonal statistics, it was possible to identify the habitat class that occupies the greatest area within each segmentation object. This process identified the most abundant habitat within the object, and populated the shapefile with this information, ready for the next phase.

1.2.10 Quality assurance

The output classification was then visually assessed, both internally and by St Helena Government. Any comments based on spatial error were evaluated, and if possible, incorporated into the rule-base. For example, by reducing/increasing the NDVI threshold (used to differentiate the productivity of vegetation) for shrubland classes, those areas were expand/contract into/out of other regions, such as deserts, woodlands and pasturelands. The next iteration was then be exported and sent for quality assurance (QA)

1.2.11 API

The repeated QA process continues, through multiple iterations, until the fine-tuning of the rule-base no longer enhance or improve the classification output. At this point, manual editing was required to identify those objects that do not accurately represent the habitat automatically classified. This is the final stage.

1.3 Results

1.3.1 IUCN level 1 land cover

Level 1 is the broadest habitat category, providing an overview of the landscape-scale habitats that exist on the island (Figure 1.7). At this level, those broad-scale classes that are predominantly vegetation, cover 38 % of the island, with natural non-vegetated areas occupying just one percent less (37%). Freshwater, saltwater and artificial habitats (e.g., quarries), based habitats make up 13 % of the total area, with the lowest land cover percentage derived from anthropologically active habitats at just 12 %. On an individual habitat scale, shrubland has the greatest ground cover at just over 400 ha, followed by inland barren areas (2319 ha), and desert (2255 ha). A table of the IUCN Level1 habitats and their percentage land cover are available in Table 1.4. The map is also available in Appendix C.

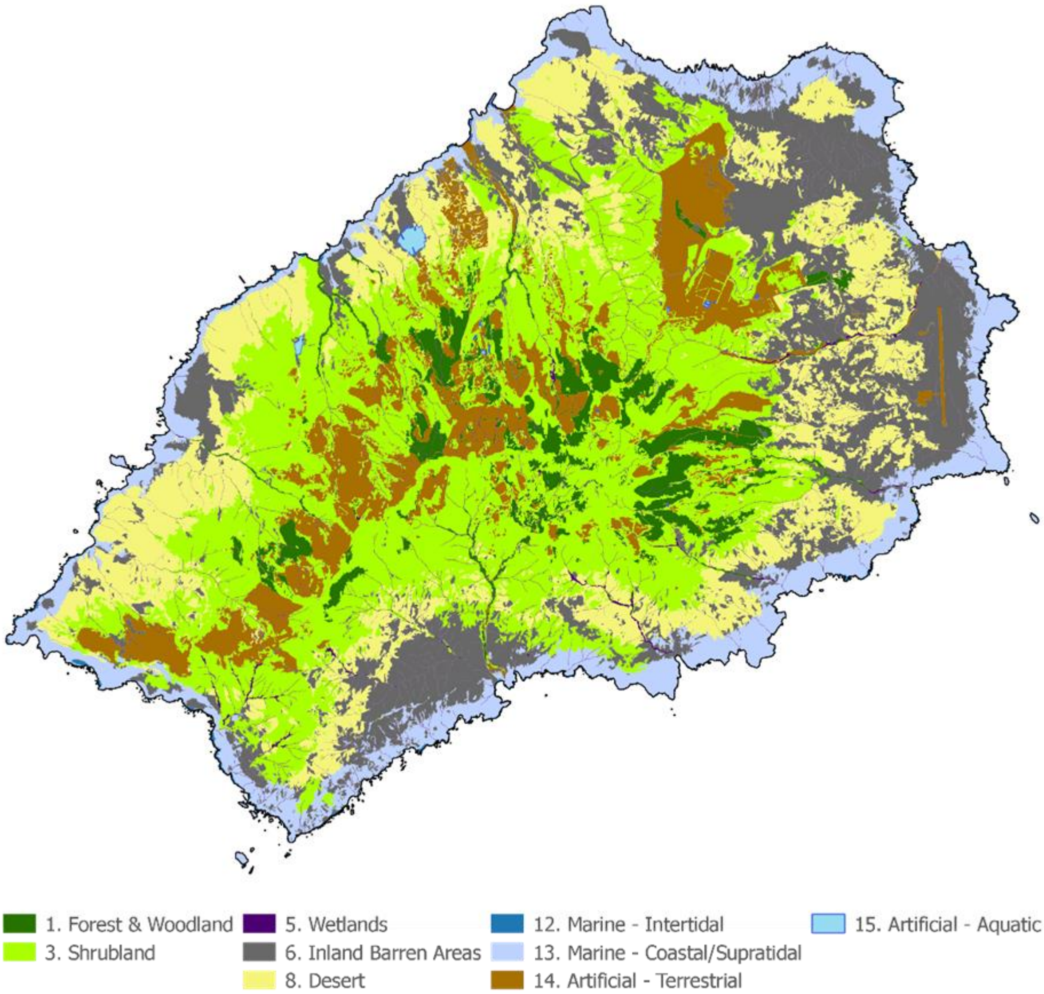


Figure 1.7: IUCN habitat classification, Level 1

Table 1.4: IUCN Level 1 land cover and percentage areas (%)

IUCN Level 1	*Land cover, percent (%)*
1. Forest & Woodland	5
3. Shrubland	33
5. Wetlands	2
6. Inland Barren Areas	19
8. Desert	18
12. Marine - Intertidal	1
13. Marine - Coastal/Supratidal	11
14. Artificial - Terrestrial	12
15. Artificial - Aquatic	0

1.3.2 IUCN level 2 land cover

Level 2 is the field-scale habitat category, splitting the landscape into its constituent parts, such as differentiating pastureland from rural gardens (Figure 1.8). At this level, those field-scale classes that are predominantly natural vegetation cover 38 % of the island, with natural non-vegetated areas occupying 50 % (including those from freshwater, saltwater and artificial habitats (e.g., quarries)). Anthropologically active vegetation habitats cover 11 % with their non-vegetated counterparts just 2 %. On an individual habitat scale, subtropical/tropical dry shrubland has the greatest ground cover at 3681 ha, followed by subtropical/tropical semi-desert (2255 ha), and inland bare ground areas (1650 ha). The map is also available, with colour legends, in Appendix C. A table of the IUCN2 habitats and their percentage land cover are available in Appendix E.

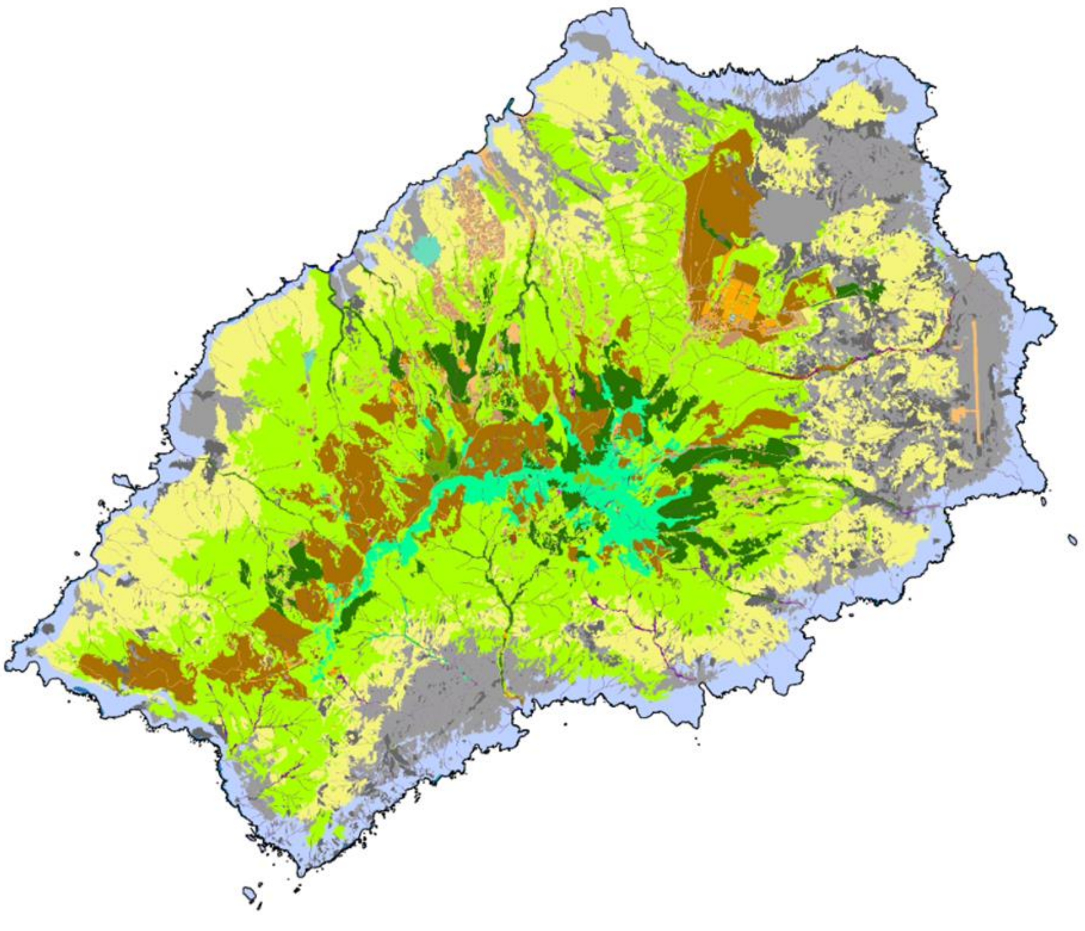


Figure 1.8: IUCN habitat classification, Level 2

1.3.3 IUCN level 3 land cover

Level 3 is the feature-scale habitat category, splitting the field-scale into its predominantly homogenous and abundant habitats; such as pine woodland from wild mango within a subtropical/tropical dry forest context (Figure 1.9). On an individual habitat scale, dense shrub mixture has the greatest ground cover at 2329 ha, followed by barren soil (1514 ha), and introduced low shrub semi-desert (1501 ha). The data suggests that flax occupies 2.48 % of the land cover area. The map is also available, with colour legends, in Appendix C. A table of the IUCN Level 3 habitats and their percentage land cover are available in Appendix E.

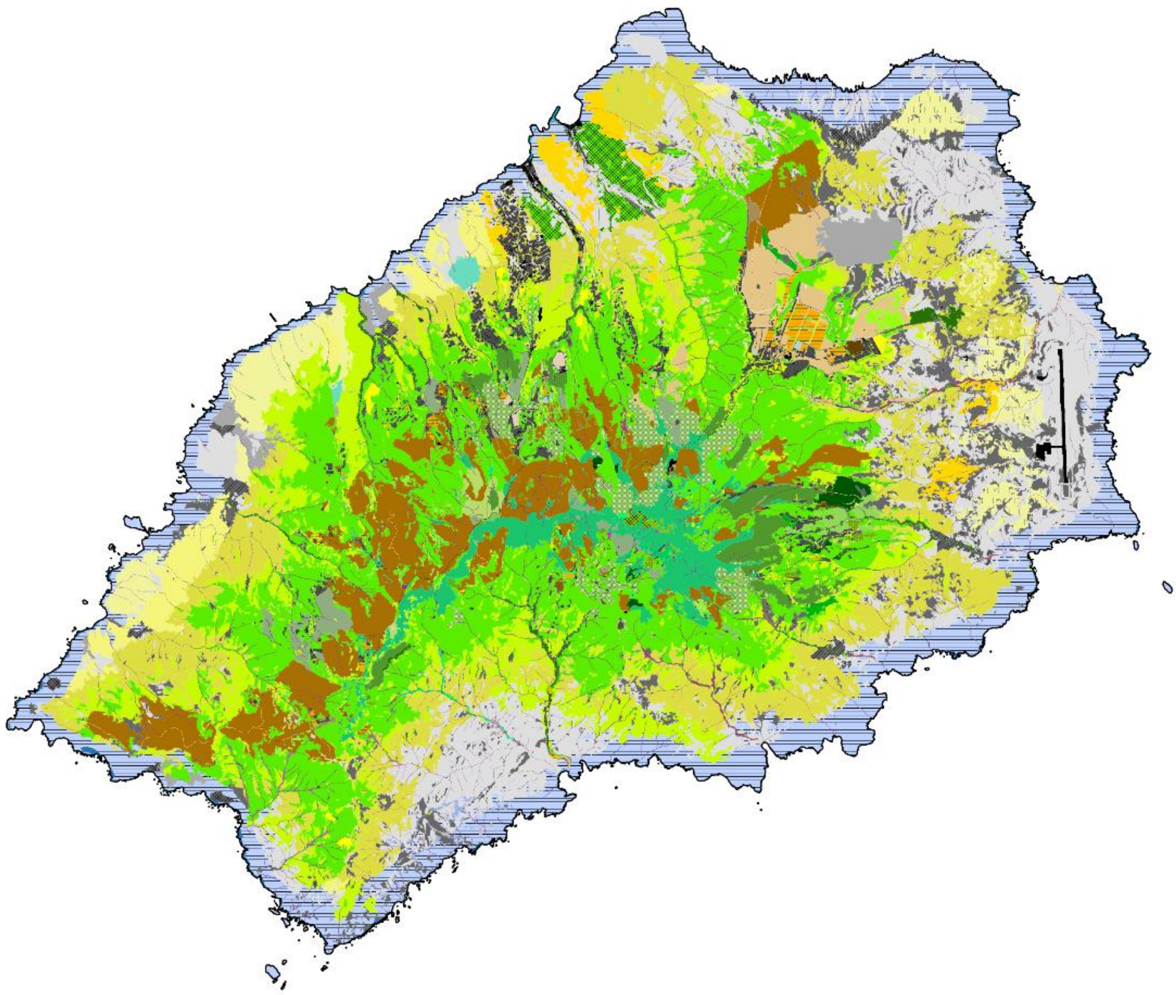


Figure 1.9: IUCN habitat classification, Level 3

2 St Helena soil data

2.1 Introduction

2.1.1 Why it is important to understand the spatial distribution of the islands soil

Soils provide a range of ecosystems services supporting production, carbon (C) storage, water regulation and biodiversity (below and above-ground). Production by plants for food and fibre has traditionally been seen as the primary provisioning service of soils. Although productive species vary in their requirements, in general they require from soil adequate supplies of nutrients and water, and avoidance of deleterious conditions for any prolonged length of time. Active management of soils aims to optimise these conditions for plants grown. More recently, an awareness of the broader range of ecosystem services provided by soils has arisen.

One such ecosystem regulation service provided by soils is the storage of carbon in soil organic matter (SOM), increasingly important with the rise of atmospheric carbon based greenhouse gases and associated climate change impacts. It is little appreciated that the amount of carbon globally in soils is more than three times that in the atmosphere. Soil carbon can be a source of carbon to the atmosphere or a sink. Whether or not a particular soil is a sink or a source depends on management. For example, conversion of land from permanent grassland or woodland to agriculture has turned soils from sinks to sources of carbon. Climate change itself, through altered soil temperature and moisture regimes, can perturb the balance between losses and gains. Soil organic matter also participates directly in nutrient cycling and soil stabilisation, underpinning production services.

Water infiltration into soils, its retention and amelioration, provide an ecosystem regulation service that a soil can provide and one that is influenced by the level of SOM. SOM improves soil structure increasing both infiltration and retention of moisture. The incorporation and retention of water into the soil profile reduces runoff and erosion during severe rainfall events, but also replenishes reserves of plant available water. The frequency of intense rainfall and of droughts is likely to increase with global warming. Soils also control to a large extent the chemical properties of water resources and loss of soil into watercourses.

Soils have a role in supporting biodiversity services. Variation in soil physiochemical characteristics is a major driver of below- and above-ground biodiversity. These characteristics are often closely linked to soil biota which in turn interact with roots and above-ground plant communities. Where soils are subject to erosion, this can lead to their sedimentation impacting across freshwater and marine ecosystems.

2.1.2 Aims and objectives

The soil research on St Helena aimed to:

- estimate current carbon stocks;
- to classify soils according to rainfall acceptance and water retention capacity;
- to identify soils particularly susceptible to erosion;
- to provide an initial assessment of the potential for habitat restoration

Outputs are soil maps giving classes for ecosystem service characteristics such as:

- current carbon stocks;

- rainfall acceptance & moisture retention capacity;
- susceptibility to erosion;

Generation of a robust habitat restoration map, taking account of important soil biodiversity parameters, will require further research beyond the scope of this project but some initial investigations were undertaken.

During the soil and habitat work on the island, the gumwood plantations were particularly noted as having a possibility of having interesting soil/vegetation relations. This became a further piece of work which will be reported on separately as a scientific publication.

Research on Ascension Island was aimed primarily at producing baseline data for soil conditions on the island, though it shared many of the soil analyses undertaken on St Helena.

2.1.3 Approaches to soil mapping

The current soil map for St Helena dating from 1979 was evaluated as the basis for prediction of environmental services using the latest DEM, habitat maps, satellite imagery and relevant existing data, with ground-truthing against samples collected and analysed. Soil sampling points were located with the aim of characterising important soil type-habitat combinations (from the existing soil map and the updated habitat map).

For most locations, samples were taken to 30 cm depth with cores split into 0 cm - 15 cm and 15 cm - 30 cm sections, and up to four cores were taken per location. Surface samples were assessed for stability and texture. In the main survey 130 sampling points were located; a further sampling included 45 sampling locations targeted on native and restored gumwood sites and areas revisited to confirm preliminary soil carbon results.

The first 130 samples were prepared on St Helena (wet weight, air drying to reduce weight for shipment and calculation of moisture content by oven drying a subsample at 100 ^{o}C) prior to shipment to Aberystwyth University (subject to export permits and under UK import licence 50791/261040/0) where further measurements were made. An additional 45 samples were weighed and carried.

Map generation was undertaken in collaboration with Environment Systems based on appropriate classification of soil and remote sensing data, taking account of habitat classifications and broader environmental factors.

2.2 Data collection

This section describes the soil parameters measured, how they relate to environmental services, and practical details of the procedure followed. Common soil analytical procedures were followed for samples from St Helena (and Ascension Island), though for the latter a wider range of analyses was undertaken.

2.2.1 Soil pH - production, water regulation and biodiversity services.

Soil pH varies normally between 4.0 pH and 8.0 pH due to various mechanisms buffering against extremes. Productive agricultural soils lie or are managed in the pH range 5.5 pH to 7.5 pH. In acid soils microbial activity is reduced and mainly fungal driven; important invertebrates such as earthworms are scarce. The other major impact of soil acidity is on the solubility/plant availability of major and trace nutrients. Acid soils have limited mineral nitrogen (N) (mainly as ammonium, NH_4^+), have a high capacity to adsorb phosphates, have elevated concentrations of potentially toxic metals (especially aluminium) and deficient concentrations of some trace nutrients (e.g., molybdenum and to a lesser extent boron and copper). High organic contents tend to mitigate some of these toxicities/deficiencies although copper deficiency is enhanced in organic soils. Extremes of pH lead to diverse, specialised plant communities adapted to the resulting physiochemical conditions.

Critical pH values vary for different elements. Usually, problems begin to emerge when pH falls below 5.5 pH - 5.0 pH and becomes critical when pH falls below 4.5 pH. Increased aluminium availability (from around 5.0 pH to 4.5 pH), rather than pH per se, is the usual limiting factor in acid soils. In some grazing systems on acid soils animal licks are provided to supplement nutrition for deficient trace nutrients.

For pH, 25 ml of distilled water was added to 5.0 g of 4.0 mm sieved soil in a 50 ml tube and shaken for one hour. After shaking the solution was allowed to settle for a further one hour, before the solution pH was measured using a Hach H170 portable pH meter fitted with a stainless steel probe.

2.2.2 Soil salinity - production, water regulation and biodiversity services.

Salinity in soils arises primarily where evapotranspiration exceeds rainfall leading to the surface accumulation of salts. The problem is exacerbated where there is a salt–rich groundwater close to the soil surface and though inappropriate irrigation practices.

Soil electrical conductivity (Ec) is a proxy measurement for salinity. Various units are used for Ec; here values were expressed in µS/cm. Saline soils are classified according to impacts on agricultural crops, with thresholds that are somewhat arbitrary. Values < 2000 µS/cm are considered to present no limitations, values 2000 µS/cm – 4000 µS/cm may limit growth of susceptible crops, values 4000 µS/cm – 8000 µS/cm would limit growth of most crops and values > 8000 µS/cm would begin to select for halophyte species. Higher values are important indictors of actual or potential saline habitats and associated species.

Electrical conductivity was measured on the same solution as pH using an Omega CDH-SD1 conductivity meter. Readings were multiplied by 6.4 to determine the conductivity of the saturation extract from that of the 1:5 extract (Rodwell, 1994).

For soils with a conductivity > 2000 µS/cm anion (F^-, Cl^-, NO^{3-}, PO_4^{3-}, SO_4^{2-}) and cation (Na^+, NH_4^+, Mg^{2+}, Ca^{2+}, K^+) concentrations were measured. The water extract was centrifuged for 5.0 min at 4000 g and the supernatant analysed by ion exchange chromatography (Metrohm - Metrosep A sup 5 anion column, Metrosep C4 cation column).

2.2.3 Soil carbon:nitrogen ratio - production, C sequestration and biodiversity services

Carbon and nitrogen ratios in soils usually vary between 10 and 20. High ratios normally indicate impaired decomposition which may arise where soils are very wet or acidic. Higher ratios can also occur where inputs of plant residues are nutrient poor or consist of high proportions of structural C components such as lignin.

Total N and C were measured on an Elementar Macro Cube analyser (High temperature combustion linked to C and N oxide detection). Approximately 0.2 g of dried soil was weighed into a steel crucible and analysed following the manufacturer's instructions.

2.2.4 Soil organic matter concentration and stock - production, water regulation, biodiversity and C sequestration services

Soil organic matter plays a crucial role in supporting soil organisms, storing and cycling nutrients, and stabilising the soil against particle dispersion and surface capping. Soils are also a major store of C such that gains in C represent a global sink whilst losses cause soils to become a significant global source for atmospheric CO_2 enrichment. Soil C exists as a balance between inputs (mainly plant derived) and losses (mainly microbially driven decomposition), both processes affected by land use change.

Thresholds for concentrations (%) of soil organic C are somewhat arbitrary, varying with soil type and climate, and inappropriate for organic C stocks. Soils with less than 1 % - 2 % organic C are often considered to have insufficient C to support some of the functions described herein. Where soils have very high % organic C, for example more than 12 % - 15 % organic C this often indicates impaired decomposition and therefore cycling of nutrients; these high organic soils are important C stores vulnerable to C loss if disturbed.

Carbon stocks were calculated from the C % and the bulk density of the fine earth fraction (< 2 mm) of the soil, as an average of the four cores taken in the field. These values were then converted to MgC/ha for the volume of the cores and adjusted for stone contents

2.2.5 Soil stability – soil conservation and water regulation services

Unstable soils are liable to form a cap, promoting surface runoff and enhancing water erosion risk. Provided a good vegetation cover is maintained this erosion risk is likely to be potential rather than actual. However, if the vegetation is disturbed or removed, unstable soils are at severe erosion risk. Assigning any threshold system to stability is necessarily arbitrary and would vary in practice with soil texture (e.g., high silt/fine sand soils are particularly susceptible). For the purpose of the soil characterisation on St Helena, values < 20 % are considered very unstable (broadly consistent with field observations of erosion features at sampling locations) and soils with stability > 70 % are classed as very stable (again consistent with field observations). Intermediate category thresholds are arbitrary.

Stability was measured using 10 g of soil aggregates between 2 mm - 4 mm. The aggregates were placed on a 2 mm sieve on a soil shaker and disrupted for a period of 5 min with a continuous water flow (7 l/min). The aggregates remaining on the sieve were dried and weighed to calculate stability.

2.2.6 Soil texture – production, biodiversity and water regulation services.

Soil texture is a fundamental property derived from the relative proportions of fine earth represented by sand, silt and clay. It is often represented by plotting soils on a triangle of texture (see Figure 2.1). Texture characteristics determine, directly and indirectly, a range of ecosystem supporting services. Sand dominated soils are nutrient poor, non-cohesive, drain easily but are drought prone. Silt dominated soils have characteristics much like sands but can retain more water and drain more slowly. Clay soils have greater mineral nutrients, the capacity to retain cation nutrients, are cohesive so can be difficult to manage and display swell/shrink characteristics (especially vertisols). Soils with more than around 70 % sand tend to behave as sands; soils with more than around 80 % silt behave like silts; soils with more than 35 % - 40 % clay tend to behave as clays. Intermediate (loam) soils behave as mixtures in which particles interpack; they usually need well developed structure to drain easily though their properties are influenced somewhat by those of the more dominant particle size. Soil texture classes are given in Figure 2.1.

For texture 20 g of < 2 mm soil was used. Organic matter was removed using 200 ml 20 % peroxide overnight. 20 ml of 10 % sodium hexametaphosphate were added to deflocculate clays and the sample was shaken for 2.0 h to disperse aggregates. The dispersed soils were sieved to 53 µm to remove the sand fraction, which was dried and weighed. The remaining silt and clay were then separated in a 1 l measuring cylinder. Sampling was linked to particle sedimentation times. The dried clay and silt fractions were weighed and the texture percentages calculated.

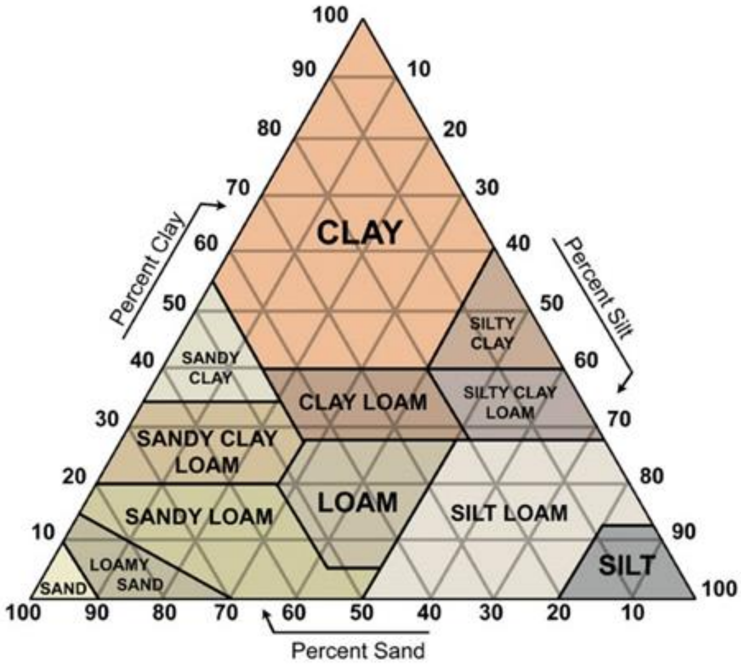


Figure 2.1: Soil texture triangle and classes

2.2.7 Water acceptance/unsaturated hydraulic conductivity – production and water regulation services

The method adopted does not measure saturated conductivity or infiltration as it does not account for water flow through larger (mainly non-capillary) pore networks such as soil cracks or root channels. It does therefore indicate relative differences in the capacity of soils to absorb water during the early stages of soil wetting (e.g., during short periods of heavier rain or longer periods of less intense rainfall) rather than what occurs during prolonged, intensive rainfall that might saturate the soil and generate significant surface runoff; as such it is probably more an indicator of water retention than an indicator of large scale hydrological impacts. It relates to soil texture and micro-aggregation only. The thresholds set for this parameter are again somewhat arbitrary. For agricultural soils in temperate regions values less than 50 would be regarded as low.

Unsaturated hydraulic conductivity was measured in the field using a Mini Disk Infiltrometer (Decagon Devices Inc). Following the infiltration of water over 5 min under tension (at a pressure head of -2 cm). Conductivity was then calculated, using the manufacturer supplied Excel spreadsheet based on the calculations of Zhang (1997).

2.2.8 Training and workshops

Several St Helena Government and National Trust staff were trained and assisted in the soil survey and in soil sampling techniques. A series of stakeholder workshops were held on St Helena during the second visit there aimed mainly at explaining the utility of the resource created.

2.3 Results

2.3.1 Existing soil data and map

Existing paper based soil data were collated and saved onto an excel file to facilitate future referencing. Georeferenced baseline data have also been saved in electronic format.

The existing soil map was evaluated as to its use in distinguishing soil parameters of relevance to ecosystem services. Data were collated according to soil type and map location; some examples are given to illustrate the values of the soil map. Data for soil pH are presented Figure 2.2. Whilst some of the soil types mapped (e.g., fluvisols) distinguish pH classes, for many types there are no significant differences. Mean Ec values for soils expected to be saline (fluvisols and xerosols) were distinguished but the variability within these soil types was extreme. In general, the existing soil map had limited value as a predictor of variations in the properties measured.

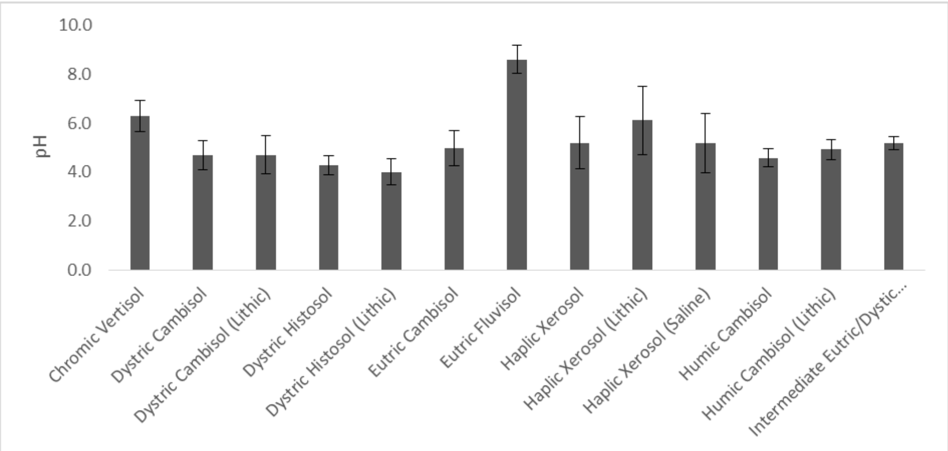


Figure 2.2: Variations in soil pH according to mapped soil units (error bars - standard deviation provide an indication of variability in the property measured).

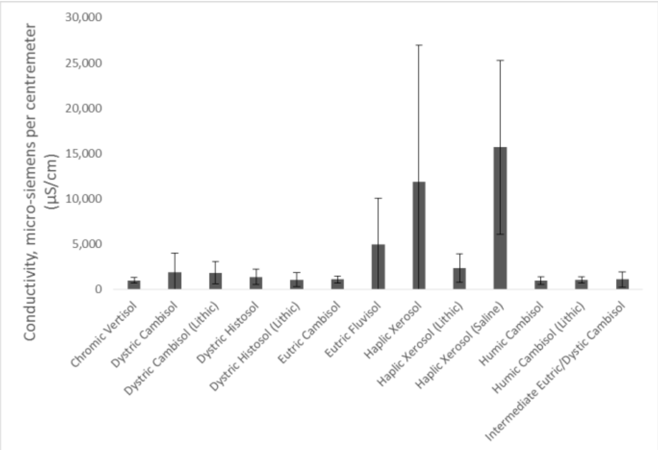


Figure 2.3: Variations in soil electrical conductivity (µS/cm) according to mapped soil units

2.3.2 Proportion of soils in ecosystem service classes

Around two thirds of the samples had intermediate soil C concentrations and stocks. A significant number had concentrations likely to limit soil function whilst a slightly smaller proportion were classed as high organic matter soils (Table 2.1)

Table 2.1: Soil % carbon and C stock classes and their frequency of occurrence

C %		Frequency %	MgC/ha	Frequency %
< 2	Deficient	16.9 %	< 30	16.5
2 - 5	Mineral	38.5 %	30 - 60	46.5
5 - 10	Humose	32.3 %	60 - 90	28.3
> 10	Organic	12.3 %	> 90	8.7

The majority of soils fell within the expected range of C:N ratios with some of the high organic matter soils having high (poor organic quality) ratios (Table 2.2).

Table 2.2: Carbon-nitrogen ratio classes and their frequency of occurrence

C:N		Frequency %
<10	Low	3.1
10-20	Normal	83.1
> 20	High	13.8

Around a third of the soils were extremely acidic with values likely to limit the growth of species without specific adaptations to these conditions. A further third had levels of acidity likely to limit production of most agricultural crops (Table 2.3).

Table 2.3: Soil pH classes and their frequency of occurrence

pH		Frequency %
< 4.5	Very acid	32.3
4.5 - 5.5	Acid	36.9
5.5 - 7.5	Productive	23.8
> 7.5	Alkaline	6.9

Over three quarters of the soils had Ec values unlikely to significantly affect plant growth. There were 17 locations however with very high salinity (Table 2.4).

Table 2.4: Soil electrical conductivity (Ec) classes and their frequency of occurrence

Conductivity (µS/cm)		Frequency %
< 2000	No limit on crops	63.8
2000 - 4000	Limit for susceptible crops	14.6
4000-8000	Limiting for most crops	8.5
> 8000	Halophyte species only	13.1

Some two thirds of the samples measured were classed as clays or variations of the textural class. Clay-rich soils covered most of the well vegetated and some poorly vegetated soils (

Table 2.5).

Table 2.5: Soil textural classes and their frequency of occurrence

Texture class	*Frequency %*
Loam	7.9
Clay	58.7
Clay loam	3.2
Loamy sand	4.8
Sandy clay loam	1.6
Sandy loam	4.8
Silt clay loam	6.3
Silty clay	12.7

Around three quarters of samples were classes as stable of highly stable, with only a small number highly unstable (Table 2.6). Soils with moderate stability are likely vulnerable to water erosion should they lose vegetation cover.

Table 2.6: Soil stability classes and their frequency of occurrence

Stability %		*Frequency %*
< 20 %	Unstable	6.5
20 - 40 %	Moderate stability	17.4
40 - 70 %	Stable	39.1
> 70 %	Very stable	37.0

The thresholds set for unsaturated hydraulic conductivity are again somewhat arbitrary. For agricultural soils in temperate regions values less than 50 obtained by this procedure are regarded as having low conductivity (Table 7). On this basis, very few soils had a high capacity to intake water during wetting, probably reflecting the dominance of clay textures.

Table 2.7: Unsaturated hydraulic conductivity - classes and their frequency of occurrence

Hydraulic conductivity mm/h		*Frequency %*
< 5	Very low HC	41.1
5 - 25	Low HC	46.7
25 - 50	Moderate HC	6.7
> 50	High HC	5.6

3 St Helena soil mapping

To investigate the spatial distribution of the soil characteristics collected in Section 1, the individual field observations must be mapped across the whole of the island. This involves a process that extracts values of a sampled variable (i.e. the soil data), and predicts the spatial distribution of those points, based on the values of an environmental dataset (e.g., elevation, habitat, rainfall etc.); a process referred to as spatial interpolation, and completely relies on physical measurements and semi-automated algorithms (Hengl, 2007).

Increasingly, natural resources and soil properties need to be regularly updated or improved upon, and usually with increased pressures in funding. This technique of spatial interpolation allows analysts to rapidly create digital datasets, which can be stand alone or fed into other models, based on a relatively small number of survey field observations.

The modelling of the soil sample points into a continuous spatial dataset required several, separate processes; each assessing the relationship between the soil sample data (e.g., the soil pH value) and an appropriate environmental factor that may influence that soil characteristic (e.g., elevation, habitat, vegetation productivity etc.), then modelling one value onto the other similar to a linear regression.

These processes included principle components analysis, semivariance and spatial kriging; all are briefly described in this section.

It is important to note that all the modelling and outputs were performed from the soil data extracted from the top 15 cm of the soil profile.

3.1 Principal component analysis

It is first integral to understand the relationships between the soil characteristic that is to be modelled (the variable), and the environmental dataset that will be used to interpolate those characterises (the predictor). Principal component analysis (PCA) was used to assess the relationship between the environmental variable and the soil characteristics. An example of this initial analysis, shown below as a biplot (Figure 3.1), illustrates the relationship between the main soil characteristics and the environmental predictors as arrows; where the length represents the variability, and the angle between the arrows represents the correlation (Reimann et al., 2009), so that arrows in the same direction indicate a positive correlation whilst those that are opposite indicate a negative correlation.

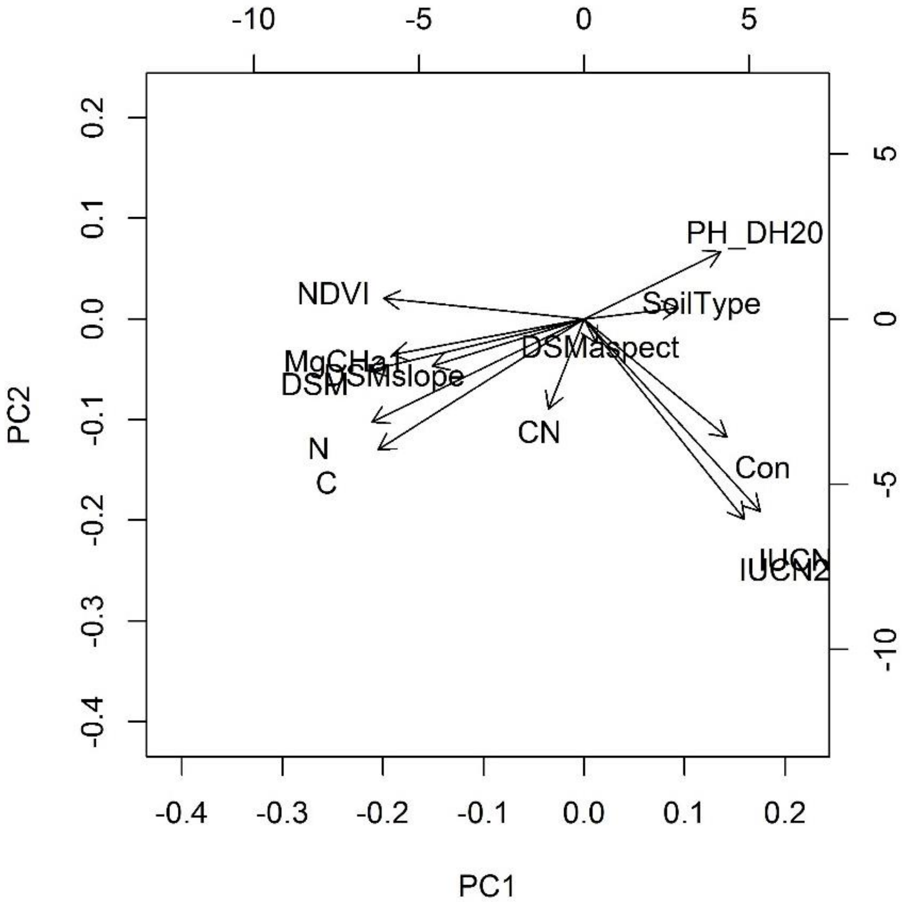


Figure 3.1: PCA for the main soil variables (pH, soil type, Ec, C:N, C, N, and Mg C Ha $^{-1}$) and the environmental variables (Elevation, aspect, slope, NDVI, and habitat (levels 1 and 2)).

Once a suitable pair of soil variable/environmental predictor is selected from the PCA, they were tested for their statistically significance using a Pearson's correlation. Those variable/predictor p-values of ≤ 0.05 were considered significant.

3.2 Autocorrelation

A semivariogram was produced for each soil variable/environmental predictor that had a statistically significance relationship, and a relatively strong PCA correlation. These graphs identify the spatial autocorrelation of measured sampled points, with distance plotted on the x-axis, and the variance plotted on the y-axis.

The distance (x-axis) at which the slope levels to a horizontal line indicates the distance from the sample points at which autocorrelation cannot be achieved. This distance is called the range. If the data is poor or there are not enough samples, then this range can be shorter.

Similarly, the distance between the minimum and maximum semivariance values (y-axis) indicate the accuracy of the autocorrelation; with greater differences representing more accurate autocorrelations.

An example of the semivariance between pH and elevation is given in Figure 3.2. In this example, there is a relatively long range until the model is flattened, approximately at 3,500 m. Within this distance from a sample point, the environmental variable show an autocorrelation with the soil variable. The graph also shows a relatively high difference in semivariance minimum and maximum values (i.e. the model has a steep incline), illustrating a relatively high accuracy in the autocorrelation.

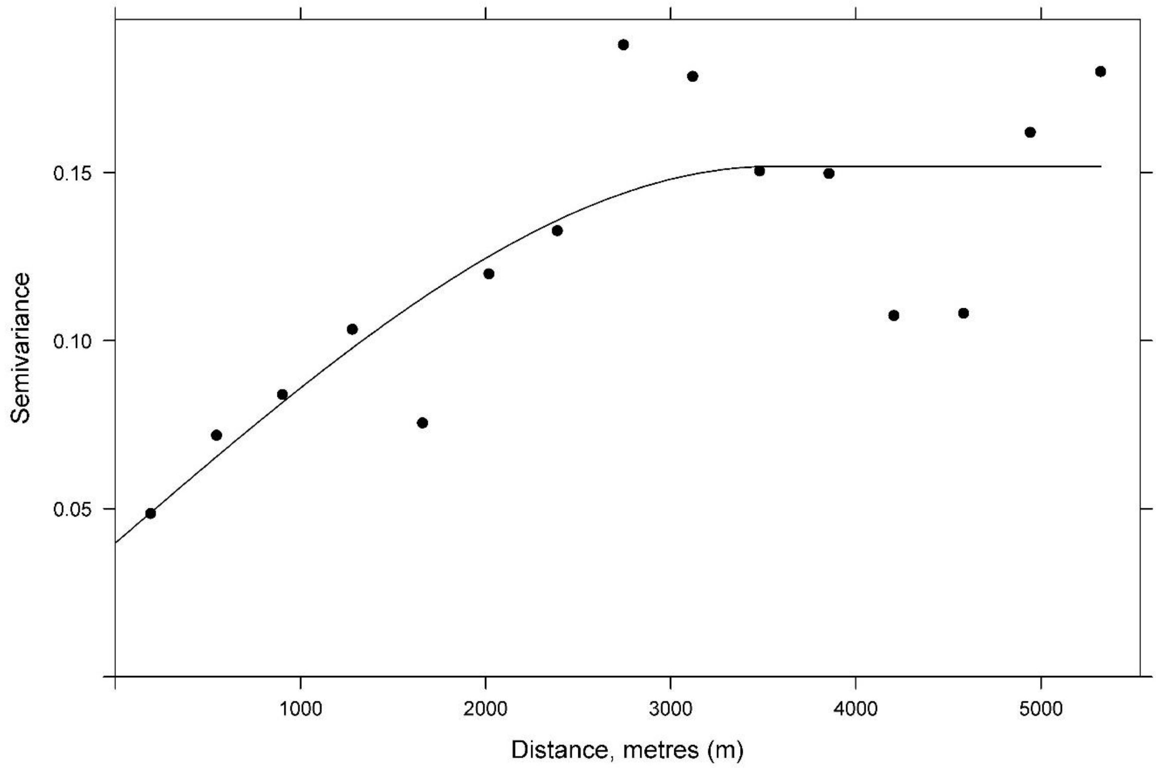


Figure 3.2: A semivariogram for pH values and elevation heights

All semivariogram outputs were visually assessed for distance range and steepness of the semivariance values. When the model demonstrated the relationship held over several thousand meters distances and there was no significant autocorrelation, the parameters were used in the spatial interpolation of the soil variable, using the appropriate environmental predictor.

3.3 Spatial interpolation

Kriging is a widely used method of spatial interpolation, and can estimate what a sample value would be (e.g., a soil characteristic such as pH), based on the environmental predictor value (e.g., elevation), from which a suitable variogram model is known.

All the output models were compared to the input spatial soil characteristics; assessing the difference between the two (the z-score). If two or more environmental predictors significantly correlated with the soil variable, and showed strong semivariance attributes, both versions would be mapped. The model had the most frequent occurrence of lowest z-score values, was the model output identified as the most accurate.

The selected outputs were visually assed by soil scientists from Aberystwyth University, to critically evaluate the accuracy, based on their knowledge and understanding of soils, and their experiences on St Helena. If an output did not pass these visual assessments, a different statistically correlated environmental predictor was selected, and then similarly evaluated. The final outputs, were then reclassed into categorical datasets, using suitable thresholds identified by the soil scientists.

The majority of the outputs were found to significantly correlate, have better semivariance models, and output z-scores, with elevation. However, MgC/ha required NDVI due to anomalous values at *The Barn*; where it was expected to have lower MgC/ha values from the sparse vegetation when compared to other areas at similar elevations. Any areas that were covered in cloud from the NDVI, were supplemented with the modelled output from the DEM.

An example output, of soil pH, is charcterised in Figure 3.3. This dataset was created using soil pH values from the soil sample data, interpolated using elevation values from the DEM. It shows that pH is lowest (i.e. acidic) where there are higher elevations.

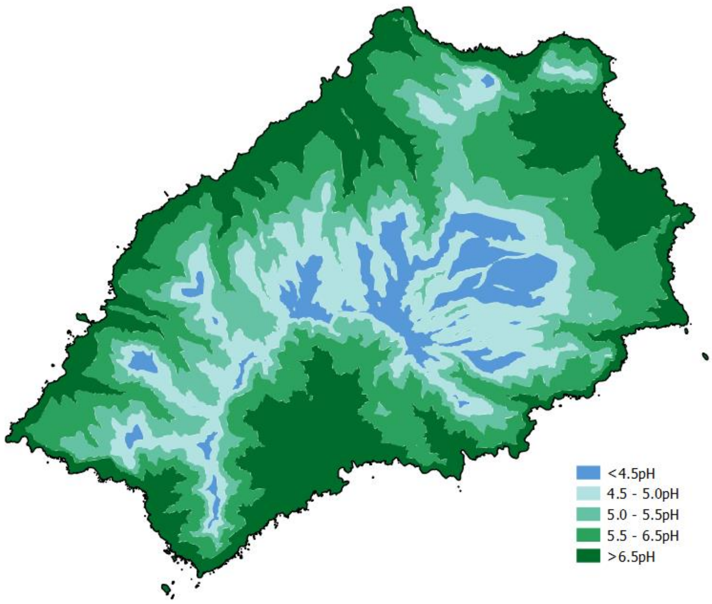


Figure 3.3: Example soil character dataset of pH values, based on the DEM

One of the issues of using an interpolation is that where there are a-typical areas the interpolation is likely to be inaccurate. For these models the area called 'The Barn', to the NE of the island, is such an untypical area and the soil parameter will need to be manuallly checked in future work to understand how they fall into this model.

Figure 3.4 illustrates the spatial autocorrelation from the semivariance of mapping soil pH values with the DEM (Figure 3.2); where the semi-transparent area represents the distance at which point the semivariance begins to curve to the horizontal (i.e. a reduction in autocorrelation), and where the curve is horizontal (i.e., has no autocorrelation). The area of reduced autocorrelation exists over '*The Barn*'.

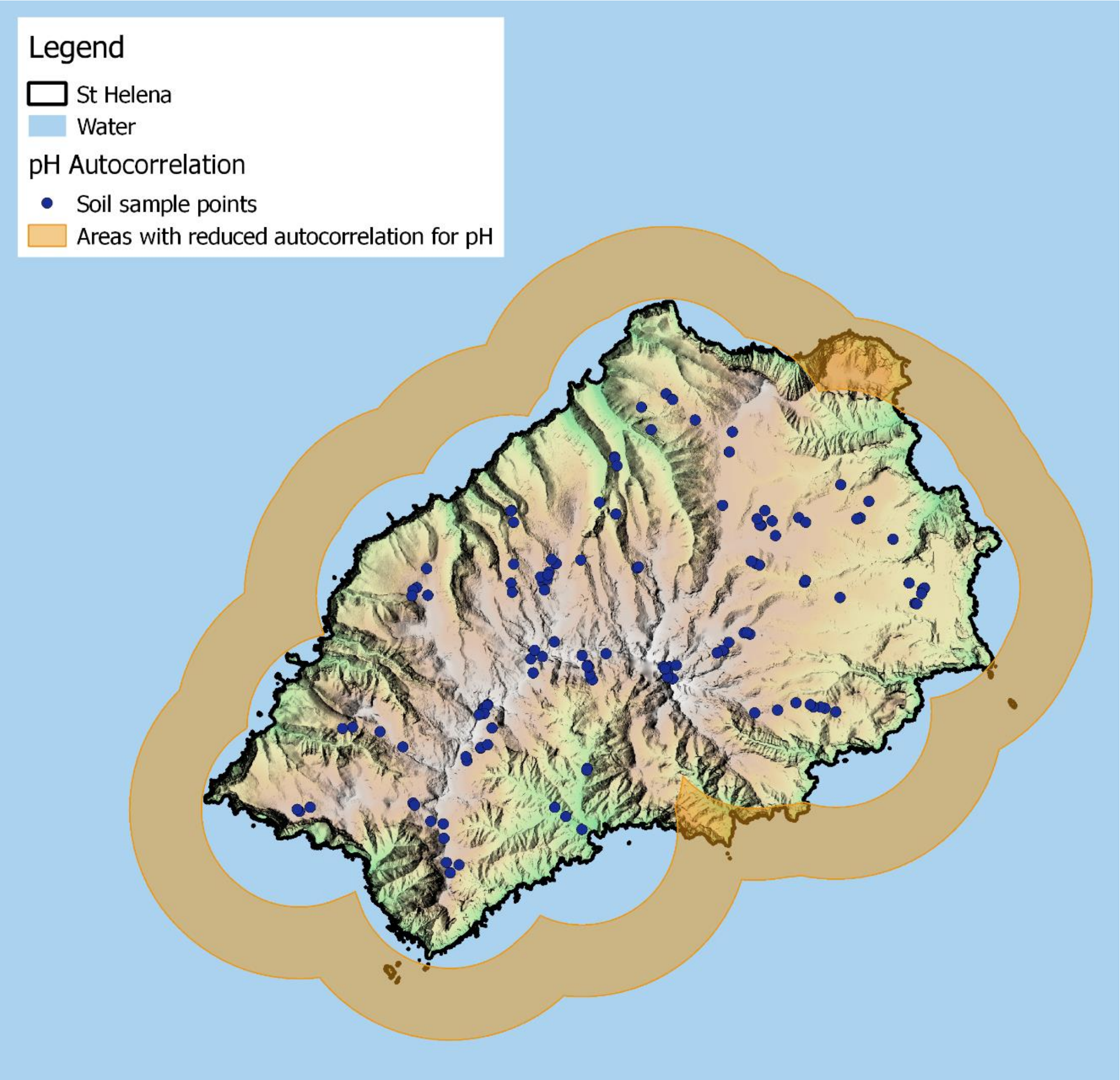


Figure 3.4: Areas of reduced autocorrelation for pH and DEM semi-variance

All the output soil characteristic models are presented in Appendix F.

4 Using the data for ecosystem service analysis

The ecosystem approach focusses on how ecosystems function and which services they provide to people. It considers the effect of any land management decision on the economy, environmental and culture in a holistic way. Providing information to involve the people affected by the management decisions into the decision-making process.

Often, the services provided by ecosystems are un-recognised, as they are less immediate in their impact than factors with more direct impact upon human wellbeing, such as lack of housing; they are often only really noticed when they fail to function properly. For example, the natural flood mitigation qualities of the land are often only recognised after a series of large storm events and subsequent damage to property. The reason for producing these maps and ecosystem information is to provide a means to help identify where land is contributing to a range of services and where there might be competing or conflicting uses of land. That way, informed decisions can be made regarding land use and development.

The SENCE (Spatial Evidence for Natural Capital Evaluation) approach developed by Environment Systems was used to consider some key ecosystem services of importance to St Helena. It shows the contribution of each area of land to the services under consideration.

The assessment takes a pragmatic approach to the mapping and modelling of ecosystem services which can be used to inform policy decisions at national, regional and local levels. It is possible, using existing data, to grade the importance of any area of land into a simple categorisation of high, medium and low effect.

The scientific rule base assessment is based on consideration of key factors which interact together in different ways for each parcel of land for each service under consideration. The key factors are:

- land cover / habitat (e.g., grassland, woodland or heathland)
- soil and geology, the substrate beneath the site
- landform that is location of the land area in the landscape (e.g., valley bottom, steep slope, proximity to water or urban areas)
- water movement through the land area
- management of the land area

These key factors are weighted according to how favourable they are for the generation of each of the services and then combined in a GIS technique called overlay analysis (Figure 4.1). For example, broadleaved woodland has a strong role in the regulation of water run-off. The trees and understory contain many layers of vegetation which help slow the velocity of rainfall so it is more likely to be absorbed into the land rather than bounce and run over the surface. The deep roots provide a channel for water flow into the soil and also a water cleansing function. Consequently, both the 'land cover' and 'underground' key factors score highly. However, steeply sloping land promotes overland flow and is not good for natural control of flood mitigation and water storage –the key factor 'landform' would thus be scored low. In combination, the area would have a medium to high rank for its contribution flood mitigation control. Where a feature has a negative effect, for example a sealed tarmac surface speeding water flow up, this will be given a negative score. When combined with the scores assigned to the other layers, this negative score will appropriately reduce the overall value.

Looking at the opportunities to enhance ecosystem services and to identify the best place for action may also help contribute to the delivery of other policy and regulatory objectives and targets

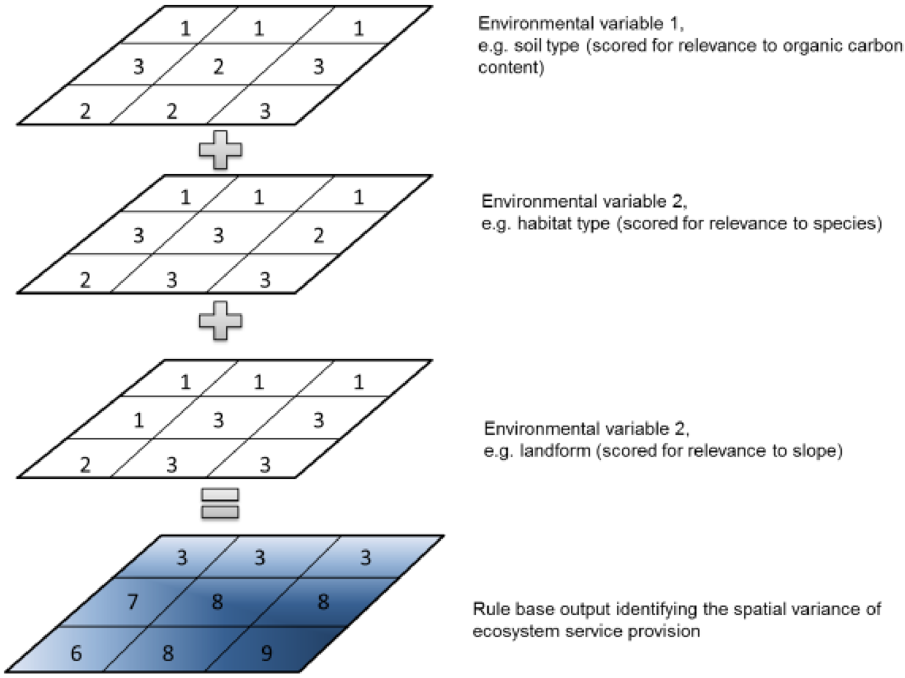


Figure 4.1: Overlay analysis

Existing scientific understanding and knowledge about how the four key factors interact was used to build spatially explicit ecosystem service map, shown in Table 4.1.

Ecosystem Service enhancement or ***opportunity maps*** show where it is possible to enhance ecosystem services and therefore identify the best place for land management action to take place. The rules to establish where these places are taken from restoration ecological principles in the same pragmatic way as for the stock maps. Opportunity maps: highlight areas where actions can be undertaken to enhance the environment; these could be used to target **mitigation** measures to the best effect.

During the workshop on island in March 2018 list of ecosystem services important to the island that could be mapped were disused. A vote was held to decide on those which had most significance to the island at this time. A practical decision based on the time left within the project and the number of votes for each service, was then made to determine which services to map (Table 4.1).

Table 4.1: Ecosystem services important to St Helena

Ecosystem service	*Number of votes*	*Map creation*
Biodiversity	13	Map created
Biodiversity (ecological networks)	13	Map possible with additional time
Food provision	12	Soil quality and food provision map created
Water quality (sediment)	4	Map possible with additional time
Water quality (nutrient)	4	Map possible with additional time
Flat ground availability	4	Map created
Flat land visible form the sea	4	Map created
Erosion risk management	3	Map created

Ecosystem service	*Number of votes*	*Map creation*
Renewable wind energy	2	Map possible with additional time
Climate regulation – soil carbon	2	Map created
Solar energy space	2	Map created to show land possible (flat land for development). A final stage of considering radiance would be needed to show this opportunity map
Pollination	0	Map possible with additional time
Natural flood management	0	Map possible with additional time
Potable water availability - surface	0	Map possible with additional time
Potable water availability - ground	0	Map possible with additional time
Climate regulation – vegetation carbon	0	Map possible with additional time
Green infrastructure	0	Map possible with additional time
Blue (water) infrastructure	0	Map possible with additional time
Open and recreational spaces	0	Map possible with additional time
Sense of place	0	Map possible with additional time
Timber provision	0	Map possible with additional time
Tourism	0	Map possible with additional time
Recreation	0	Map possible with additional time

4.1 Biodiversity

St Helena has one of the most unique biodiversity's in the world with a very large number of endemic species. Biodiversity is both inherently valuable and underpins a wide range of ecosystem services. The map in Figure 4.2: shows where these native habitats occur. These areas must be protected to maintain the islands unique biodiversity. It is a generalised map showing which areas of St Helena contain predominantly native or introduced vegetation, and also highlights which of these areas have mostly been planted or spread by natural means, which is one of many proxies for biodiversity value.

Areas of native vegetation that have been planted (shown in pink, and some habitats in yellow areas) are likely the results from conservation projects, whilst natural native areas (in green, and some habitats in yellow areas) are habitats that have either re-established by natural means over a longer time frame, or that have not been modified as of yet.

Planted areas with introduced habitats (in purple, and some habitats in dark blue areas) are most likely agricultural sites, grazing land, or plantations. On the other hand, naturally established areas with introduced vegetation (in light, and some habitats in dark blue areas) can in many cases contain invasive species that are spreading on the island by natural means.

Geological and man-made features are shown separately, as they do not fit within the introduced/native and planted/natural classification. Habitat types that appear in small patches, such as native stands (natural, planted, and natural/planted) are shown with polygon outlines to ensure visibility at the whole island scale. They will, therefore, be slightly smaller on the ground than they appear on this map.

The map is based on the habitat classification created for this project (F2 version). The habitat classification was created using very high-resolution satellite imagery, a digital terrain model, GIS data supplied by St Helena Government, and using local ecological knowledge.

Each individual habitat class at classification level 3 was then scored, based on whether this type of habitat is predominantly native or introduced, and whether it mostly establishes naturally or is planted. The scoring was supported by ecologists with wide-ranging knowledge of St Helena. This map is available in Figure 4.2.

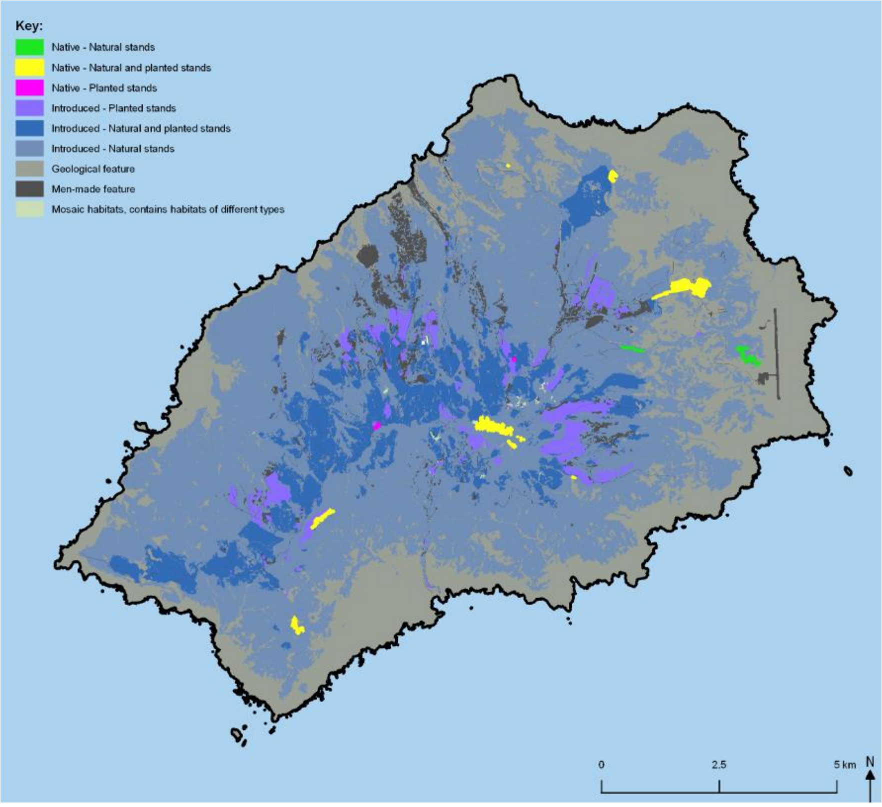


Figure 4.2: Status of habitats as introduced vs native and planted vs naturally established

Data gaps and limitations / possible refinements

The imagery used for the classification was a combination of three different dates and two different years, required to fully classify the island due to cloud-cover, with the most recent image taking priority. Where cloud-cover existed in all three datasets, the habitats were classified by visual interpretation. Due to the extreme variations in elevation, there may be slight discrepancies in the geolocational accuracy of the imagery, and the registration of one image to another.

It is assumed that all data supplied by St Helena Government, used in the classification is correct.

The digital terrain model used in the classification is derived from stereo imagery, which can have reduced accuracies under steep terrain and where cloud had formed at the moment of capture. Areas of the terrain model that were obscured by above ground features at the time of capture, such as buildings and trees, were interpolated from surrounding areas of visible ground, and could have reduced accuracies in these areas.

Next steps would be to consider the landscape statistics relating to the native vegetation and begin to build up an idea of connectivity and genetic resilience in terms of patch size. This was beyond the scope of this project.

4.2 Food provision: soil quality for productivity / agriculture

Food security is a key service for the island of St Helena. Understanding where land might be suitable for agricultural use is key to maintaining this important service into the future and developing it in a resilient way. The map shows the overall capacity of the land to support agriculture, based on consideration of pH, electrical conductivity, percentage content of carbon, and steepness of slope. Soils of overall higher quality are shown in dark green, while soils of lower quality are shown in light brown. Areas that are currently being used that are showing as less suitable for agriculture than some under for example forestry will be showing as less suitable as pH and nutrients will have been leached form the land during agricultural management, whereas under forest cover the soil pH and nutrient load can be enhanced through the input of organic matter in the form of leaf litter. This map is available in Appendix G.

Some land on the island will not be possible to use agriculturally, for example, the airport (shown in black) presents a hard constraint to any type of development; further constraints, such as wirebird conservation areas and native vegetated areas, would need to be considered to build this map into a food production potential layer (Figure 4.3).

The input data for this map were derived from the electrical conductivity, carbon content, pH, and ALC elevation datasets; modelled from survey soil data and environmental variables, such as elevation, through the processes of spatial interpolation.

All three individual measures were then scored with regards to their quality from 0 (least good) to 100 (best), so that in the resulting soil quality map soils scored as 'least good' for all measures have a value of 0, whilst soils scored as best for all measures have a value of 300. For pH, < 5 pH and > 10 pH were considered bad, 5.5 pH - 6.5 pH best, and all other values medium. For conductivity, values of < 2000 µS were scored as good, 2000 µS - 4000 µS as moderate, 4000 µS - 8000 µS as moderately bad, and > 8000 µS as bad. For carbon, < 2.5 % was scored as bad, 5 % - 10 % as good, and all else as medium. All slopes < 11° were considered good, > 18° bad, and the remainder medium. This map is available in Appendix G.

Data gaps and limitations / possible refinements

The input soil data is derived from the interpolation and modelling of soil survey data onto an environmental variable, in this case the terrain model.

The input terrain model is derived from stereo imagery, which can have reduced accuracies under steep terrain, and where cloud had formed at the moment of capture. Areas of the terrain model that were obscured by above ground features at the time of capture, such as buildings and trees, were interpolated from surrounding areas of visible ground, and could have reduced accuracies in these areas. This map is based on soil maps that are the result of statistics-based spatial interpolation of 328 soil sample points. In areas behaving anomalously with regards to environmental variables, soil data might represent these anomalies rather than on the ground condition. In these cases, field validation is recommended.

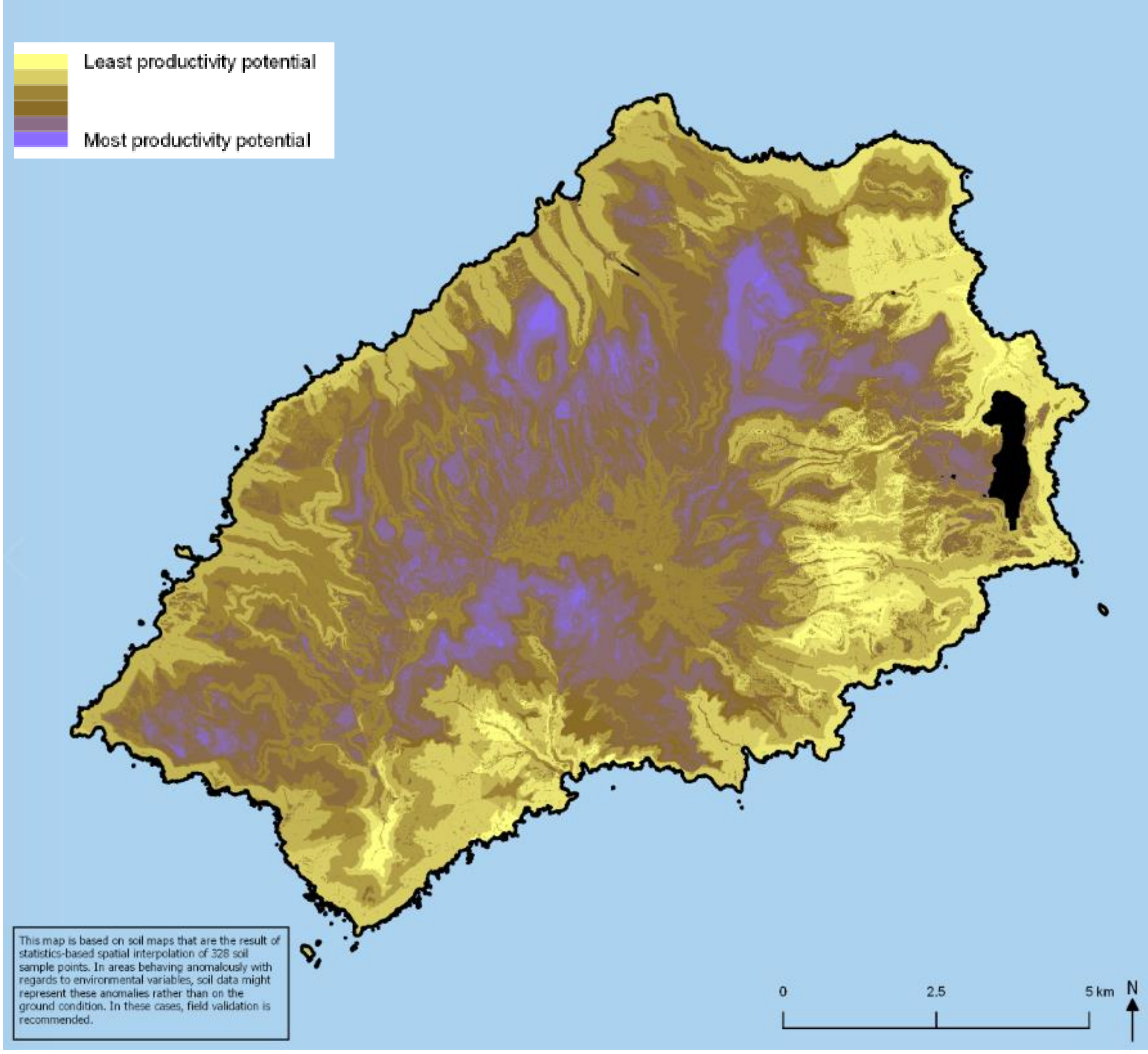


Figure 4.3: Land productivity potential

4.3 Flat land case studies

On St Helena, flat land is a very scarce resource under pressure from housing and industrial, renewable energy and tourism development. In addition, to maintain the landscape integrity of the island, due to the importance of tourism and its' forecast contribution to the overall economy, St Helena has decided to restrict development to areas which are not visible form the near sea (within 500 m of the coast).

In order to identify locations that lie out of line of sight, a range of viewpoints were created along the coastline and up to 500 m offshore. Based on the digital elevation model, for each terrestrial area on St Helena, the number of viewpoints with a direct line of sight connection were counted. Any areas where this count resulted in '0' are not visible from the coast.

Flat land which is attached to the current transport network is a much more usable resource in terms of financial outlay for development. Therefore the map (Figure 4.4) show on a gradient from dark green to orange, the distance from roads, measured as line of sight, of accessible flat land that cannot be seen from the coast. Dark green land is located in direct proximity to existing roads, while orange land is over 2000 m away from the nearest road. As distance from roads is a factor mostly important for development considerations, rather than just a topographical consideration. The airport, and other restricted areas as hard constraints to development, are shown in solid black. Other constraints to development, such as environmentally sensitive and protected sites or planning constraints, can exist and need to be taken into consideration.

This model has assumed a viewpoint of 500 m from the coast of the island. The model can be re-run with a particular distance, viewpoints or locations, both from off-shore, but also inland. The input data is derived from a terrain model, therefore the model does not take into account any surface height features, such as buildings and woodlands.

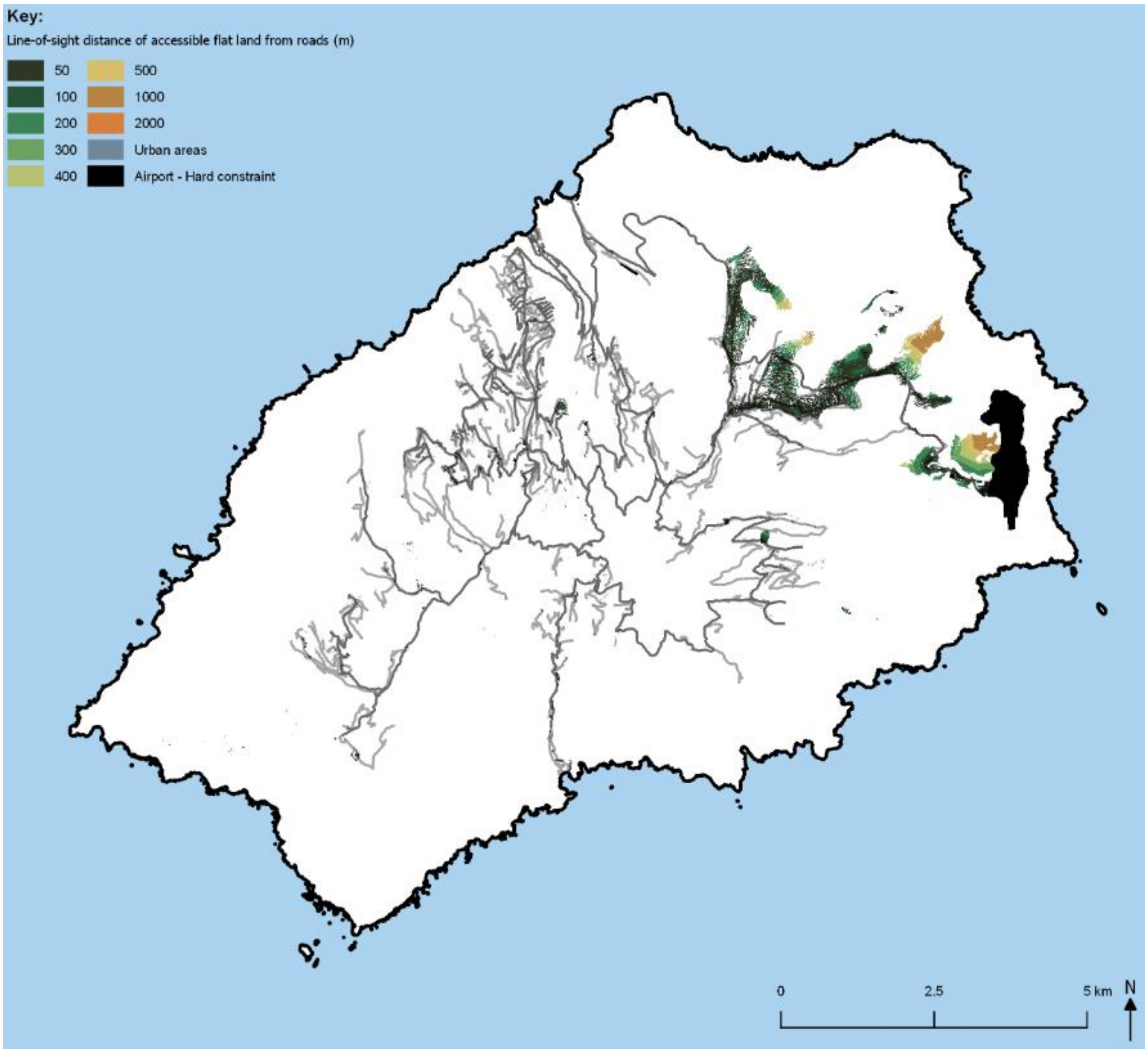


Figure 4.4 Development opportunities on flat land (less than 7°) that cannot be seen from the coast

The small maps in Figure 4.5 show the flatter areas of land in St Helena and were an intermediate to creating the map in Figure 4.4. Two cut-offs were chosen. Flat land less than 7° slope, has few restrictions to being worked or developed. Land less than 11° slope can be worked and developed without major engineering stabilisation.

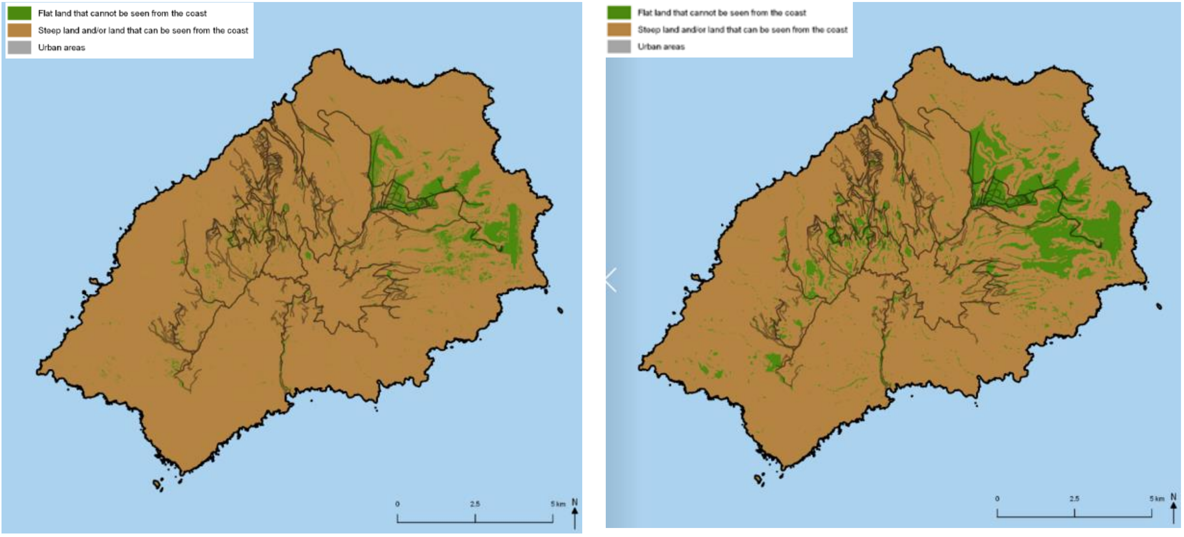


Figure 4.5: Flat land under 7° (left), and under 11° (right), that is not visible from 500m out to sea.

All the flat land case study maps are available in Appendix G.

Data gaps and limitations / possible refinements

These are topographic maps; and not all flat land that is not visible from the coast is necessarily suitable for development, for example wirebird habitats could not be developed. Compared to the map having used 11° slope, the area of flat land on the 7° slope map is more fragmented.

4.4 Erosion risk management

Because the island of St Helena is so steep, it is prone to erosion, and in certain cases rock falls which can have fatal effects. The maps in Figure 4.6 show where the soil is most erodible and where action could be taken to help control this. Soil is a non-renewable resource that is of extremely high importance for not only biodiversity, but also human land-use, most notably for agriculture, forestry, and conservation efforts. Once soil has been carried off the land, it can take a very long time (many hundreds - thousands of years) to re-establish healthy soil; in the meantime, the land cannot be used agriculturally. By managing the density and permanence of vegetation cover in areas susceptible to erosion, land managers can reduce the risk of permanent soil loss, which makes it important to identify areas with highest priority for management intervention. This map is available in Appendix G.

Erosion risk and drainage channel flow paths were calculated using the fine sediment risk module SCIMAP (Durham University, 2016). The module uses elevation data, precipitation, and erodibility information to calculate the overall risk an area of land is at from erosion. Erodibility scores were derived based on habitat and soil stability data (Appendix G). In areas with very dense vegetation cover, the erodibility score was based solely on the potential of the vegetation to prevent erosion, whilst in areas with little protective vegetation, the erodibility score was determined by the stability of the underlying soil. At intermediate levels of protective vegetation, the score assigned based on vegetation alone was modified depending on whether it is underlain by (un)stable soil.

All erosion risk maps are available in Appendix G.

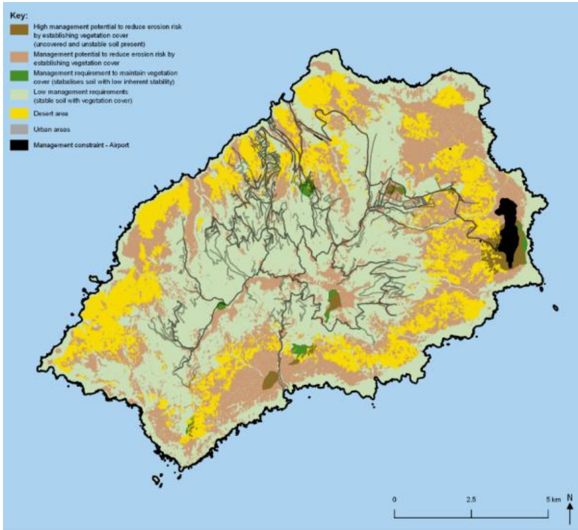
Data gaps and limitations / possible refinements

The data shown on this map has been derived through modelling and was not verified in the field. Only erosion from rainfall is considered.

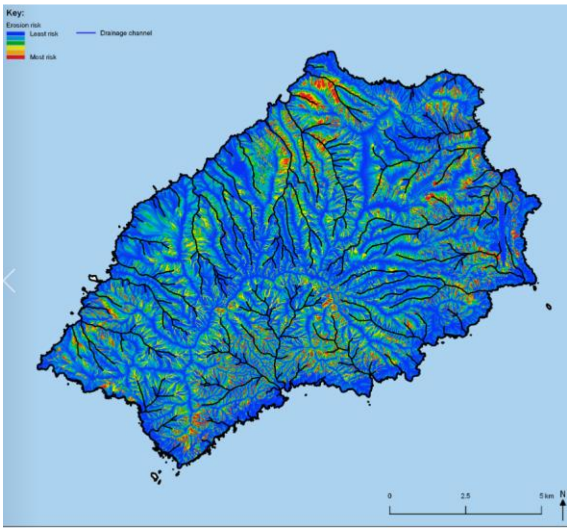
The imagery used for the habitat classification was a combination of three different dates and two different years, required to fully classify the island due to cloud-cover, with the most recent image taking priority. Where cloud-cover existed in all three datasets, the habitats were classified by visual interpretation. Due to the extreme variations in elevation, there may be slight discrepancies in the geolocational accuracy of the imagery, and the registration of one image to another.

It is assumed that all data supplied by the Saint Helena Government, used in the classification is correct. The habitat classification used was the F2 version.

The digital terrain model used in the classification is derived from stereo imagery, which can have reduced accuracies under steep terrain and where cloud had formed at the moment of capture. Areas of the terrain model that were obscured by above ground features at the time of capture, such as buildings and trees, were interpolated from surrounding areas of visible ground, and could have reduced accuracies in these areas.



Opportunities to manage erosion risk



Erosion risk and drainage channels

Figure 4.6: Maps showing current erosion risk and the opportunity to manage them

4.5 Climate regulation: soil carbon

The soil carbon pool is an important store of carbon, estimated to be three times that of the atmospheric pool. Carbon is constantly transferred from the atmospheric to the soil pool and vice versa. Carbon enters soils through plants fixing atmospheric carbon via photosynthesis and dead plant material or organic matter being returned to the soil. Carbon is lost from the soil via the action of soil organisms that decompose the organic matter and through catastrophic losses through burning or erosion.

The soil carbon stock is the actual amount of carbon stored in the soil (i.e. the pool) as a mass per unit area to a specified depth. Here the results are given as Mg of carbon per hectare to 15 cm depth.

Stocks are important because they tell us how much carbon the soil physically holds and allows for the estimation of the soil carbon pool. If we are to limit increases in atmospheric carbon, soils with high carbon stocks need to be protected. In addition those soils with low stocks provide an opportunity to sequester more atmospheric carbon in soils through promotion of plant growth

The map (Figure 4.7) shows how soil organic stocks (to 15 cm depth) vary. Since there are no function-based thresholds for C stocks, map classes are based on the distribution of stocks measured. Variations in soil organic C stocks may indicate areas that have the potential for significant C losses and therefore merit protection from disturbance. These variations may also indicate soils where there is potential for significant net C sequestration through revegetation or land use change.

The map was created by considering the 328 field work samples and calculating soil bulk density as an average density of the soils (minus stone content) from the 4 cores taken at each location during field work. The density was then multiplied by the carbon % to give a C stock per unit volume which was then converted to a stock per hectare to a depth of 15 cm.

The carbon stocks for the soil survey points were analysed for any relationship between the soil characteristic and environmental variables. Any environmental variable found to be significantly correlated with the soil property, in this case NDVI, was used as a basis of spatial interpolation using semivariance and kriging. This processes models the soil characteristic values using the environmental variable as a proxy. The output model values were categorised based on their effect on plant growth.

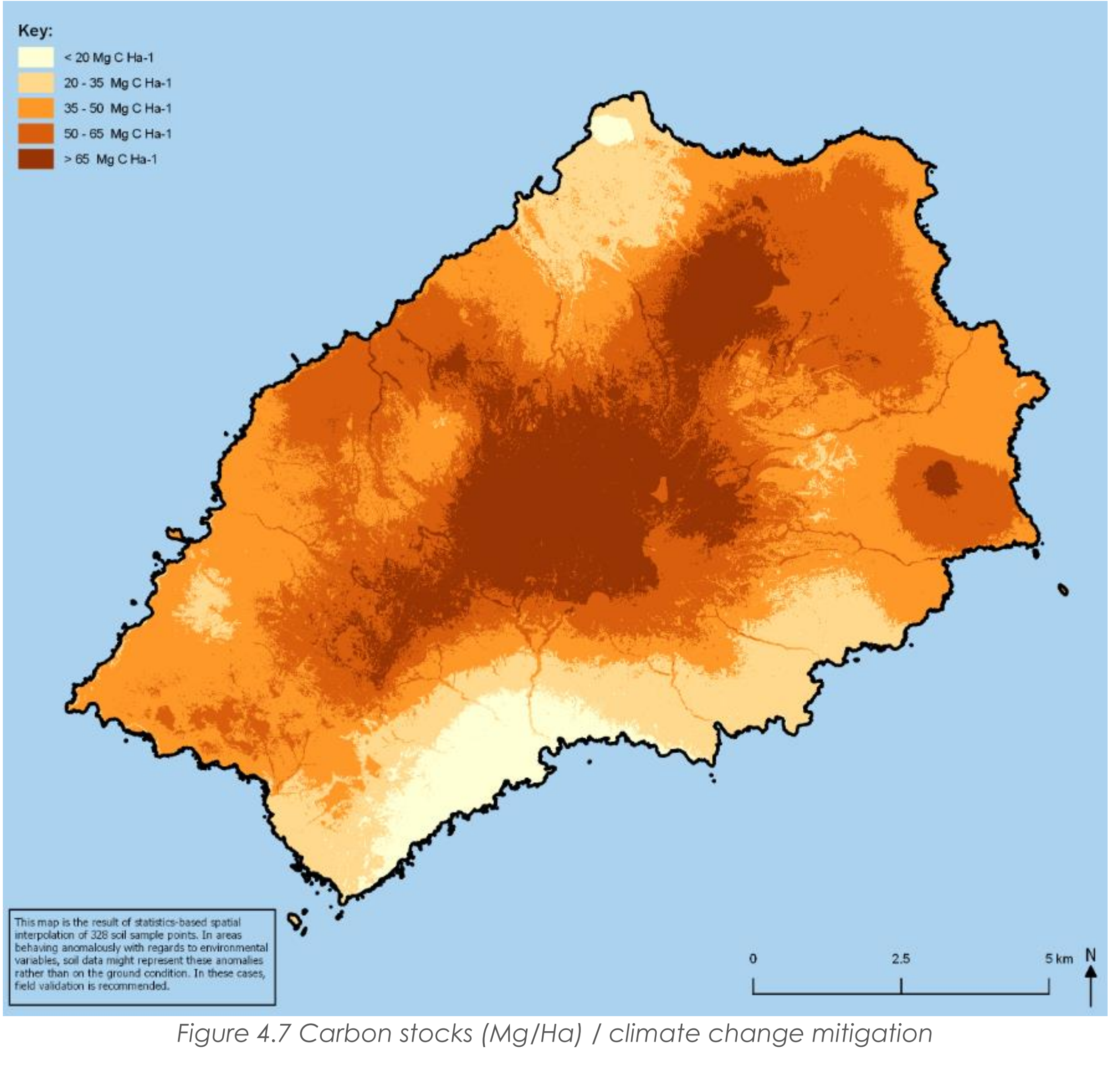


Figure 4.7 Carbon stocks (Mg/Ha) / climate change mitigation

Data gaps and limitations / possible refinements

The input soil data is derived from the interpolation and modelling of soil characteristics onto an environmental variable, in this case NDVI. The accuracy of this layer decreases the greater the distance away from the initial survey point.

The terrain model used as the environmental variable is derived from stereo imagery, which can have reduced accuracies under steep terrain or cloud cover. Areas of the terrain model that were obscured by above ground features at the time of capture, such as buildings and trees, were interpolated from surrounding areas of visible ground, and could have reduced accuracies in these areas.

4.6 Ecosystem services and natural capital

Habitat and soil information form the fundamental building blocks to being to understand ecosystem services because each habitat and soil influences the services that area of land provides. These services in turn bring benefits whose value can be measured. Measuring and reporting these values can result in natural capital accounts. These area structured set of information relating to the stocks of natural capital and flows of services. Accounts are of two kinds: physical accounts which classify and record measures of extent, condition and annual service flow; and, monetary accounts which assign a monetary value to selected services on an annual basis and record the present value of the natural asset's ability to generate future flows of services.

Figure 4.8 shows the link between biophysical structures (habitats soil, landform etc.), ecosystem services and the benefits and value those services provide. Because each ecosystem service has a benefit and a value the 'Natural Capital' of that services can be described and evaluated. It is hoped the results of this Darwin Project can feed into work on creation of natural capital accounts for St Helena.

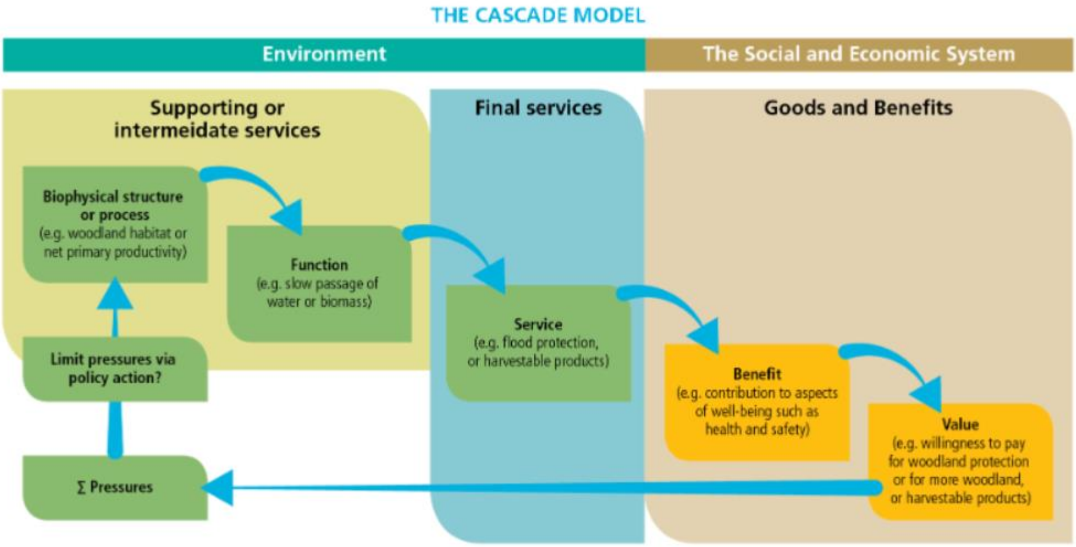


Figure 4.8 Diagram showing the link between habits and soil (biophysical structures), ecosystem services and the socio economic system as shown by the cascade model (Potchin and Haines-Young, 2011)

Natural capital accounts provide a strong mechanism which allow non-environmental specialist to track natural assets and shines a light on the benefits of the services provided or the risks to delivery. National capital accounts are by their nature backward looking and foundational tools, albeit there is a forward-looking element in having to make assumptions about future streams of services and benefits. The use of the maps created as part of this Darwin Project and the future creation of national capital accounts for the island will help ensure a strong, healthy and resilient environment into the future by ensuring the role of the environment is fully integrated into policy and planning arena.

5 The 'Living Map' process

EO data provides a means of collecting data over a large geographic area on a regular basis, in a repeatable fashion; meaning that EO-based analyses can play an important role in the long-term monitoring of the environment in St Helena. Due to continual changes in land use and ecological conditions, the habitat map should be reviewed periodically in order to ascertain its currency, and to establish whether an update is needed. Generally, a full monitoring update should be considered every three to five years.

The 'Living Map' assumes that the map data will be constantly updated as and when required, and when sufficient new imagery allows. Through fieldwork and occasional manual and/or semi-automatic interpretation of imagery, local organisations could be provided with a cost-effective and up-to-date habitat map, along with a record of the changes that have occurred over time. This 'Living Map' process could provide a means of recording change over the entire island, and can act as a powerful tool for identifying and targeting land and habitat management, along with monitoring change in habitat extent (Medcalf et al, 2015).

As part of the 'Living Map', change detection techniques can provide local partners with a mapped output of 'likely changes' across the entire island; which partners (or enthusiastic local residents) can then check through fieldwork, or a combination of fieldwork and aerial photographic interpretation (Medcalf et al, 2015).

The 'Living Map' process also holds true for the soil maps. A number of staff on island were trained in soil sampling techniques. Areas where anomalies may occur (such as 'The Barn') can be visited and examined in the field to check the interpolation is placing the area in the correct class. For this testing of broad categories simple field kits, such as pH paper, and simple soil tests, such as Loss on ignition (carried out by qualified laboratory technicians), could be used to confirm the on-the-ground condition and alter the classified shapefile accordingly. To change the underlying raster data and interpolation model, the soil analysis techniques should be repeated exactly as they were carried out for this study to ensure scientific consistency. Areas of pasture, where positive actions such as liming have been undertaken, could also be sampled with field pH kits in order to keep the shapefile data up to date.

To ensure the cost- and time-benefits of the Living Map approach, it is vital that a monitoring strategy will have to be devised; otherwise a costly remapping exercise may be required to update the existing data. This strategy will need to consider:

1. Who will manage the Living Map
2. How often will it be updated
3. Purposes, outcomes, and potential impact for the monitoring

6 Monitoring

Monitoring protected areas, their surroundings, and vulnerable habitats is an essential practise, particularly in those areas that may be influenced by external anthropological pressures. Though habitat monitoring has commonly been centred on field survey data, remote sensing techniques can be integral in identifying the initial baseline of habitat extent and character, but also quantifying their change through time (Nagendra et al., 2013). The use of remote sensing allows the analyst and field surveyor to combine their expertise; using the satellite imagery to identify possible areas and habitats that may have changed, then allowing the field surveyor to target their work accordingly,

This section will characterise the different types of change a habitat and landscape are likely to experience, understand what can and cannot be measured, and describe two possible methods of updating and maintaining a Living Map process.

6.1 Monitoring theory and types of natural change

Before any monitoring action can take place, it is vital to assess the current composition and extent of the habitat; i.e. the baseline. This baseline assessment should be documented at the appropriate scale (both spatial and habitat description) for long-term monitoring assessments.

Following this, an understanding of how the habitat may naturally vary, and at what timescales, is required to ensure that normal or cyclical change (e.g., habitat maturity, seasonal change etc.) is not flagged as actual habitat change. That is, that the habitat change being observed is outside the normal, natural variation that might be experienced. It is this part of the monitoring system that remote sensing plays the largest part.

There are four main categories that a habitat may change, given in Table 6.1 below.

Table 6.1: Types of habitat change

Change type	*Description*
Substantive change	A land use change, such as the felling of a woodland, and conversion to agriculture or urban development
Evolutionary change	Due to growth, which can be rapid or slow
Management change	Subject to different cropping or management techniques (e.g., hedgerow management, coppicing in a woodland)
Transitional change	e.g., leaf-on/leaf-off senescence

Once a habitat is flagged as experiencing change, the field surveyors have confirmed it as real change, and the Living Map is updated to reflect the change, the cause can be investigated. This would require experienced ecologists with a local knowledge of the area. Earth observation imagery, and previous, documented renditions of the Living Map can also play a vital part in providing a contextual history of the surrounding area. Previous habitat maps could provide evidence of past habitat extents, whilst a time-series of satellite imagery, and relevant spectral indices, could provide clues of any rate of change. With this information, a tailored solution can be formulated to protect and conserve the remaining baseline habitat, revert the changed habitat back to the baseline condition, mitigate against further change.

6.2 Considerations on using Earth observation

There are three perspectives regarding scale that can influence the analysis of a habitat through time; a technical perspective such as the sensor resolution, a habitat perspective looking at the size of the vegetation sward, and the perspective of time through change in habitat condition as well as the natural seasonal cycle of that habitat.

It is also important to recognise that processes influencing the condition of a particular patch of habitat can be occurring at three scales (Figure 6.1):

- within the habitat itself, affecting the component features of the habitat
- within the site in which the habitat is located (e.g., parcel, management unit)
- the condition of the area surrounding the site.

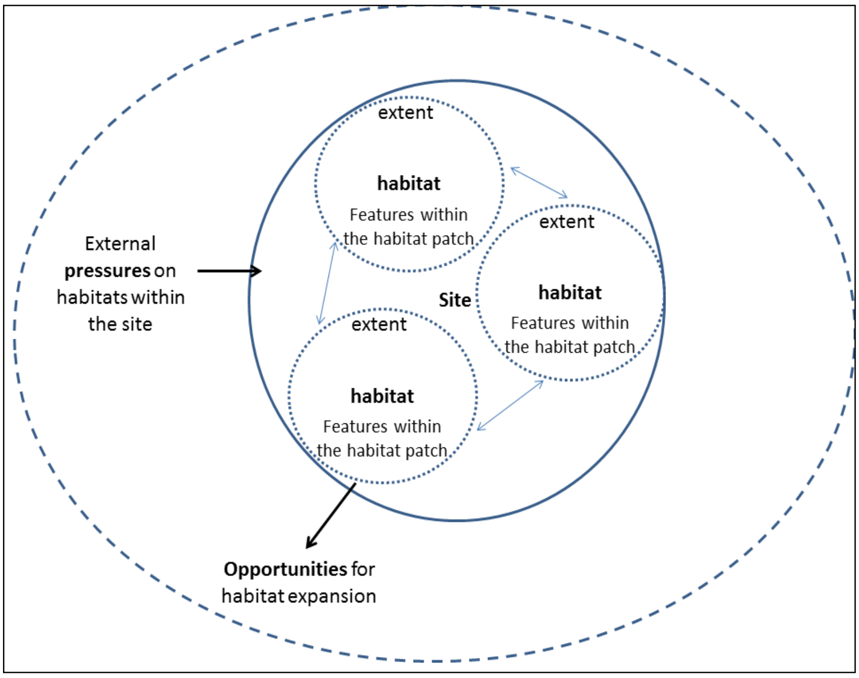


Figure 6.1: Processes present around and within a site

6.2.1 Scale of sensor resolution

The spatial resolution of a sensor relates to the smallest distance between two objects that can be distinguished in an image; this normally corresponds to the area of a pixel in optical sensors such as Sentinel-2, or Pléiades. The higher the image resolution, the easier it is to distinguish between different objects and map their physical extent on the ground. Figure 6.2 demonstrates the ease with which it is possible to identify ground features with a higher resolution system. While the lower resolution systems (left) can broadly identify different fields but not their physical boundary, the VHR systems (right) are able to identify the field boundary and the individual stands of vegetation.

Through an object-based analysis, the effects of spatial resolution can be demonstrated by comparing a segmentation of the same area, derived from RapidEye (5 m resolution) and WorldView-3 (pan-sharpened to 0.5 m resolution), shown in Figure 6.3.

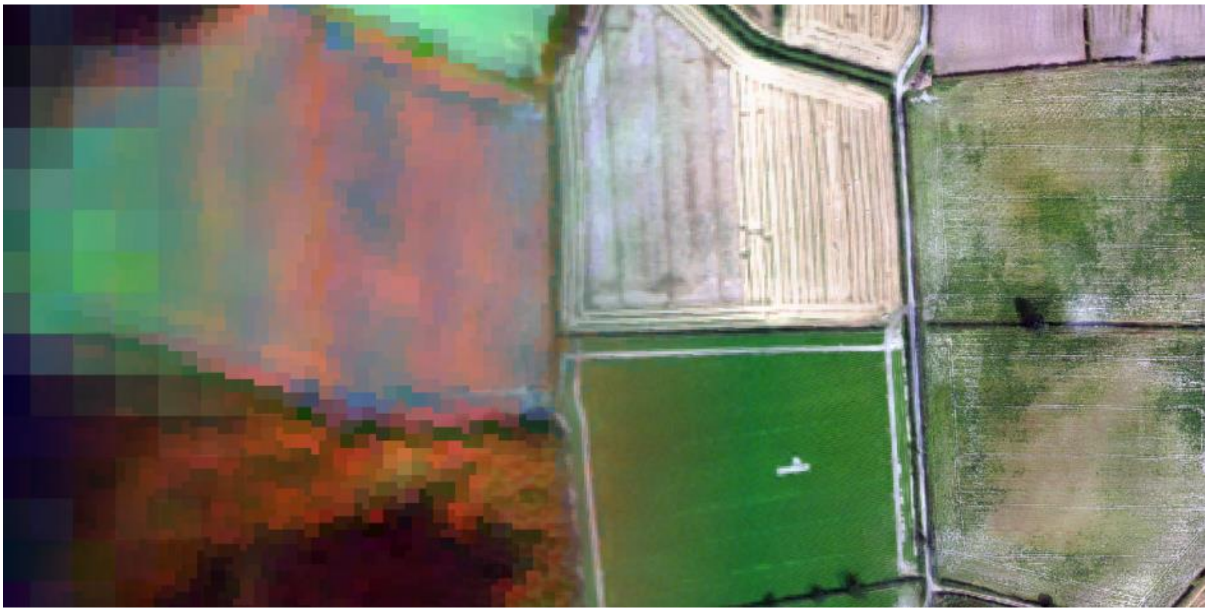


Figure 6.2: Examples of spatial resolutions from different EO sensors, from low resolution (left) to VHR (right)

In this example, the VHR of the WorldView-3 sensor allows for the correct spatial delineation of the features within the target area, when compared to the RapidEye segmentation.

Figure 6.3: Comparison of Segmentation from RapidEye (left) and pansharpened WorldView-3 (right)

However, the degree of image coverage by higher resolution systems, and the actual area of land captured in an image, are generally not as high as for their lower resolution counterparts (Figure 6.4). As an example, the swath (width) of an image from WorldView-3 is (at 2 m resolution) about 13.1 km compared to a Sentinel-2 swath (at 10 m resolution) of 290 km.

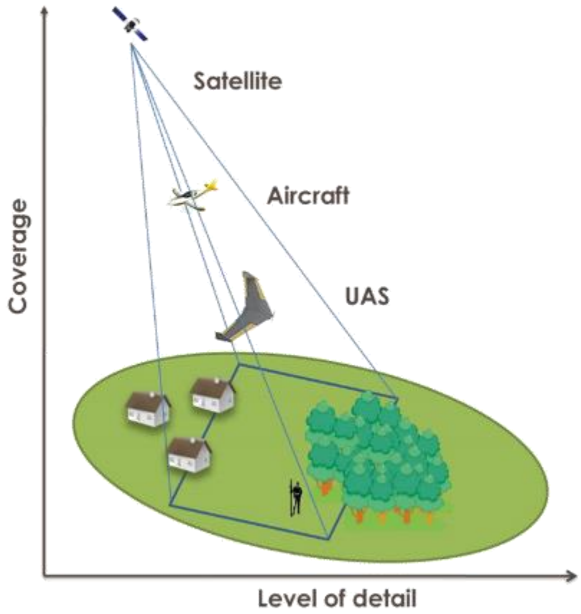


Figure 6.4: EO platform coverage vs level of detail captured

6.2.2 Scale of the habitat change

Related to the sensor resolution, it is important to understand the scale of the habitat being assessed, and the habitat factor being analysed, such as flax encroachment. If the sensor for analysis is Sentinel-2 (at 10 m resolution) and it is unlikely that the encroaching flax will reach an area of 100 m^2, then the likelihood of that feature being identified is reduced.

However, even if the spatial extent of the feature to be analysed (such as flax) is of an area smaller than a pixel, the spectral characteristics of that pixel would still be influenced by the feature in question, and could therefore be flagged as potential change.

6.2.3 Scale of habitat change through time

The ability to distinguish and identify a change in habitat over time is inherent on the sensor resolution, the size of the habitat, and the time-scale over which change is likely to occur. Habitat change events that occur quickly (such as landslides) could be analysed either during a time-series analysis, or during the next scheduled EO survey. However, changes in habitat that can take years, or decades, to form (e.g., the cloud forest) would not be identified by comparing consecutive annual surveys.

6.3 Monitoring for specific habitats

The purpose of assessing and monitoring habitat, and its condition, is to establish whether the habitat are in a satisfactory quality compared to agreed thresholds for a range of condition indicators, and whether the condition has changed in a measurable way; this is generally assessed by field monitoring.

It is important to note that in many habitat monitoring programmes, the detailed measurements are of the feature(s) of interest within a bigger site. The condition of the site in which the habitat is located (e.g., a field or protected area) and the surrounding context are not necessarily monitored in any detail, although notes are often taken about site management and pressures (such as invasive species) that are present.

For example, the purpose of site condition monitoring of protected areas (PA’s) can be to determine the condition of the designated natural feature within the site. This is to establish whether the natural feature is likely to maintain itself in the medium to longer term under the current management regime and wider environmental or other influences.

The use of remote sensing can be viewed as a ‘toolbox’; employed in various combinations, with complementary field surveys to answer questions around habitat extent and condition. To gain the maximum benefit for both applications the appropriate data and technical solutions have to be applied while considering factors such as scale, phenology and imagery availability/quality.

Monitoring habitats and change detection through Earth observation techniques requires detailed planning, especially in the context of the limitation of what Earth observation can do. It is important to consider the sensor used for the monitoring system in terms of:

- sensor repeat frequency (i.e., how many times a week/month/season/year is an image needed, what are the cloud-cover considerations?)
- sensor spatial resolution (how large are the habitat stands relative to the sensor pixel size, how much detail is required?)
- sensor spectral resolution (how sensitive does the sensor need to be, in order to identify any change?)

In terms of the habitats being monitored, it is important to consider:

- the spatial scale of the habitats
- the temporal scale of potential change
- the context of the habitats location
- the type of change that might occur
- the time of year that any change may be visible from a birds-eye-view

The factors above illustrate the complications of establishing a one-size-fits-all approach, and that different habitats required different solutions.

6.4 Monitoring with EO imagery

A manual/semi-automatic approach to monitoring can be performed on the habitat dataset, making the most of any available high temporal frequency but low resolution data (such as Sentinel-2), and/or VHR but low frequency data (e.g., Pléiades, WorldView-3 etc.).

The process involves identifying those polygons whose spectral response are outside of the statistical norm for that particular habitat. The theory being that the ground/canopy-cover that changes, would alter the spectral reflectance of the target polygon/habitat (e.g., the felling of a woodland canopy would drastically reduce the NDVI signal).

The polygons identified as been a statistical outlier would then be targeted for an API survey, to either visually confirm or deny the change. If the polygon is confirmed through visual means to have changed, a site-visit could be arranged to target the exact area, and identify the new habitat.

Figure 6.5 illustrates this workflow.

This whole process can be performed manually; a technical report for this manual process is provided in the accompanying document *DPLUS_052_TechnicalReport_Monitoring_20180629*. However, it is possible to script the processes that do not require visual confirmation, such as the zonal statistics and outlier selection.

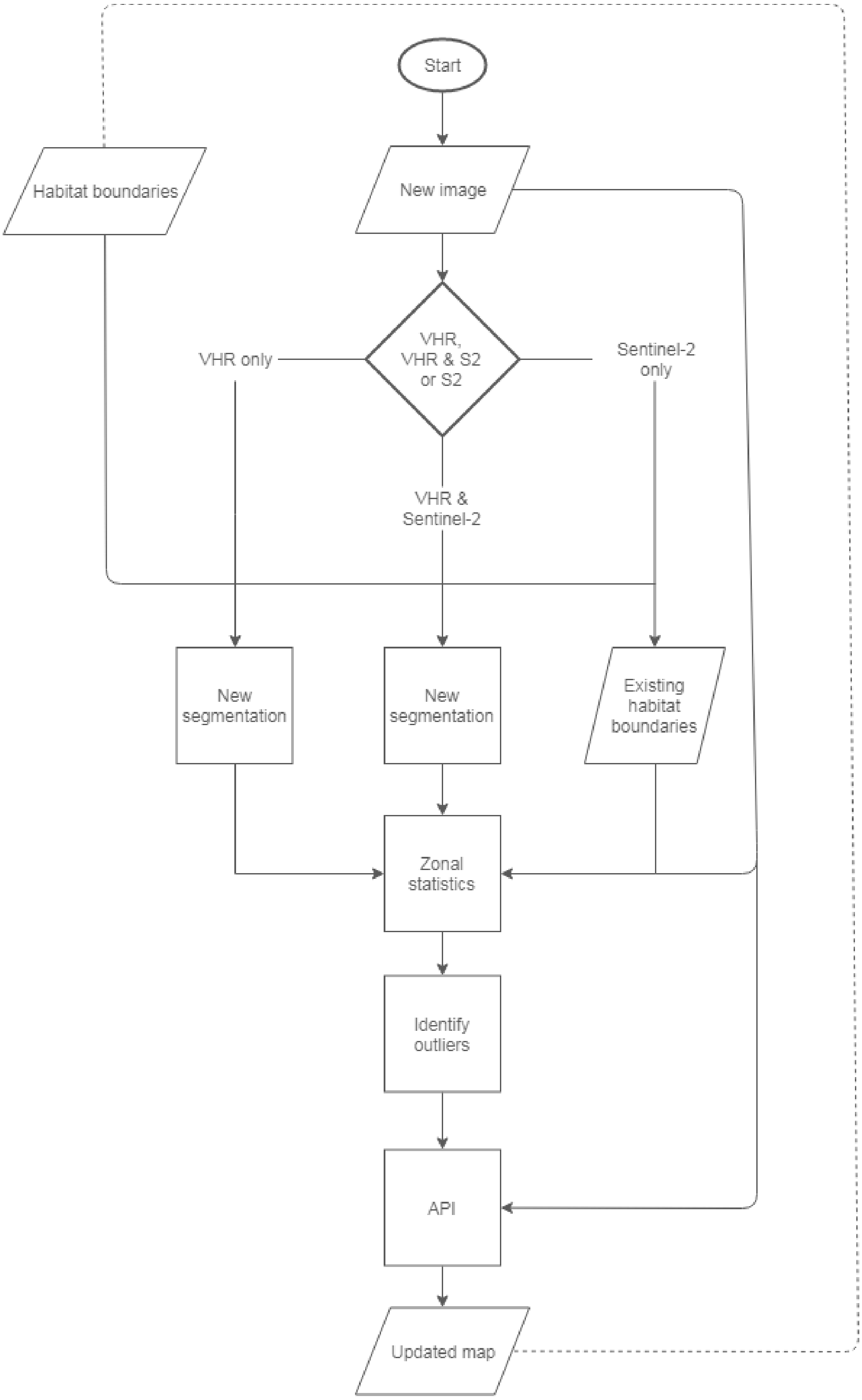


Figure 6.5: Semi-automatic monitoring workflow

7 Conclusion and Impact

7.1 St Helena habitat mapping

This project has resulted in the creation of comprehensive and updatable 'living' habitat and soil condition maps for St Helena hosted within an online GIS Portal. Having the data online will allow the information to support long-term strategic planning and development. The data will also enable St Helena's public, private and voluntary sectors to incorporate environmental considerations into their land-management decision. The baseline data collected forms an important resource to both track and help design mitigation efforts to support the island through climate change issues.

Using remote sensing data to create the habitat map had a number of significant advantages:

- The whole island was covered by the habitat map within the project budget giving complete island coverage at a significant level of detail at Level 3 of a three tier hierarchical system developed as part of the project.
- Remote sensing was found to be an ideal tool as it allowed survey of the hard to access, dangerous and remote locations. Three images of very-high resolution imagery were necessary to gain a nearly cloud free image set over the island. Some areas of cloud were infilled using Sentinel 2 imagery and field checked or validated by manual interpretation.
- An object and 'rule based' approach to classification of the imagery was used. This has the advantage that ecological knowledge is built into the classification. This technique relies on the skills of the remote sensing analysis team. The team involved were able to bring these skills to the project with good knowledge sharing between specialists on and off island, which worked well. The team had strong ecological, remote sensing, on Island, and 'on the ground' knowledge. This analysis technique has the advantages over the popular 'machine learning and supervised classification techniques', in that iterations following field validation enhanced the accuracy of the map, building up habitat class by class certainty. Errors and inaccuracies can be tracked and field work effort focused on these areas with more complexity and less data.

A consistent, rigorous habitat classification for the whole island was designed which is robust enough to be used for multiple purposes. It follows standard IUCN nomenclature and is therefore compliant with international standards, whilst also being specific enough to reflect the unique and complex habitats of St Helena.

The hierarchal nature of the classification and habitat maps also means they can be put to many different purposes, Level 1 strategic data, Level 2 is ideal for Natural Capital evaluation and modelling, and Level 3 for ecological and biodiversity use.

7.2 St Helena soil data and mapping

Soil datasets have been stored electronically and soil property maps derived in part from these data are available on the St Helena Government website.

There has been a comprehensive soil sampling on the island resulting in 130 sample points across habitats and soil types. These data have been used to generate maps that can be used to inform land use planning, land management and programmes of habitat restoration. Where there is a risk of soil degradation and loss of ecosystem function it is important to recognise where this process is approaching a tipping point, where significant loss of function may occur that would require major restorative effort to reinstate. The soil data and associated maps will also help to identify where there may be opportunities to enhance ecosystem services or where there is a need to build further resilience into systems. Some examples are given below, for illustrative purposes only.

The pH data and maps will allow for targeted amendments to improve plant growth, and animal health and nutrition. Liming materials are a scarce resource on the island so being able to pinpoint areas where applications will provide a benefit is an important consideration. These areas will primarily be where grazing land and low pH areas coincide.

Where planning policy is being made, incorporation of soil data into the decision making process would inform the potential for erosion during site development or the location of such developments as they affect hydrological processes. Soils not at risk of erosion currently because they are vegetated could be highly susceptible to erosion if that vegetation is removed.

Soil data will indicate soils close to tipping points where limited management resources can be focussed to build resilience into these systems. These considerations might be integrated with projected climate changes to further identify risk locations.

Active programmes of habitat or species restoration exist on St Helena, for example the Millennium Forest planting of *Commidendrum robustum* (St Helena gumwood). Soils data and the maps generated will inform selection of locations where these actions have the greatest potential of achieving restoration objectives.

7.3 Ecosystem service analyses

On island training, which took place over two workshops, has resulted in experts on St Helena being fully training in soil sampling and vegetation sampling, use of remote sensing and analysis of the data to consider ecosystem service mapping and modelling.

In order to demonstrate the use of the maps several ecosystem services were modelled showing how the soil and habitat data can be used together with landform, hydrology and management data to demonstrate the value of the individual areas of land on St Helena in providing important services. The services mapped were decided on island during the workshop, as those having most relevance to current policy needs for the environment and ensuring well-being:

- availability of flat land for development;
- erosion risk reduction;
- biodiversity;
- food provision through soil quality for agriculture and
- climate regulation through soil carbon storage.

The data demonstrates the power of the habitat and soil information and could be further developed into models showing existing stock of services (Natural Capital), opportunities to enhance them and demand for and risks to these services.

During workshops on Island the results were presented to the Government Officials. Feedback from this session showed that the maps and data collected would be useful for a wide range of work on the island.

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Appendix A. Earth observation imagery

All EO sensors use measurements of electromagnetic (EM) radiation to understand the target of interest, whether crops, habitats or man-made structures. These sensors can be classified into two categories; passive and active (see Figure 8.1). Passive sensors, such as optical instruments, use an external source of EM radiation, e.g., the sun, to illuminate the Earth. By contrast active sensors, such as radar and lidar, generate their own EM radiation.

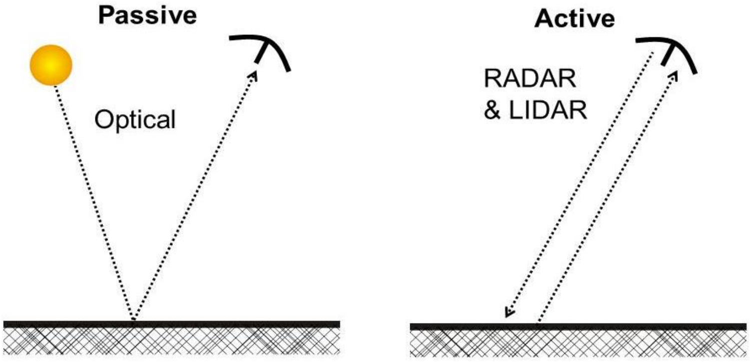


Figure 8.1: EO passive (left) and active (right) sensing.

Optical imagery - core considerations

The most common forms of EO used for mapping crops, vegetation and man-made features have been aerial photography and satellite-based optical sensors. Over the past 50 years there have been progressive improvements in the spatial, temporal and spectral resolution of these sensors, making them a valuable resource across a range of mapping scales and for a variety of mapping requirements. Imagery at different working scales and timings can provide information from the crop level right through to the wider area perspective and can be used to track change.

Optical remote sensing techniques have been used for many years, typically through the manual (i.e. visual) interpretation of RGB (red, green, blue, or true-colour) aerial photography. Satellite imagery contains additional information as it records information in a greater range of wavelengths to those visible to the naked eye. These include the near-infrared (NIR) bands and the shortwave-infrared bands (SWIR). These bands are particularly useful for land cover mapping as they can help distinguish a range of types of vegetative cover from one another, because they pick up variation in reflectance arising from water content and water absorption, as well as chlorophyll absorption

The most widely available optical sensors are multispectral instruments that carry a limited number of channels across the RGB-NIR spectrum. Channels are typically centred on red, green, blue, near-infrared and shortwave-infrared wavelengths; although increasingly systems with channels focussed on red edge and yellow wavelengths are becoming available. Figure 8.2 shows an example of Landsat-8 imagery, comparing an RGB image (red, green and blue bands) which appears similar to how the human eye would view the world, versus a colour-infrared (CIR) image (NIR, red and green bands). Vegetation appears red in the CIR, and so the variation between the different crop types is easier to distinguish.

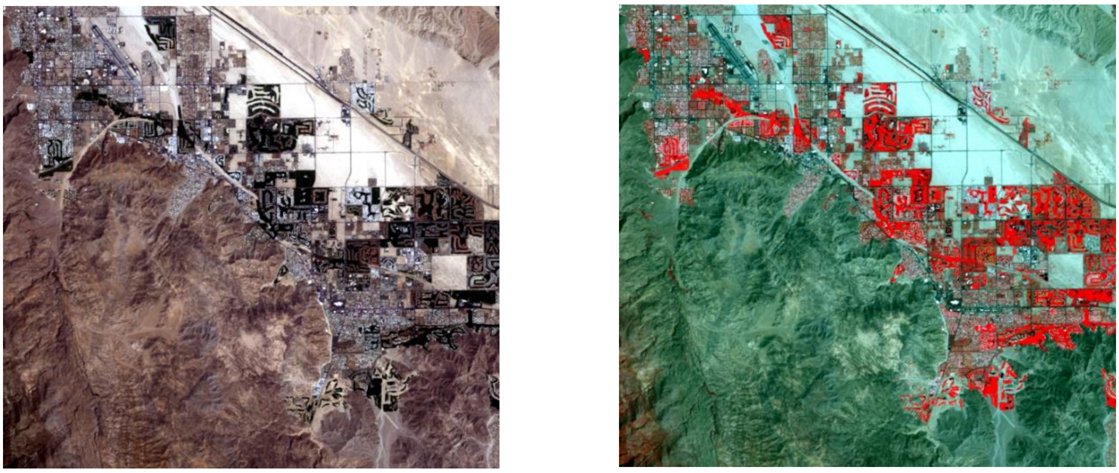


Figure 8.2: RGB (left) and CIR (right) composites, Landsat 8.

The well-known limitation of optical systems is that images are affected by cloud cover, hence in regions with persistent cloud cover, such as the tropics or tropical forests, data availability may be incomplete and unreliable, especially for satellite optical sensors.

Radar imagery - core considerations

Synthetic aperture radar (SAR) sensors are active imaging systems that operate at microwave wavelengths' ranging from millimetres to tens of centimetres. Radar sensors generate pulses of energy towards the Earth's surface. This energy is scattered by objects on the ground, with some of the energy reflected (i.e. backscattered) towards the radar system. The intensity and orientation (polarisation) of the backscattered energy is then measured by the radar system. In the context of vegetation, backscatter intensity is strongly related to biomass, with higher biomass leading to higher backscatter as Figure 8.3 illustrates.

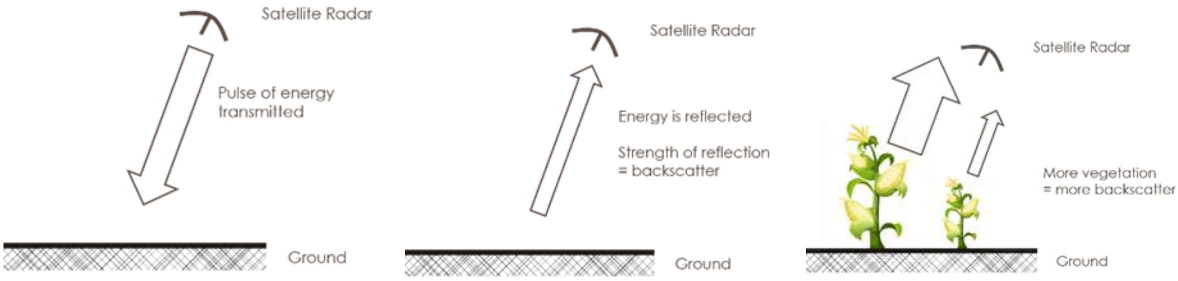


Figure 8.3: Radar signal transmission, reflection and backscatter

SAR systems are also capable of measuring the orientation, or polarisation, of backscatter. Most systems will generate energy at a single polarisation, either vertical or horizontal, and will record the strength of backscatter at both vertical and horizontal wavelengths. The combinations of transmitted and received energy are referred to as co-polarised when transmitted and received are in the same orientation (i.e. VV or HH), and cross-polarised when transmitted and received are in different orientations (i.e. VH or HV). Smooth surfaces, such as roads, bare earth or urban structures produce a strong co-polarised and a weak cross-polarised response. By contrast, vegetation is chaotic in structure and will change the orientation of an EM wave. Therefore, backscatter from vegetation will produce a significant cross-polarised response, allowing for vegetation to be easily identified in SAR imagery.

The interaction between microwave energy and plants is also strongly related to the radar wavelength used. SAR systems operate at different wavelength allocations, or bands; these are X (2-3 cm), C (4-7 cm), L (15-30 cm), and P (40-60 cm) (Figure 8.4). The SAR signal interacts most strongly with objects of similar or larger size than the wavelength; therefore in a vegetation context different wavelengths will interact with different structural components of a plant. X- and C-bands will mainly interact with leaves and twigs/plant stems, while L-and P-bands will largely interact with trunks and branches of trees, but will pass through leaves and stems/twigs.

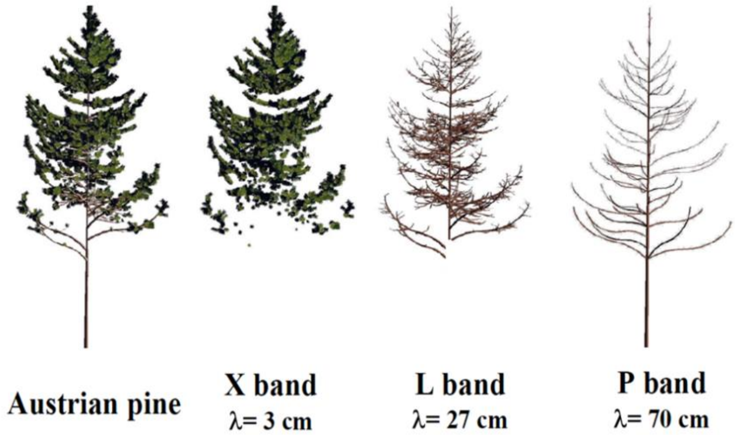


Figure 8.4: Interaction of vegetation canopy with different structural elements of a pine tree (adapted from Walker, 2010)

Images captured through radar systems suffer from 'speckle'; a noise-like phenomena that generates the characteristic "salt and pepper" appearance of SAR imagery. This effect is a result of the interference of the coherent electromagnetic waves scattered from the target objects (Huang and Genderen, 1996). While chaotic and unpredictable, it is not random; given the same configuration of sensor and target, the same speckle pattern would be generated. Therefore, careful efforts must be made to reduce the influence of speckle without destroying the statistical validity of the underlying data.

In addition to revealing information on vegetation structure and biomass, microwaves have the additional advantage of passing through clouds and being capable of day or night operation. This allows SAR images to be captured more reliably than optical imagery for cloudy areas such as the tropics. However, SAR systems produce images that appear noisier and can be less easy to interpret than optical.

Appendix B. Opportunities from EO missions

Sentinel-1

Sentinel-1 is an ESA space mission of the Copernicus Programme. It consists of a constellation of two satellites and provides continuity of radar data from the previous ERS and Envisat missions.

Wavelength: Sentinel-1 operates in C-band (7.5 m – 3.75 cm wavelength), selected to provide continuity with the ERS and ENVISAT missions where this wavelength proved ideal for operational ocean and sea-ice monitoring. In a habitat-mapping context, C-band mostly interacts with smaller elements within the canopy meaning that its ability to differentiate between different high-biomass vegetation covers is limited. However, numerous studies have demonstrated the use of C-band SAR for vegetation mapping and monitoring.

Polarisation: Sentinel-1 allows for either single-polarised (VV or HH) or dual-polarised (VV/VH or HH/HV) capture. For vegetation studies, either dual-polarised configuration will prove preferable to single-polarised data as variations in vegetation structure are most clearly observed in the cross-polarised channel (VH or HV).

Acquisition modes: There are three image acquisition modes available from the Sentinel-1 missions suitable for land cover mapping. As Table 8.1 illustrates, these modes have differing swath widths and resolutions. In each case, increasing swath width results in a lower resolution product. While stripmap and interferometric wide swath are both noted as having the same 10 m^2 pixel spacing, the reduced swath width of stripmap data allows it to provide a product with greatly improved radiometric characteristics and reduced speckle. Despite its improved image quality, stripmap is not a routinely planned capture mode.

Table 8.1: Sentinel-1 image modes

Terrestrial acquisition mode	*Swath width*	*Pixel spacing*	*Spatial resolution*
Stripmap (SM)	80 km	10 x 10 m	23 x 23 m
Interferometric Wide (IW)	250 km	10 x 10 m	20 x 22 m
Extra-Wide (EW)	400 km	25 x 25 m	50 x 50 m

Stripmap (SM) will be available upon request, such as disaster and emergency management, and is therefore a non-standard product. The Interferometric Wide (IW) swath is the default mode over terrestrial areas. The Extra-Wide (EW) swath mode will be predominantly programmed over European, Arctic and Southern Ocean areas (European Space Agency, 2012).

The final resolution of a fully processed image captured in IW mode could be in the region of 10m to 20m in UTM projection.

Coverage: Figure 8.5 illustrates differences in the geographic coverage provided by the different acquisition modes.

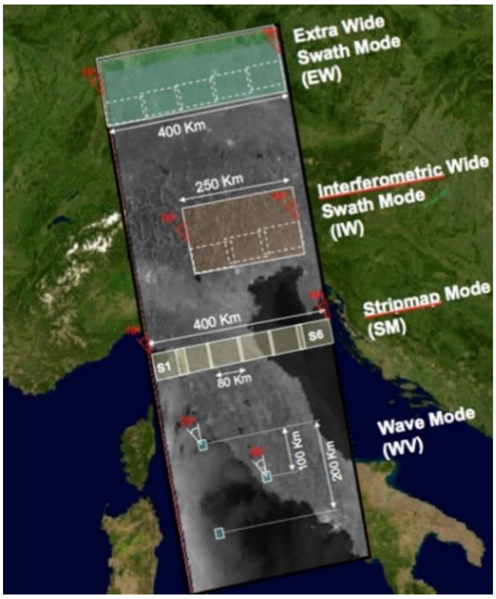


Figure 8.5: Spatial differences between the different acquisition modes

At full operation, a single Sentinel-1 satellite will be able to map the world once every 12 days (Figure 8.6), and six days in constellation (i.e. with Sentinel-1A and Sentinel-1B).

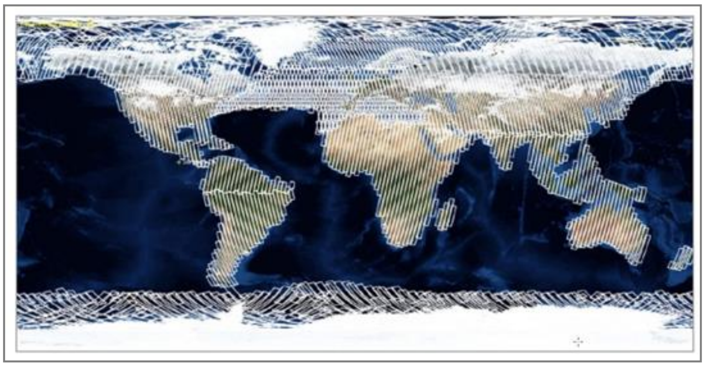


Figure 8.6: Coverage of Sentinel-1 in IW mode over a 12 day period (European Space Agency, 2013)

Sentinel-2

Description of mission

Sentinel-2 is an ESA space mission of the Copernicus Programme. It consists of a constellation of two satellites contributing to ongoing multispectral observation missions (e.g., SPOT, Landsat) and enhancing average global image capture revisit times.

Wavelengths: Sentinel-2 is a multispectral imager (MSI) covering 13 spectral bands (443 nm – 2190 nm) with a swath width of 290 km and spatial resolutions of 10 m (in visible and near-infrared bands), 20 m (in red-edge and shortwave-infrared bands) and 60 m (the atmospheric correction bands).

Coverage: The Sentinel-2 mission provides systematic coverage over the following areas:

- all continental land surfaces (including inland waters) between latitudes 56° south and 83° north,
- all coastal waters up to 20 km from the shore,

- all islands greater than 100 km^2,
- all EU islands,
- the Mediterranean Sea,
- all closed seas (e.g., Caspian Sea),

Revisit time: The two satellites in the Sentinel-2 constellation provide an average revisit time of 10 days in cloud-free conditions. Due to overlap between swaths from adjacent orbits, the revisit frequency will be increased with different viewing conditions.

Appendix C. St Helena survey habitats

Table 8.2: IUCN habitats identified and located during the habitat surveys

IUCN Level 3	*Number of observations*
1.5.1 Gumwood Woodland	12
1.5.2 Eucalyptus Woodland	74
1.5.3 Pine Woodland	98
1.5.4 Bermudan Cedar Woodland	75
1.5.5 Wild Mango Woodland	49
1.5.6 She-Oak Woodland	2
1.5.7 Mixed Woodland	84
1.5.8 Peruvian Pepper Tree Woodland	14
1.5.9 Acacia Woodland	34
1.6.1 Thorn Tree Woodland	33
1.6.2 Blackwood Woodland	11
1.6.3 Cape Yew Woodland	28
1.6.4 Dark Sclerophyllous Woodland	1
1.6.5 Bamboo Thicket Woodland	2
1.6.6 Cypress Woodland	16
1.6.7 White Poplar Woodland	1
1.6.8 Chinese Fir Woodland	1
1.9.1 Tree Fern Thicket	6
1.9.3 She Cabbage Tree Woodland	2
1.9.4 Jellico Stands	2
1.9.5 Moist Upland Species Mix	7
1.9.6 Dogwood & White Wood Mix	1
3.5.1 Scrubwood Scrub	11
3.5.2 Sparse Shrub Mixture	56
3.5.3 Mixed Leucaena Shrubland	4
3.5.6 Furze Scrub	8
3.5.7 Dense Shrub Mixture	51
3.5.8 Lantana Scrub	14
3.5.9 Wild Coffee Scrub	2
3.5.10 Acacia Scrub	36
3.5.11 Vegetation with Exposed Soil	23
3.5.12 Eucalyptus Dominated Shrub	2
3.6.2 Bilberry	7
3.6.3 Buddleja Thickets	5
3.6.5 Blue Weed	1
3.6.6 Ginger Stands	7
3.6.7 Upland Complex Mosaic	16
3.6.8 Flax	108
3.6.9 Whiteweed	18
3.7.1 Native Open Fern Mix	2
4.5.1 Native Rush Grasses	2
4.5.2 Lowland Endemic Grass Mix	1
5.1.2 Permanent Riparian Margins	4
5.1.3 Permanent Riparian Scrub	8
5.2.1 Semi-permanent Stream	1
5.2.2 Semi-permanent Riparian Margins	2

5.2.4 Dry Gully	4
5.3.2 Fern Swards	1
5.3.3 Rice Paper Plant	5
5.8.3 Dense of Rush/Sedge Species	5
5.8.5 Chow-chow Dominated Area	1
5.8.6 Aracea Dominated Area	3
5.9.1 Freshwater Springs/Seepage	1
6.1.1 Rocky Areas	11
6.1.2 Lichen Covered Ground	1
6.1.3 Barren Rubble	23
6.1.4 Scree	3
6.1.5 Inland Rocky Cliffs	25
6.2.1 Succulent Native Annuals	3
6.2.3 Barren Soil	64
6.2.4 Sparse Shrub	11
8.4.1 Fountain Grass and Prickly Pear Semi-Desert Mix	16
8.4.2 Agave Scrub Semi-Desert	9
8.4.3 Introduced Low Shrub Semi-Desert	5
8.4.5 Samphire Semi-Desert	16
8.4.6 Creeper Waste Semi-Desert	18
8.4.7 Sparse Prickly Pear	21
12.1.1 Rocky Shoreline	13
12.2.1 Sandy Shore	5
12.3.1 Shingle/Pebble Shore	3
12.6.1 Tidepools	9
13.1.1 Sea Cliffs	10
13.1.2 Offshore Island	1
14.1.1 Planted Crops	40
14.2.1 Kikuyu Grass Dominated Pasture	175
14.2.2 Cardinal Tussocks	2
14.2.3 Grassland Transition Area	2
14.2.4 Scattered Tree Pasturelands	6
14.2.5 Mixed Grass Pasturelands	15
14.2.6 Elephant Grass Meadow	2
14.2.7 Tussock Grassland	1
14.2.8 Thatching Grass Meadow	8
14.2.9 Neglected Alien Herb Areas	17
14.2.10 Bull Grass Dominated Pastureland	1
14.2.11 Bamboo Grass Patches	2
14.2.12 Wire Grass Dominated Ground	4
14.3.2 Commercial Plantation	7
14.4.1 Rural Gardens	28
14.5.1 Urban Areas & Buildings	6
14.5.4 Tarmacadam	15
14.5.5 Unsurfaced Tracks	11
14.5.6 Vegetated Banks	10
14.5.7 Earth Banks	1
14.5.10 Open Grass Field	18
15.1.1 Reservoir	12
15.2.1 Pond	3
15.11.1 Dock/Jetty	3

17.2.0 Other Vegetated (add to notes)	2
Bamboo	1
NEW (add to notes)	6
Not specified	3

Appendix D. St Helena habitat maps

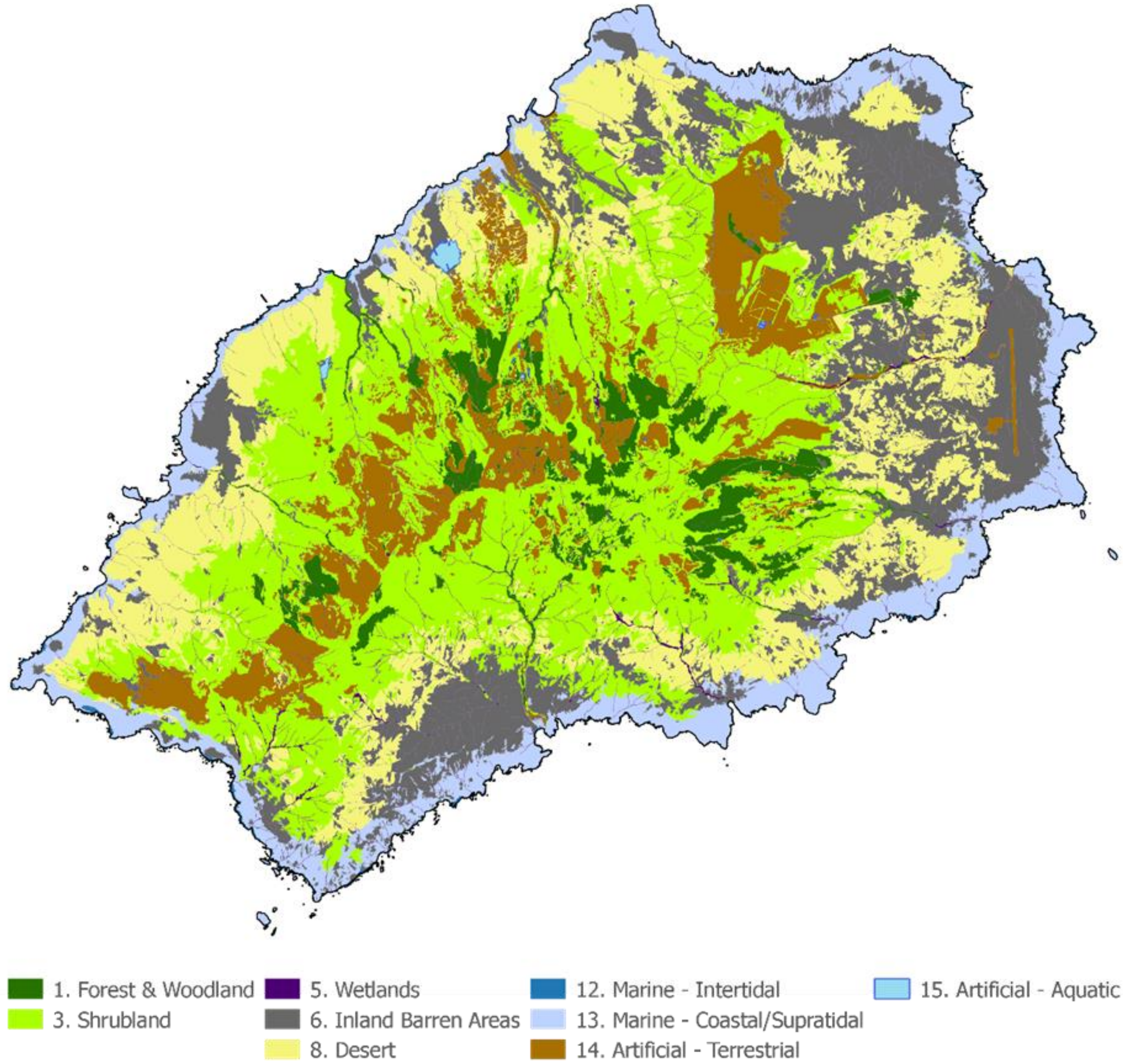


Figure 8.7: IUCN habitat classification, Level 1

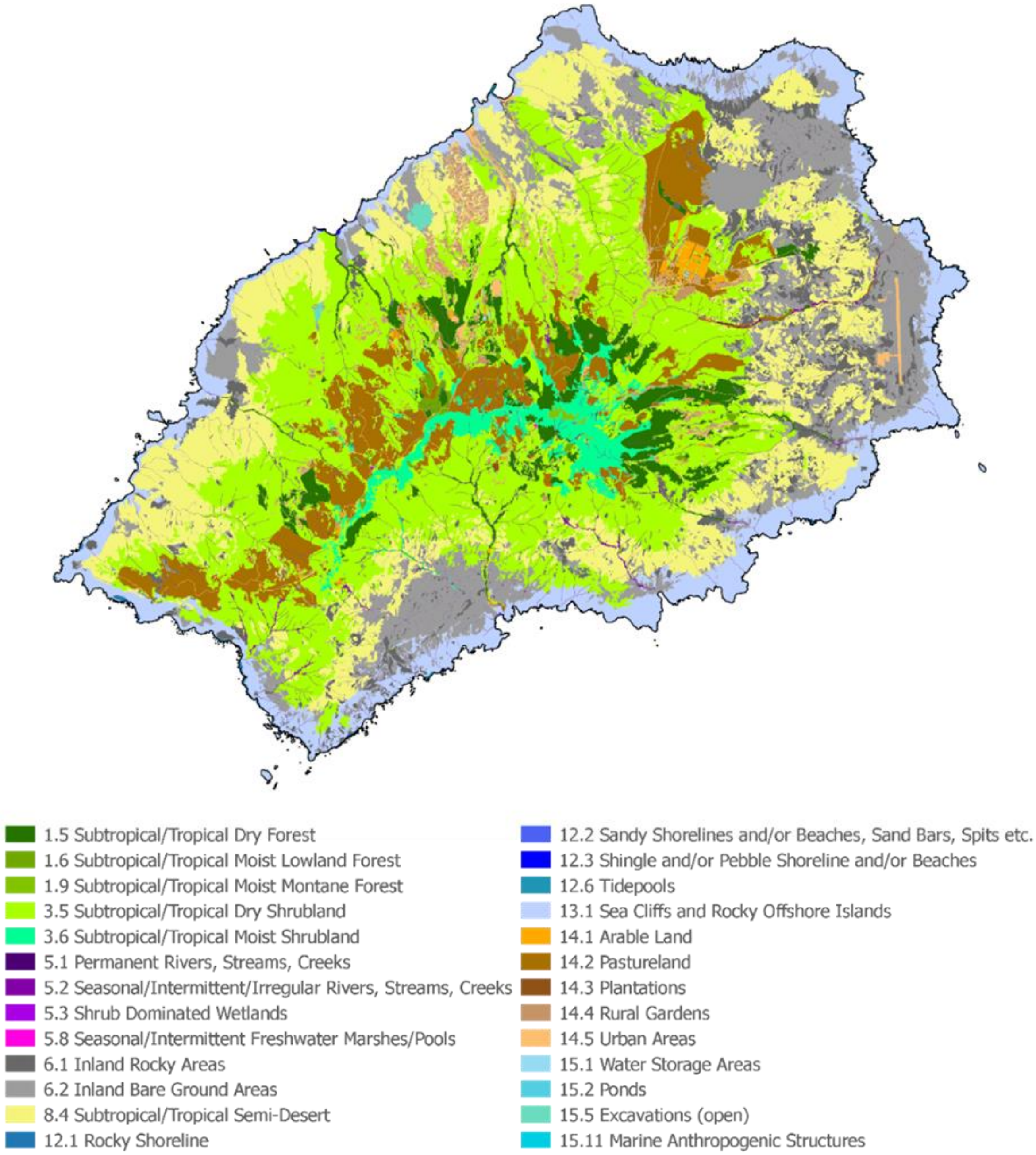


Figure 8.8: IUCN habitat classification, Level 2

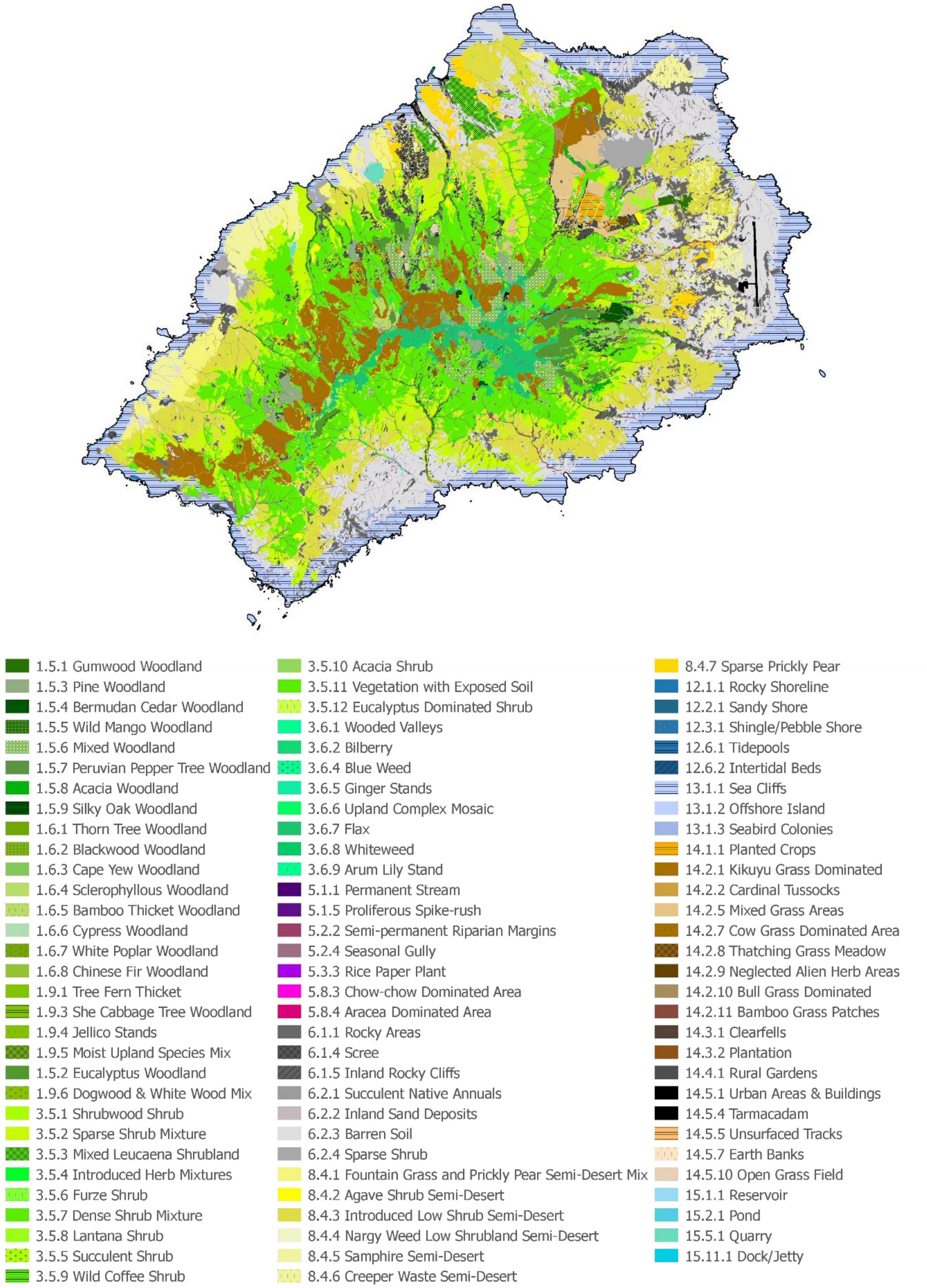


Figure 8.9: IUCN habitat classification, Level 3

Appendix E. St Helena habitat distributions

Table 8.3: IUCN Level 2 land cover and percentage areas (%)

IUCN Level 2	*Land cover, percent (%)*
1.5 Subtropical/Tropical Dry Forest	4.7
1.6 Subtropical/Tropical Moist Lowland Forest	0.5
1.9 Subtropical/Tropical Moist Montane Forest	0.1
3.5 Subtropical/Tropical Dry Shrubland	29.9
3.6 Subtropical/Tropical Moist Shrubland	2.6
5.1 Permanent Rivers, Streams, Creeks	1.5
5.2 Seasonal/Intermittent/Irregular Rivers, Streams, Creeks	0.2
5.3 Shrub Dominated Wetlands	0.0
5.8 Seasonal/Intermittent Freshwater Marshes/Pools	0.0
6.1 Inland Rocky Areas	5.4
6.2 Inland Bare Ground Areas	13.4
8.4 Subtropical/Tropical Semi-Desert	18.3
12.1 Rocky Shoreline	0.5
12.2 Sandy Shorelines and/or Beaches, Sand Bars, Spits etc.	0.0
12.3 Shingle and/or Pebble Shoreline and/or Beaches	0.0
12.6 Tidepools	0.0
13.1 Sea Cliffs and Rocky Offshore Islands	10.6
14.1 Arable Land	0.4
14.2 Pastureland	8.8
14.3 Plantations	0.0
14.4 Rural Gardens	1.5
14.5 Urban Areas	1.3
15.1 Water Storage Areas	0.0
15.11 Marine Anthropogenic Structures	0.0
15.2 Ponds	0.0
15.5 Excavations (open)	0.2

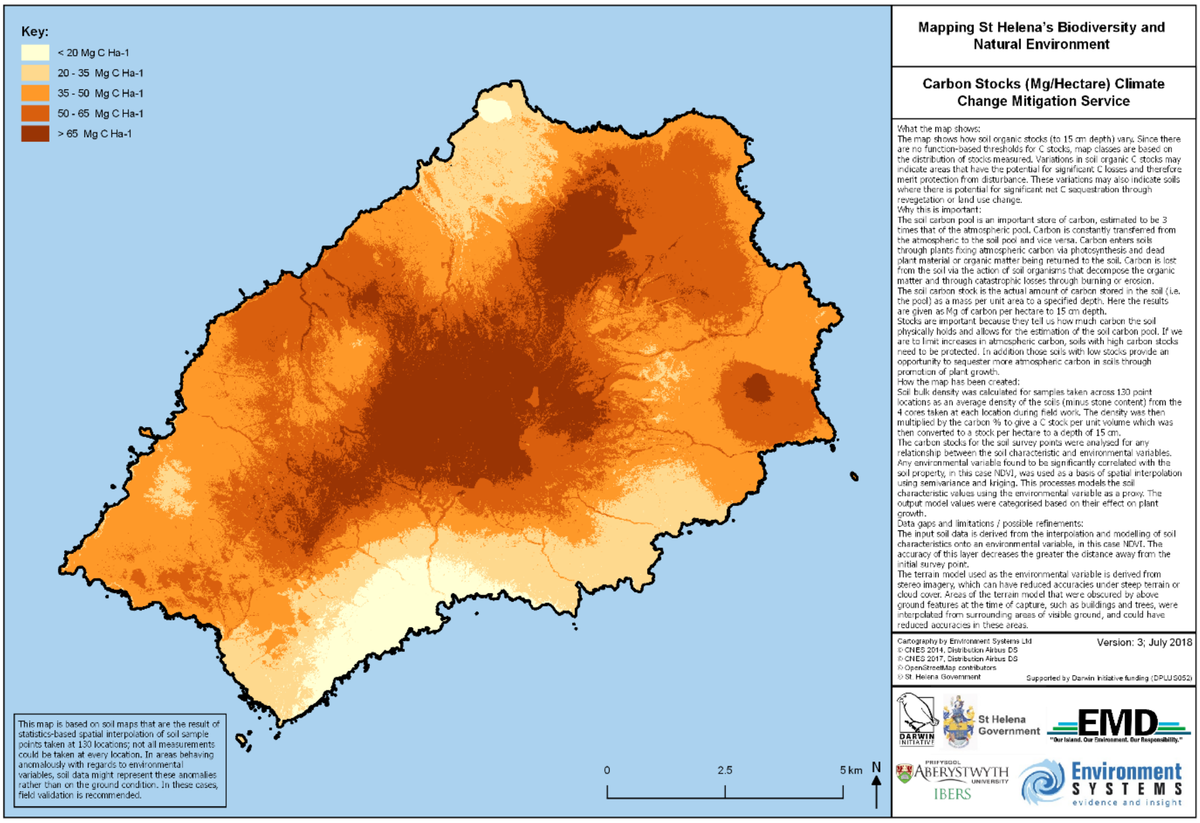
Table 8.4: IUCN Level 3 land cover and percentage areas (%)

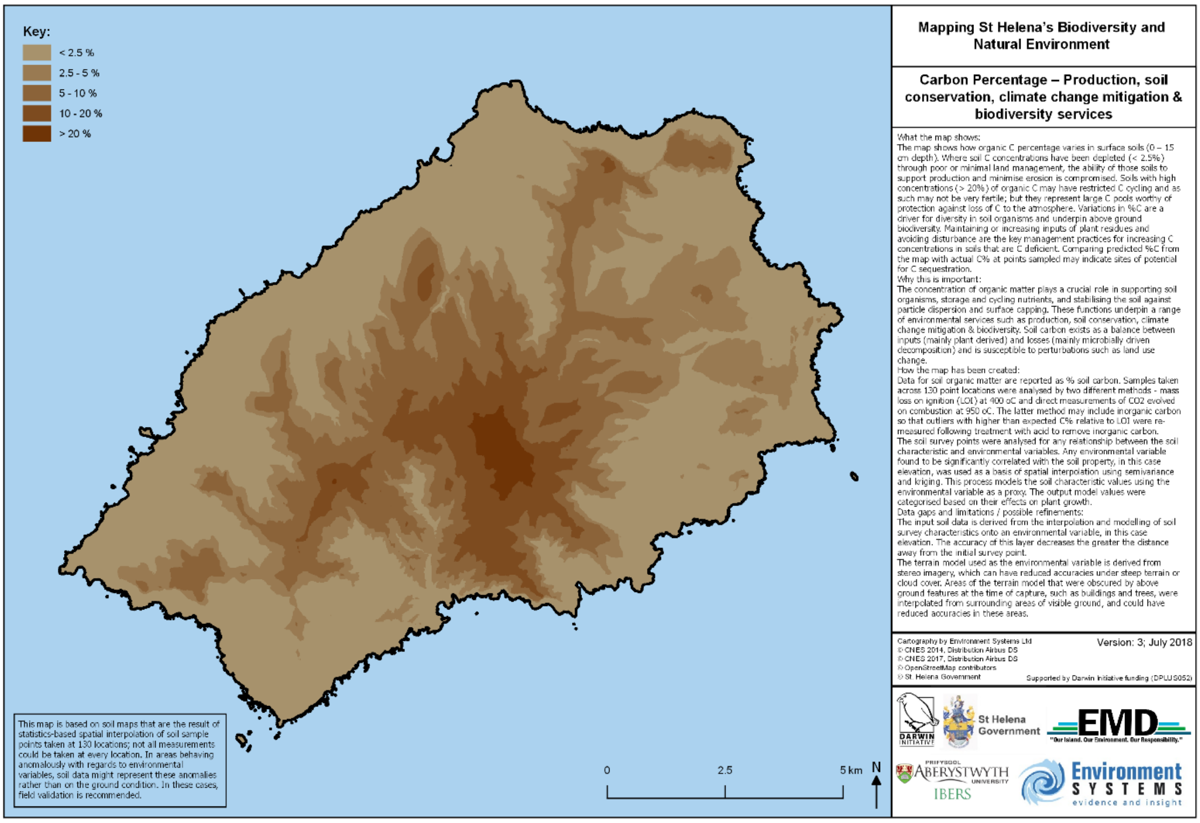
IUCN Level 3	*Land cover, percent (%)*
1.5.3 Pine Woodland	0.82
1.5.4 Bermudan Cedar Woodland	0.25
1.5.5 Wild Mango Woodland	0.40
1.5.6 Mixed Woodland	1.61
1.5.7 Peruvian Pepper Tree Woodland	0.02
1.5.8 Acacia Woodland	0.11
1.5.9 Silky Oak Woodland	0.02
1.6.1 Thorn Tree Woodland	0.16
1.6.2 Blackwood Woodland	0.12
1.6.3 Cape Yew Woodland	0.06
1.6.4 Sclerophyllous Woodland	0.21
1.6.5 Bamboo Thicket Woodland	0.00
1.6.6 Cypress Woodland	0.00
1.6.7 White Poplar Woodland	0.00
1.6.8 Chinese Fir Woodland	0.00
1.9.1 Tree Fern Thicket	0.02
1.9.3 She Cabbage Tree Woodland	0.00
1.9.4 Jellico Stands	0.00
1.9.5 Moist Upland Species Mix	0.05
1.9.6 Dogwood & White Wood Mix	0.00
3.5.1 Shrubwood Shrub	0.03
3.5.2 Sparse Shrub Mixture	9.82

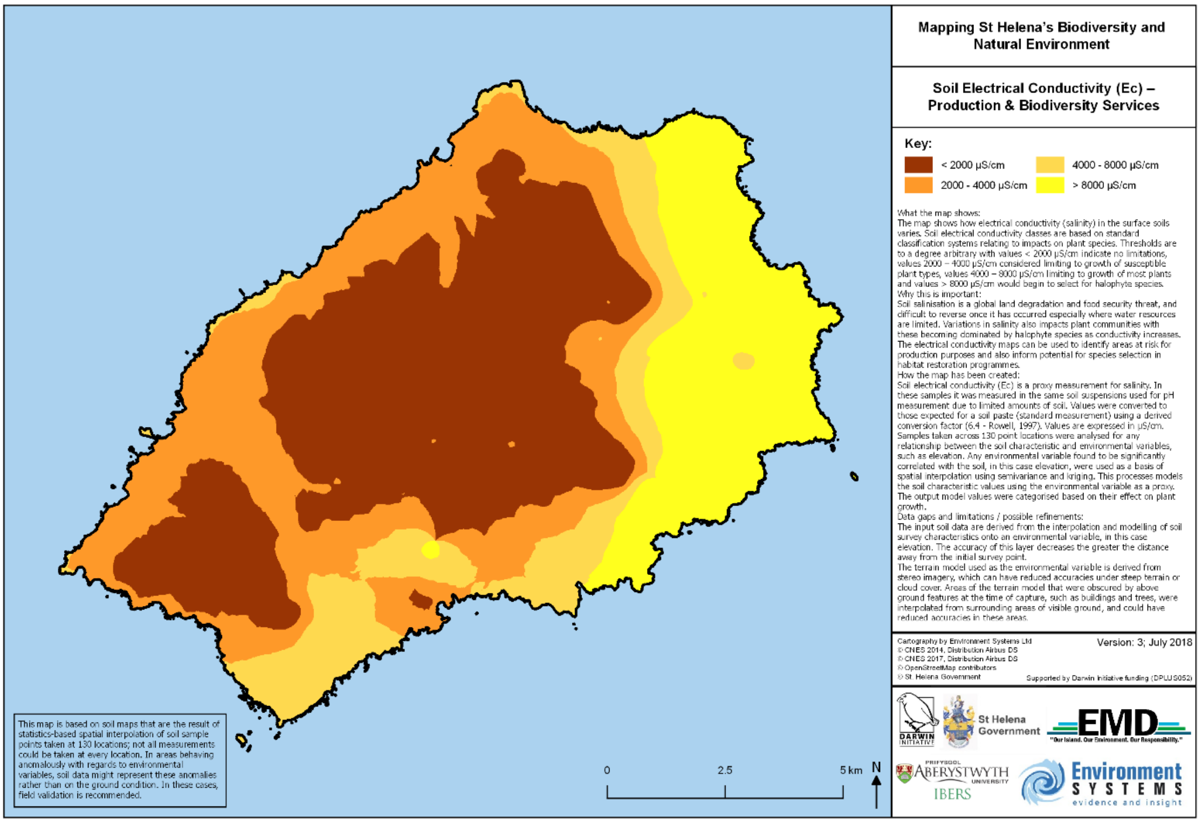
IUCN Level 3	*Land cover, percent (%)*
3.5.3 Mixed Leucaena Shrubland	0.76
3.5.4 Introduced Herb Mixtures	0.00
3.5.5 Succulent Shrub	0.00
3.5.6 Furze Shrub	0.12
3.5.7 Dense Shrub Mixture	19.19
3.5.8 Lantana Shrub	0.11
3.5.9 Wild Coffee Shrub	0.02
3.5.10 Acacia Shrub	0.23
3.5.11 Vegetation with Exposed Soil	0.02
3.5.12 Eucalyptus Dominated Shrub	0.01
3.6.1 Wooded Valleys	0.04
3.6.2 Bilberry	0.00
3.6.4 Blue Weed	0.00
3.6.5 Ginger Stands	0.00
3.6.6 Upland Complex Mosaic	0.06
3.6.7 Flax	2.48
3.6.8 Whiteweed	0.09
3.6.9 Arum Lily Stand	0.00
5.1.1 Permanent Stream	1.54
5.1.5 Proliferous Spike-rush	0.00
5.2.2 Semi-permanent Riparian Margins	0.12
5.2.4 Seasonal Gully	0.06
5.3.3 Rice Paper Plant	0.00
5.8.3 Chow-chow Dominated Area	0.00
5.8.4 Aracea Dominated Area	0.00
6.1.1 Rocky Areas	4.40
6.1.4 Scree	0.22
6.1.5 Inland Rocky Cliffs	0.89
6.2.1 Succulent Native Annuals	0.01
6.2.2 Inland Sand Deposits	0.02
6.2.3 Barren Soil	12.47
6.2.4 Sparse Shrub	1.09
8.4.1 Fountain Grass and Prickly Pear Semi-Desert Mix	1.91
8.4.2 Agave Shrub Semi-Desert	0.20
8.4.3 Introduced Low Shrub Semi-Desert	12.37
8.4.4 Nargy Weed Low Shrubland Semi-Desert	0.02
8.4.5 Samphire Semi-Desert	1.65
8.4.6 Creeper Waste Semi-Desert	1.33
8.4.7 Sparse Prickly Pear	1.10
12.1.1 Rocky Shoreline	0.49
12.2.1 Sandy Shore	0.01
12.3.1 Shingle/Pebble Shore	0.02
12.6.1 Tidepools	0.00
12.6.2 Intertidal Beds	0.01
13.1.1 Sea Cliffs	10.48
13.1.2 Offshore Island	0.15
13.1.3 Seabird Colonies	0.09
14.1.1 Planted Crops	0.42
14.2.1 Kikuyu Grass Dominated	7.20
14.2.2 Cardinal Tussocks	0.00
14.2.5 Mixed Grass Areas	1.58
14.2.7 Cow Grass Dominated Area	0.01
14.2.8 Thatching Grass Meadow	0.03
14.2.9 Neglected Alien Herb Areas	0.07
14.2.10 Bull Grass Dominated	0.06

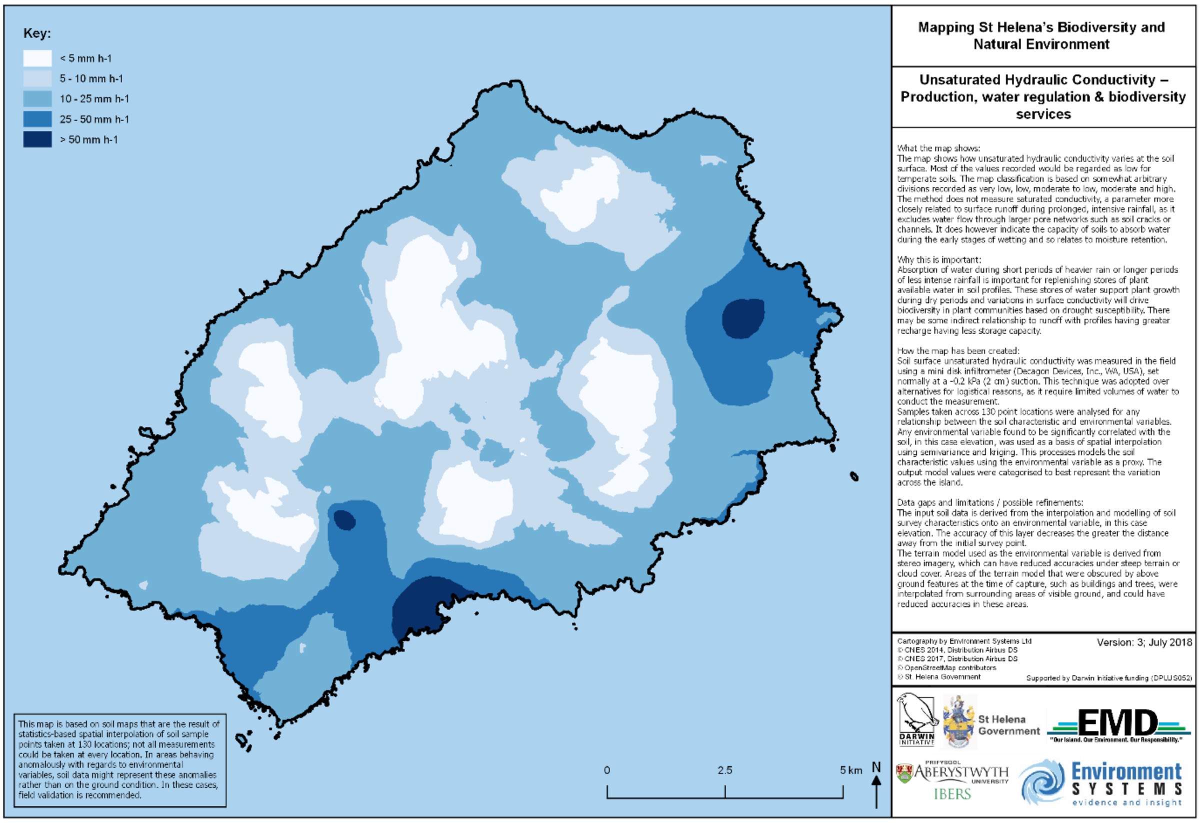
IUCN Level 3	*Land cover, percent (%)*
14.2.11 Bamboo Grass Patches	0.01
14.3.1 Clearfells	0.00
14.3.2 Plantation	0.03
14.4.1 Rural Gardens	1.55
14.5.1 Urban Areas & Buildings	0.64
14.5.4 Tarmacadam	0.51
14.5.5 Unsurfaced Tracks	0.12
14.5.7 Earth Banks	0.00
14.5.10 Open Grass Field	0.06
15.1.1 Reservoir	0.02
15.2.1 Pond	0.00
15.5.1 Quarry	0.16
15.11.1 Dock/Jetty	0.02

Appendix F. St Helena soil maps






Mapping St Helena’s Biodiversity and Natural Environment
Soil Electrical Conductivity (Ec) – Production & Biodiversity Services
Key:
< 2000 µS/cm
2000 - 4000 µS/cm
4000 - 8000 µS/cm
> 8000 µS/cm
What the map shows:
The map shows how electrical conductivity (salinity) in the surface soils varies. Soil electrical conductivity classes are based on standard classification systems relating to impacts on plant species. Thresholds are to a degree arbitrary with values < 2000 µS/cm indicate no limitations, values 2000 – 4000 µS/cm considered limiting to growth of susceptible plant types, values 4000 – 8000 µS/cm limiting to growth of most plants and values > 8000 µS/cm would begin to select for halophyte species.
Why this is important:
Soil salinisation is a global land degradation and food security threat, and difficult to reverse once it has occurred especially where water resources are limited. Variations in salinity also impacts plant communities with these becoming dominated by halophyte species as conductivity increases. The electrical conductivity maps can be used to identify areas at risk for production purposes and also inform potential for species selection in habitat restoration programmes.
How the map has been created:
Soil electrical conductivity (Ec) is a proxy measurement for salinity. In these samples it was measured in the same soil suspensions used for pH measurement due to limited amounts of soil. Values were converted to those expected for a soil paste (standard measurement) using a derived conversion factor (6.4 - Rowell, 1997). Values are expressed in µS/cm. Samples taken across 130 point locations were analysed for any relationship between the soil characteristic and environmental variables, such as elevation. Any environmental variable found to be significantly correlated with the soil, in this case elevation, were used as a basis of spatial interpolation using semivariance and kriging. This processes models the soil characteristic values using the environmental variable as a proxy. The output model values were categorised based on their effect on plant growth.
Data gaps and limitations / possible refinements:
The input soil data are derived from the interpolation and modelling of soil survey characteristics onto an environmental variable, in this case elevation. The accuracy of this layer decreases the greater the distance away from the initial survey point.
The terrain model used as the environmental variable is derived from stereo imagery, which can have reduced accuracies under steep terrain or cloud cover. Areas of the terrain model that were obscured by above ground features at the time of capture, such as buildings and trees, were interpolated from surrounding areas of visible ground, and could have reduced accuracies in these areas.
Cartography by Environment Systems Ltd
© CNES 2014, Distribution Airbus DS
© CNES 2017, Distribution Airbus DS
© OpenStreetMap contributors
© St. Helena Government
Version: 3; July 2018
Supported by Darwin Initiative funding (DPLUS052)
This map is based on soil maps that are the result of statistics-based spatial interpolation of soil sample points taken at 130 locations; not all measurements could be taken at every location. In areas behaving anomalously with regards to environmental variables, soil data might represent these anomalies rather than on the ground condition. In these cases, field validation is recommended.
0
2.5
5 km
N


Key:
< 5 mm h-1
5 - 10 mm h-1
10 - 25 mm h-1
25 - 50 mm h-1
> 50 mm h-1
Mapping St Helena’s Biodiversity and Natural Environment
Unsaturated Hydraulic Conductivity – Production, water regulation & biodiversity services
What the map shows:
The map shows how unsaturated hydraulic conductivity varies at the soil surface. Most of the values recorded would be regarded as low for temperate soils. The map classification is based on somewhat arbitrary divisions recorded as very low, low, moderate to low, moderate and high. The method does not measure saturated conductivity, a parameter more closely related to surface runoff during prolonged, intensive rainfall, as it excludes water flow through larger pore networks such as soil cracks or channels. It does however indicate the capacity of soils to absorb water during the early stages of wetting and so relates to moisture retention.
Why this is important:
Absorption of water during short periods of heavier rain or longer periods of less intense rainfall is important for replenishing stores of plant available water in soil profiles. These stores of water support plant growth during dry periods and variations in surface conductivity will drive biodiversity in plant communities based on drought susceptibility. There may be some indirect relationship to runoff with profiles having greater recharge having less storage capacity.
How the map has been created:
Soil surface unsaturated hydraulic conductivity was measured in the field using a mini disk infiltrometer (Decagon Devices, Inc., WA, USA), set normally at a -0.2 kPa (2 cm) suction. This technique was adopted over alternatives for logistical reasons, as it require limited volumes of water to conduct the measurement.
Samples taken across 130 point locations were analysed for any relationship between the soil characteristic and environmental variables. Any environmental variable found to be significantly correlated with the soil, in this case elevation, was used as a basis of spatial interpolation using semivariance and kriging. This processes models the soil characteristic values using the environmental variable as a proxy. The output model values were categorised to best represent the variation across the island.
Data gaps and limitations / possible refinements:
The input soil data is derived from the interpolation and modelling of soil survey characteristics onto an environmental variable, in this case elevation. The accuracy of this layer decreases the greater the distance away from the initial survey point.
The terrain model used as the environmental variable is derived from stereo imagery, which can have reduced accuracies under steep terrain or cloud cover. Areas of the terrain model that were obscured by above ground features at the time of capture, such as buildings and trees, were interpolated from surrounding areas of visible ground, and could have reduced accuracies in these areas.
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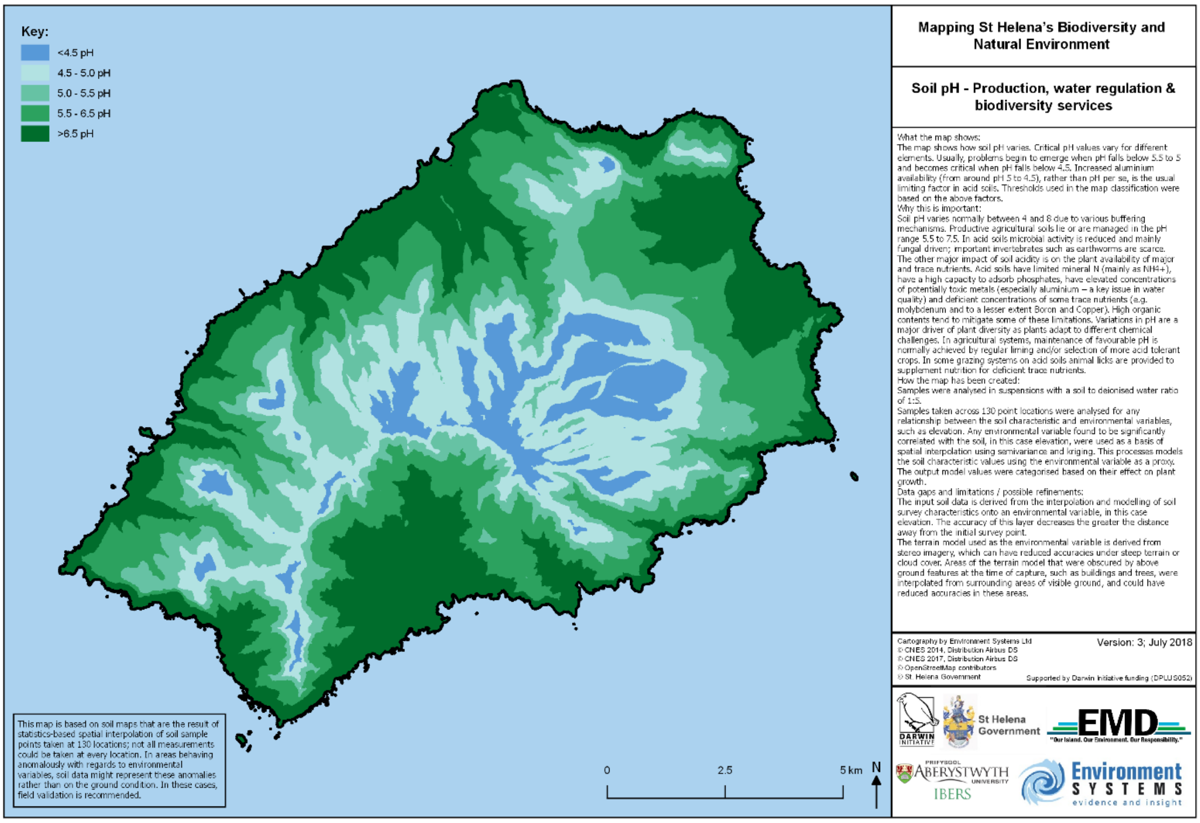
This map is based on soil maps that are the result of statistics-based spatial interpolation of soil sample points taken at 130 locations; not all measurements could be taken at every location. In areas behaving anomalously with regards to environmental variables, soil data might represent these anomalies rather than on the ground condition. In these cases, field validation is recommended.
0
2.5
5 km
N


Key:
<4.5 pH
4.5 - 5.0 pH
5.0 - 5.5 pH
5.5 - 6.5 pH
>6.5 pH
This map is based on soil maps that are the result of statistics-based spatial interpolation of soil sample points taken at 130 locations; not all measurements could be taken at every location. In areas behaving anomalously with regards to environmental variables, soil data might represent these anomalies rather than on the ground condition. In these cases, field validation is recommended.
0
2.5
5 km
N
Mapping St Helena's Biodiversity and Natural Environment
Soil pH - Production, water regulation & biodiversity services
What the map shows:
The map shows how soil pH varies. Critical pH values vary for different elements. Usually, problems begin to emerge when pH falls below 5.5 to 5 and becomes critical when pH falls below 4.5. Increased aluminium availability (from around pH 5 to 4.5), rather than pH per se, is the usual limiting factor in acid soils. Thresholds used in the map classification were based on the above factors.
Why this is important:
Soil pH varies normally between 4 and 8 due to various buffering mechanisms. Productive agricultural soils lie or are managed in the pH range 5.5 to 7.5. In acid soils microbial activity is reduced and mainly fungal driven; important invertebrates such as earthworms are scarce. The other major impact of soil acidity is on the plant availability of major and trace nutrients. Acid soils have limited mineral N (mainly as NH4+), have a high capacity to adsorb phosphates, have elevated concentrations of potentially toxic metals (especially aluminium – a key issue in water quality) and deficient concentrations of some trace nutrients (e.g. molybdenum and to a lesser extent Boron and Copper). High organic contents tend to mitigate some of these limitations. Variations in pH are a major driver of plant diversity as plants adapt to different chemical challenges. In agricultural systems, maintenance of favourable pH is normally achieved by regular liming and/or selection of more acid tolerant crops. In some grazing systems on acid soils animal licks are provided to supplement nutrition for deficient trace nutrients.
How the map has been created:
Samples were analysed in suspensions with a soil to deionised water ratio of 1:5.
Samples taken across 130 point locations were analysed for any relationship between the soil characteristic and environmental variables, such as elevation. Any environmental variable found to be significantly correlated with the soil, in this case elevation, were used as a basis of spatial interpolation using semivariance and kriging. This processes models the soil characteristic values using the environmental variable as a proxy. The output model values were categorised based on their effect on plant growth.
Data gaps and limitations / possible refinements:
The input soil data is derived from the interpolation and modelling of soil survey characteristics onto an environmental variable, in this case elevation. The accuracy of this layer decreases the greater the distance away from the initial survey point.
The terrain model used as the environmental variable is derived from stereo imagery, which can have reduced accuracies under steep terrain or cloud cover. Areas of the terrain model that were obscured by above ground features at the time of capture, such as buildings and trees, were interpolated from surrounding areas of visible ground, and could have reduced accuracies in these areas.
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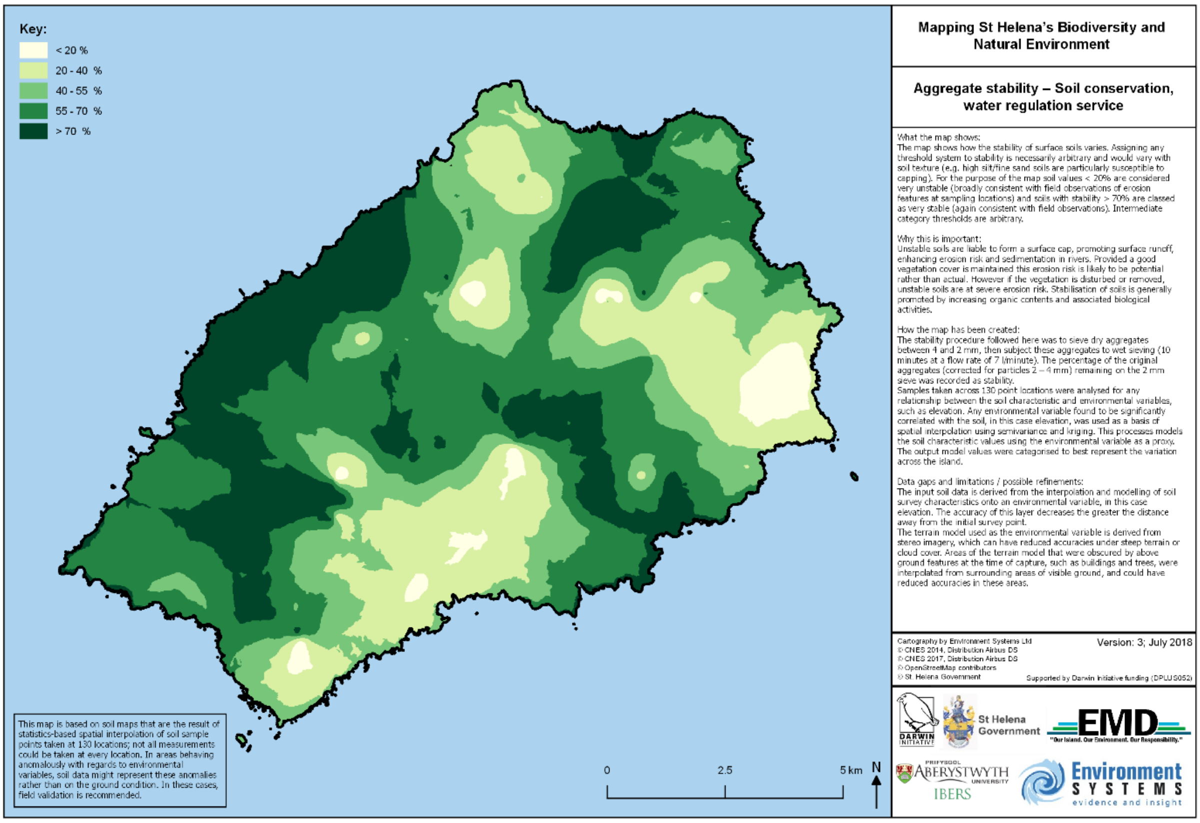
Key:
< 20 %
20 - 40 %
40 - 55 %
55 - 70 %
> 70 %
This map is based on soil maps that are the result of statistics-based spatial interpolation of soil sample points taken at 130 locations; not all measurements could be taken at every location. In areas behaving anomalously with regards to environmental variables, soil data might represent these anomalies rather than on the ground condition. In these cases, field validation is recommended.
0
2.5
5 km
N
Mapping St Helena's Biodiversity and Natural Environment
Aggregate stability – Soil conservation, water regulation service
What the map shows:
The map shows how the stability of surface soils varies. Assigning any threshold system to stability is necessarily arbitrary and would vary with soil texture (e.g. high silt/fine sand soils are particularly susceptible to capping). For the purpose of the map soil values < 20% are considered very unstable (broadly consistent with field observations of erosion features at sampling locations) and soils with stability > 70% are classed as very stable (again consistent with field observations). Intermediate category thresholds are arbitrary.
Why this is important:
Unstable soils are liable to form a surface cap, promoting surface runoff, enhancing erosion risk and sedimentation in rivers. Provided a good vegetation cover is maintained this erosion risk is likely to be potential rather than actual. However if the vegetation is disturbed or removed, unstable soils are at severe erosion risk. Stabilisation of soils is generally promoted by increasing organic contents and associated biological activities.
How the map has been created:
The stability procedure followed here was to sieve dry aggregates between 4 and 2 mm, then subject these aggregates to wet sieving (10 minutes at a flow rate of 7 l/minute). The percentage of the original aggregates (corrected for particles 2 – 4 mm) remaining on the 2 mm sieve was recorded as stability.
Samples taken across 130 point locations were analysed for any relationship between the soil characteristic and environmental variables, such as elevation. Any environmental variable found to be significantly correlated with the soil, in this case elevation, was used as a basis of spatial interpolation using semivariance and kriging. This processes models the soil characteristic values using the environmental variable as a proxy. The output model values were categorised to best represent the variation across the island.
Data gaps and limitations / possible refinements:
The input soil data is derived from the interpolation and modelling of soil survey characteristics onto an environmental variable, in this case elevation. The accuracy of this layer decreases the greater the distance away from the initial survey point.
The terrain model used as the environmental variable is derived from stereo imagery, which can have reduced accuracies under steep terrain or cloud cover. Areas of the terrain model that were obscured by above ground features at the time of capture, such as buildings and trees, were interpolated from surrounding areas of visible ground, and could have reduced accuracies in these areas.
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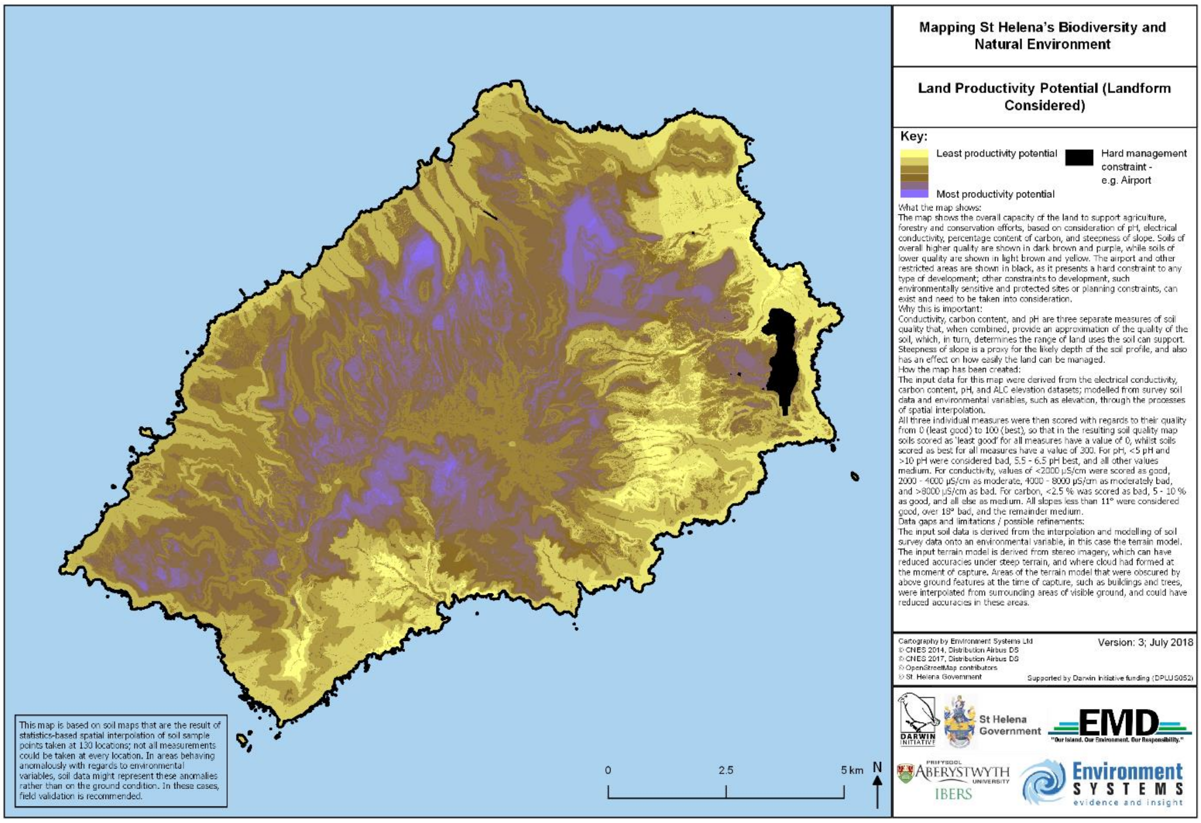
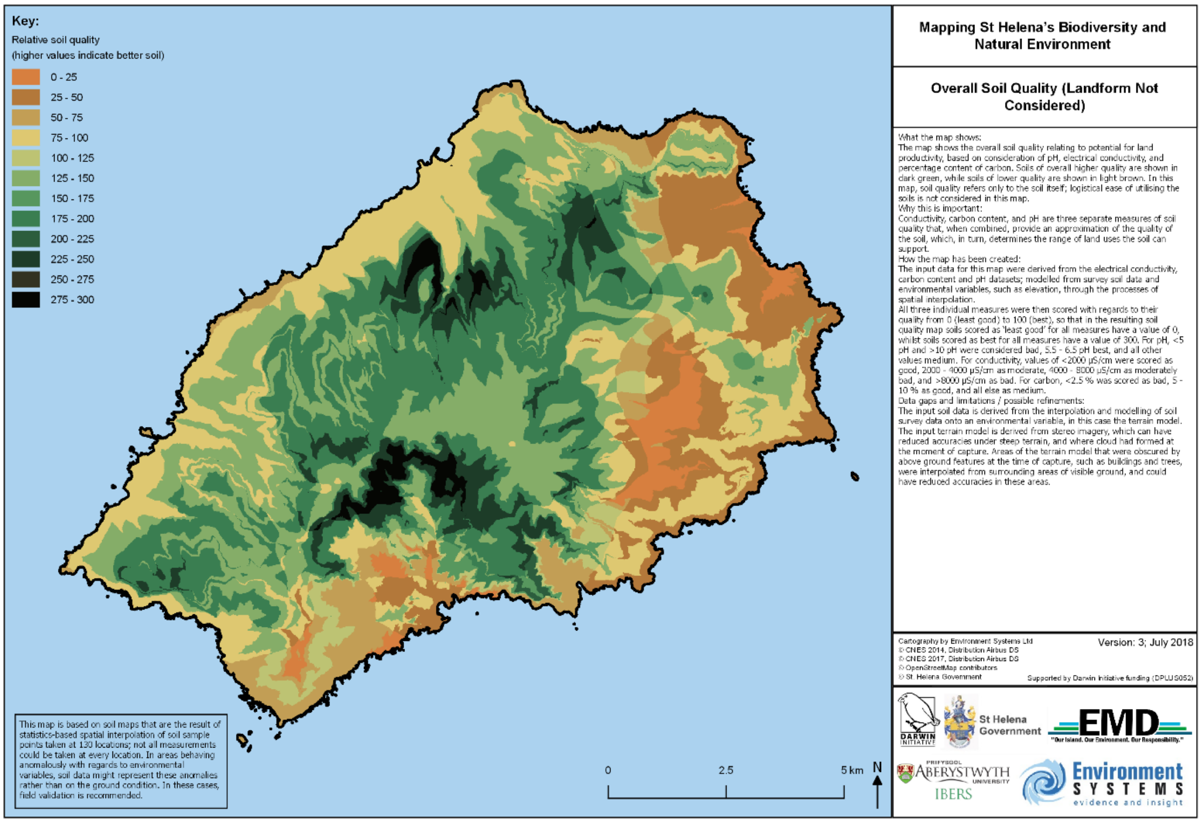
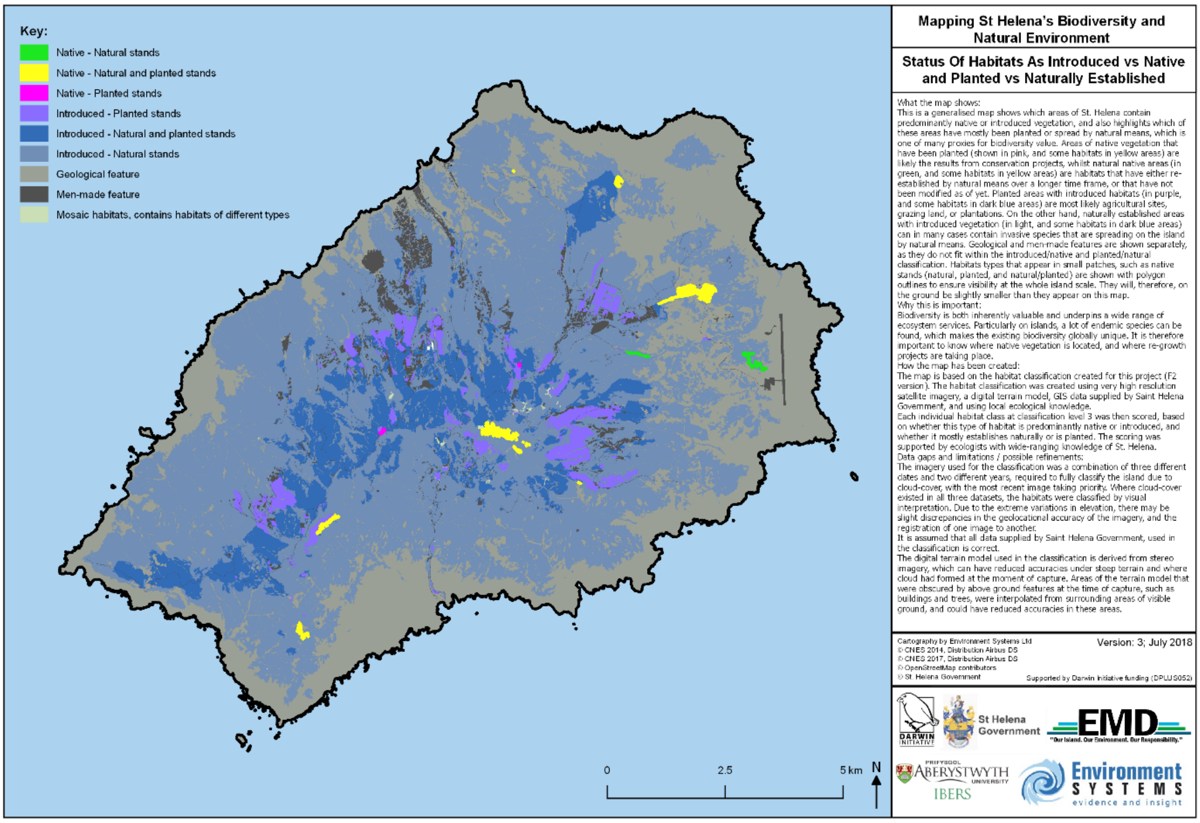
Appendix G. St Helena ecosystem services maps






Key:
Native - Natural stands
Native - Natural and planted stands
Native - Planted stands
Introduced - Planted stands
Introduced - Natural and planted stands
Introduced - Natural stands
Geological feature
Men-made feature
Mosaic habitats, contains habitats of different types
0
2.5
5 km
N
Mapping St Helena's Biodiversity and Natural Environment
Status Of Habitats As Introduced vs Native and Planted vs Naturally Established
What the map shows:
This is a generalised map shows which areas of St. Helena contain predominantly native or introduced vegetation, and also highlights which of these areas have mostly been planted or spread by natural means, which is one of many proxies for biodiversity value. Areas of native vegetation that have been planted (shown in pink, and some habitats in yellow areas) are likely the results from conservation projects, whilst natural native areas (in green, and some habitats in yellow areas) are habitats that have either re-established by natural means over a longer time frame, or that have not been modified as of yet. Planted areas with introduced habitats (in purple, and some habitats in dark blue areas) are most likely agricultural sites, grazing land, or plantations. On the other hand, naturally established areas with introduced vegetation (in light, and some habitats in dark blue areas) can in many cases contain invasive species that are spreading on the island by natural means. Geological and men-made features are shown separately, as they do not fit within the introduced/native and planted/natural classification. Habitats types that appear in small patches, such as native stands (natural, planted, and natural/planted) are shown with polygon outlines to ensure visibility at the whole island scale. They will, therefore, on the ground be slightly smaller than they appear on this map.
Why this is important:
Biodiversity is both inherently valuable and underpins a wide range of ecosystem services. Particularly on islands, a lot of endemic species can be found, which makes the existing biodiversity globally unique. It is therefore important to know where native vegetation is located, and where re-growth projects are taking place.
How the map has been created:
The map is based on the habitat classification created for this project (F2 version). The habitat classification was created using very high resolution satellite imagery, a digital terrain model, GIS data supplied by Saint Helena Government, and using local ecological knowledge.
Each individual habitat class at classification level 3 was then scored, based on whether this type of habitat is predominantly native or introduced, and whether it mostly establishes naturally or is planted. The scoring was supported by ecologists with wide-ranging knowledge of St. Helena.
Data gaps and limitations / possible refinements:
The imagery used for the classification was a combination of three different dates and two different years, required to fully classify the island due to cloud-cover, with the most recent image taking priority. Where cloud-cover existed in all three datasets, the habitats were classified by visual interpretation. Due to the extreme variations in elevation, there may be slight discrepancies in the geolocational accuracy of the imagery, and the registration of one image to another.
It is assumed that all data supplied by Saint Helena Government, used in the classification is correct.
The digital terrain model used in the classification is derived from stereo imagery, which can have reduced accuracies under steep terrain and where cloud had formed at the moment of capture. Areas of the terrain model that were obscured by above ground features at the time of capture, such as buildings and trees, were interpolated from surrounding areas of visible ground, and could have reduced accuracies in these areas.
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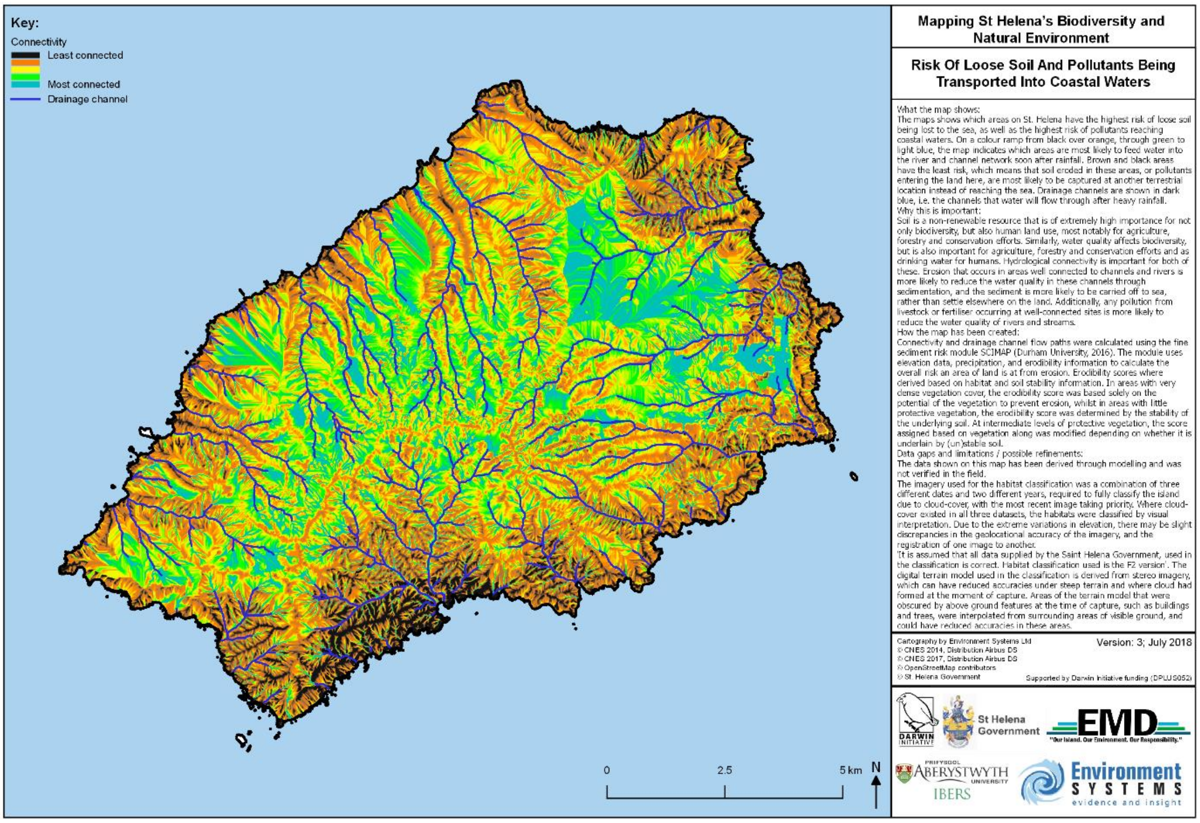
Key:
Connectivity
Least connected
Most connected
Drainage channel
0
2.5
5 km
N
Mapping St Helena's Biodiversity and Natural Environment
Risk Of Loose Soil And Pollutants Being Transported Into Coastal Waters
What the map shows:
The maps shows which areas on St. Helena have the highest risk of loose soil being lost to the sea, as well as the highest risk of pollutants reaching coastal waters. On a colour ramp from black over orange, through green to light blue, the map indicates which areas are most likely to feed water into the river and channel network soon after rainfall. Brown and black areas have the least risk, which means that soil eroded in these areas, or pollutants entering the land here, are most likely to be captured at another terrestrial location instead of reaching the sea. Drainage channels are shown in dark blue, i.e. the channels that water will flow through after heavy rainfall.
Why this is important:
Soil is a non-renewable resource that is of extremely high importance for not only biodiversity, but also human land use, most notably for agriculture, forestry and conservation efforts. Similarly, water quality affects biodiversity, but is also important for agriculture, forestry and conservation efforts and as drinking water for humans. Hydrological connectivity is important for both of these. Erosion that occurs in areas well connected to channels and rivers is more likely to reduce the water quality in these channels through sedimentation, and the sediment is more likely to be carried off to sea, rather than settle elsewhere on the land. Additionally, any pollution from livestock or fertiliser occurring at well-connected sites is more likely to reduce the water quality of rivers and streams.
How the map has been created:
Connectivity and drainage channel flow paths were calculated using the fine sediment risk module SCIMAP (Durham University, 2016). The module uses elevation data, precipitation, and erodibility information to calculate the overall risk an area of land is at from erosion. Erodibility scores where derived based on habitat and soil stability information. In areas with very dense vegetation cover, the erodibility score was based solely on the potential of the vegetation to prevent erosion, whilst in areas with little protective vegetation, the erodibility score was determined by the stability of the underlying soil. At intermediate levels of protective vegetation, the score assigned based on vegetation along was modified depending on whether it is underlain by (un)stable soil.
Data gaps and limitations / possible refinements:
The data shown on this map has been derived through modelling and was not verified in the field.
The imagery used for the habitat classification was a combination of three different dates and two different years, required to fully classify the island due to cloud-cover, with the most recent image taking priority. Where cloud-cover existed in all three datasets, the habitats were classified by visual interpretation. Due to the extreme variations in elevation, there may be slight discrepancies in the geolocational accuracy of the imagery, and the registration of one image to another.
'It is assumed that all data supplied by the Saint Helena Government, used in the classification is correct. Habitat classification used is the F2 version'. The digital terrain model used in the classification is derived from stereo imagery, which can have reduced accuracies under steep terrain and where cloud had formed at the moment of capture. Areas of the terrain model that were obscured by above ground features at the time of capture, such as buildings and trees, were interpolated from surrounding areas of visible ground, and could have reduced accuracies in these areas.
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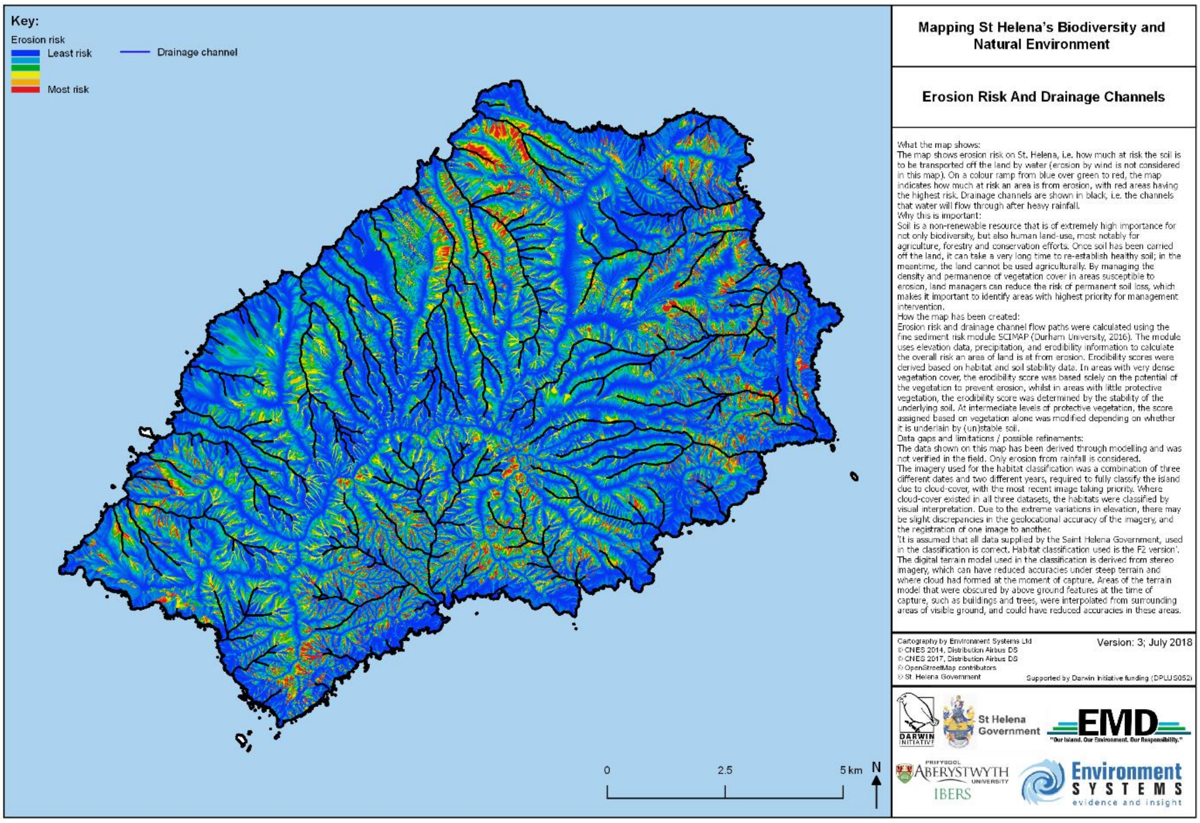
Key:
Erosion risk
Least risk
Most risk
Drainage channel
Mapping St Helena's Biodiversity and Natural Environment
Erosion Risk And Drainage Channels
What the map shows:
The map shows erosion risk on St. Helena, i.e. how much at risk the soil is to be transported off the land by water (erosion by wind is not considered in this map). On a colour ramp from blue over green to red, the map indicates how much at risk an area is from erosion, with red areas having the highest risk. Drainage channels are shown in black, i.e. the channels that water will flow through after heavy rainfall.
Why this is important:
Soil is a non-renewable resource that is of extremely high importance for not only biodiversity, but also human land-use, most notably for agriculture, forestry and conservation efforts. Once soil has been carried off the land, it can take a very long time to re-establish healthy soil; in the meantime, the land cannot be used agriculturally. By managing the density and permanence of vegetation cover in areas susceptible to erosion, land managers can reduce the risk of permanent soil loss, which makes it important to identify areas with highest priority for management intervention.
How the map has been created:
Erosion risk and drainage channel flow paths were calculated using the fine sediment risk module SCIMAP (Durham University, 2016). The module uses elevation data, precipitation, and erodibility information to calculate the overall risk an area of land is at from erosion. Erodibility scores were derived based on habitat and soil stability data. In areas with very dense vegetation cover, the erodibility score was based solely on the potential of the vegetation to prevent erosion, whilst in areas with little protective vegetation, the erodibility score was determined by the stability of the underlying soil. At intermediate levels of protective vegetation, the score assigned based on vegetation alone was modified depending on whether it is underlain by (un)stable soil.
Data gaps and limitations / possible refinements:
The data shown on this map has been derived through modelling and was not verified in the field. Only erosion from rainfall is considered.
The imagery used for the habitat classification was a combination of three different dates and two different years, required to fully classify the island due to cloud-cover, with the most recent image taking priority. Where cloud-cover existed in all three datasets, the habitats were classified by visual interpretation. Due to the extreme variations in elevation, there may be slight discrepancies in the geolocational accuracy of the imagery, and the registration of one image to another.
'It is assumed that all data supplied by the Saint Helena Government, used in the classification is correct. Habitat classification used is the F2 version'.
The digital terrain model used in the classification is derived from stereo imagery, which can have reduced accuracies under steep terrain and where cloud had formed at the moment of capture. Areas of the terrain model that were obscured by above ground features at the time of capture, such as buildings and trees, were interpolated from surrounding areas of visible ground, and could have reduced accuracies in these areas.
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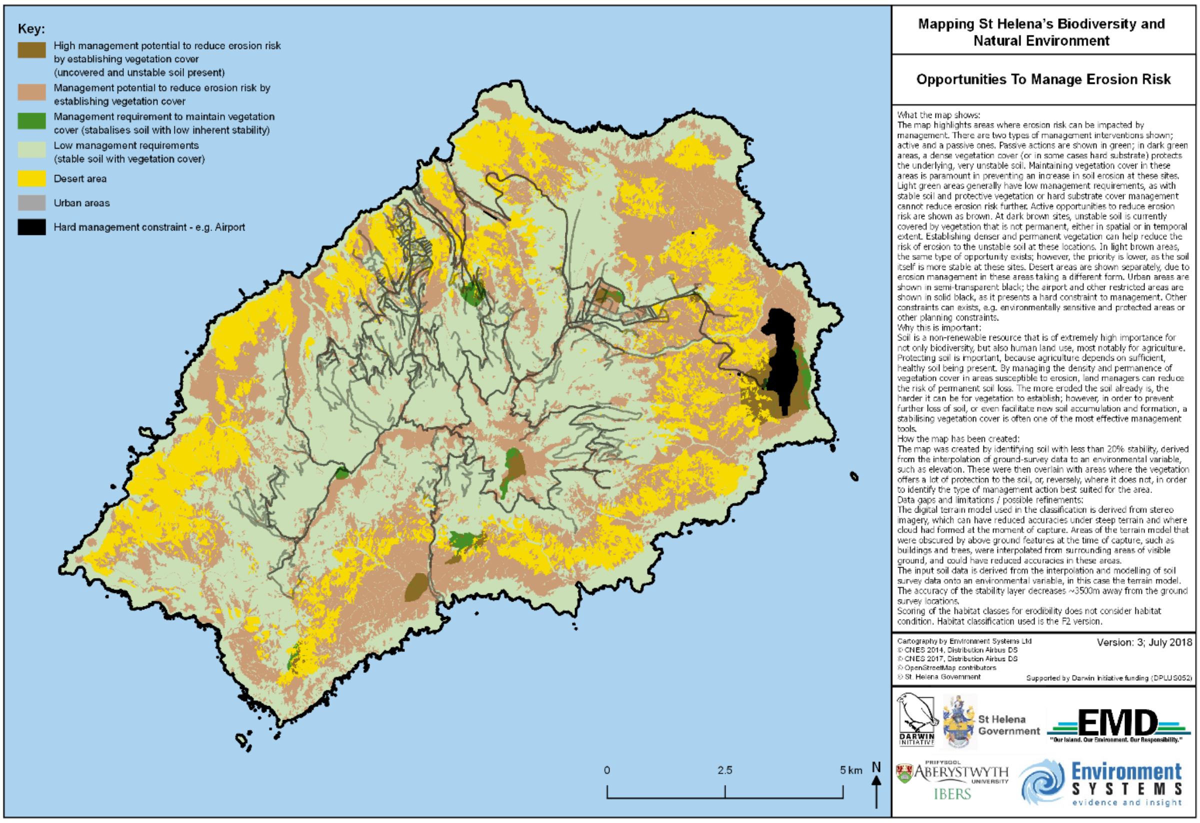
0
2.5
5 km
N


Key:
High management potential to reduce erosion risk by establishing vegetation cover (uncovered and unstable soil present)
Management potential to reduce erosion risk by establishing vegetation cover
Management requirement to maintain vegetation cover (stabalises soil with low inherent stability)
Low management requirements (stable soil with vegetation cover)
Desert area
Urban areas
Hard management constraint - e.g. Airport
Mapping St Helena's Biodiversity and Natural Environment
Opportunities To Manage Erosion Risk
What the map shows:
The map highlights areas where erosion risk can be impacted by management. There are two types of management interventions shown; active and a passive ones. Passive actions are shown in green; in dark green areas, a dense vegetation cover (or in some cases hard substrate) protects the underlying, very unstable soil. Maintaining vegetation cover in these areas is paramount in preventing an increase in soil erosion at these sites. Light green areas generally have low management requirements, as with stable soil and protective vegetation or hard substrate cover management cannot reduce erosion risk further. Active opportunities to reduce erosion risk are shown as brown. At dark brown sites, unstable soil is currently covered by vegetation that is not permanent, either in spatial or in temporal extent. Establishing denser and permanent vegetation can help reduce the risk of erosion to the unstable soil at these locations. In light brown areas, the same type of opportunity exists; however, the priority is lower, as the soil itself is more stable at these sites. Desert areas are shown separately, due to erosion management in these areas taking a different form. Urban areas are shown in semi-transparent black; the airport and other restricted areas are shown in solid black, as it presents a hard constraint to management. Other constraints can exists, e.g. environmentally sensitive and protected areas or other planning constraints.
Why this is important:
Soil is a non-renewable resource that is of extremely high importance for not only biodiversity, but also human land use, most notably for agriculture. Protecting soil is important, because agriculture depends on sufficient, healthy soil being present. By managing the density and permanence of vegetation cover in areas susceptible to erosion, land managers can reduce the risk of permanent soil loss. The more eroded the soil already is, the harder it can be for vegetation to establish; however, in order to prevent further loss of soil, or even facilitate new soil accumulation and formation, a stabilising vegetation cover is often one of the most effective management tools.
How the map has been created:
The map was created by identifying soil with less than 20% stability, derived from the interpolation of ground-survey data to an environmental variable, such as elevation. These were then overlain with areas where the vegetation offers a lot of protection to the soil, or, reversely, where it does not, in order to identify the type of management action best suited for the area.
Data gaps and limitations / possible refinements:
The digital terrain model used in the classification is derived from stereo imagery, which can have reduced accuracies under steep terrain and where cloud had formed at the moment of capture. Areas of the terrain model that were obscured by above ground features at the time of capture, such as buildings and trees, were interpolated from surrounding areas of visible ground, and could have reduced accuracies in these areas.
The input soil data is derived from the interpolation and modelling of soil survey data onto an environmental variable, in this case the terrain model. The accuracy of the stability layer decreases ~3500m away from the ground survey locations.
Scoring of the habitat classes for erodibility does not consider habitat condition. Habitat classification used is the F2 version.
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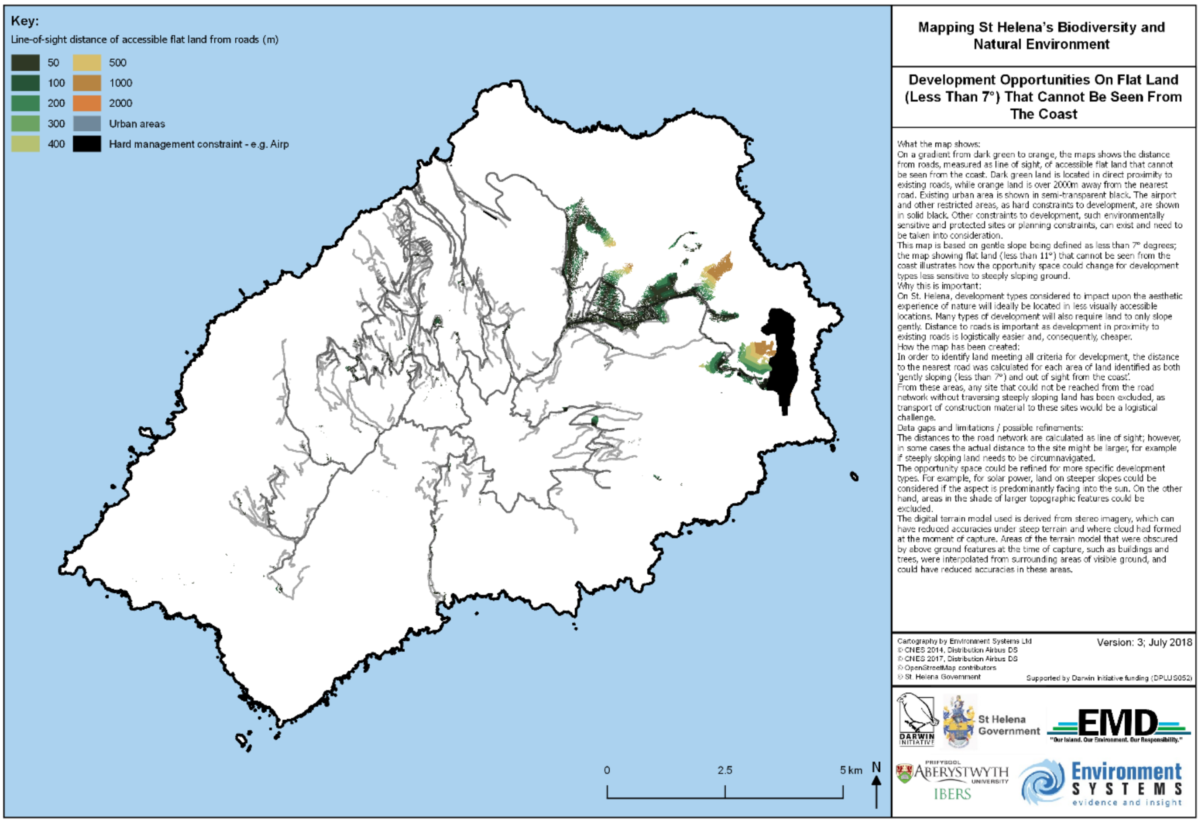
0
2.5
5 km
N


Key:
Line-of-sight distance of accessible flat land from roads (m)
50
100
200
300
400
500
1000
2000
Urban areas
Hard management constraint - e.g. Airp
Mapping St Helena's Biodiversity and Natural Environment
Development Opportunities On Flat Land (Less Than 7°) That Cannot Be Seen From The Coast
What the map shows:
On a gradient from dark green to orange, the maps shows the distance from roads, measured as line of sight, of accessible flat land that cannot be seen from the coast. Dark green land is located in direct proximity to existing roads, while orange land is over 2000m away from the nearest road. Existing urban area is shown in semi-transparent black. The airport and other restricted areas, as hard constraints to development, are shown in solid black. Other constraints to development, such environmentally sensitive and protected sites or planning constraints, can exist and need to be taken into consideration.
This map is based on gentle slope being defined as less than 7° degrees; the map showing flat land (less than 11°) that cannot be seen from the coast illustrates how the opportunity space could change for development types less sensitive to steeply sloping ground.
Why this is important:
On St. Helena, development types considered to impact upon the aesthetic experience of nature will ideally be located in less visually accessible locations. Many types of development will also require land to only slope gently. Distance to roads is important as development in proximity to existing roads is logistically easier and, consequently, cheaper.
How the map has been created:
In order to identify land meeting all criteria for development, the distance to the nearest road was calculated for each area of land identified as both 'gently sloping (less than 7°) and out of sight from the coast'.
From these areas, any site that could not be reached from the road network without traversing steeply sloping land has been excluded, as transport of construction material to these sites would be a logistical challenge.
Data gaps and limitations / possible refinements:
The distances to the road network are calculated as line of sight; however, in some cases the actual distance to the site might be larger, for example if steeply sloping land needs to be circumnavigated.
The opportunity space could be refined for more specific development types. For example, for solar power, land on steeper slopes could be considered if the aspect is predominantly facing into the sun. On the other hand, areas in the shade of larger topographic features could be excluded.
The digital terrain model used is derived from stereo imagery, which can have reduced accuracies under steep terrain and where cloud had formed at the moment of capture. Areas of the terrain model that were obscured by above ground features at the time of capture, such as buildings and trees, were interpolated from surrounding areas of visible ground, and could have reduced accuracies in these areas.
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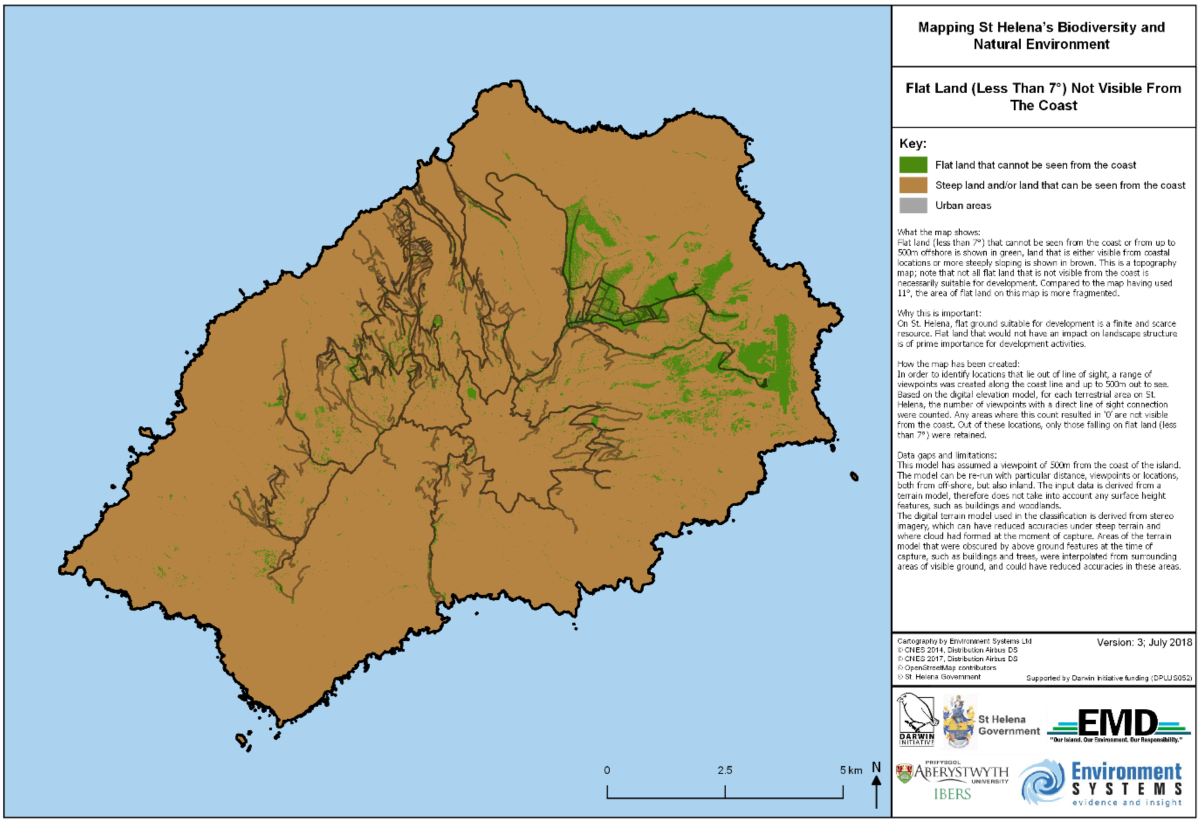
0
2.5
5 km
N


Mapping St Helena's Biodiversity and Natural Environment
Flat Land (Less Than 7°) Not Visible From The Coast
Key:
Flat land that cannot be seen from the coast
Steep land and/or land that can be seen from the coast
Urban areas
What the map shows:
Flat land (less than 7°) that cannot be seen from the coast or from up to 500m offshore is shown in green, land that is either visible from coastal locations or more steeply sloping is shown in brown. This is a topography map; note that not all flat land that is not visible from the coast is necessarily suitable for development. Compared to the map having used 11°, the area of flat land on this map is more fragmented.
Why this is important:
On St. Helena, flat ground suitable for development is a finite and scarce resource. Flat land that would not have an impact on landscape structure is of prime importance for development activities.
How the map has been created:
In order to identify locations that lie out of line of sight, a range of viewpoints was created along the coast line and up to 500m out to see. Based on the digital elevation model, for each terrestrial area on St. Helena, the number of viewpoints with a direct line of sight connection were counted. Any areas where this count resulted in '0' are not visible from the coast. Out of these locations, only those falling on flat land (less than 7°) were retained.
Data gaps and limitations:
This model has assumed a viewpoint of 500m from the coast of the island. The model can be re-run with particular distance, viewpoints or locations, both from off-shore, but also inland. The input data is derived from a terrain model, therefore does not take into account any surface height features, such as buildings and woodlands.
The digital terrain model used in the classification is derived from stereo imagery, which can have reduced accuracies under steep terrain and where cloud had formed at the moment of capture. Areas of the terrain model that were obscured by above ground features at the time of capture, such as buildings and trees, were interpolated from surrounding areas of visible ground, and could have reduced accuracies in these areas.
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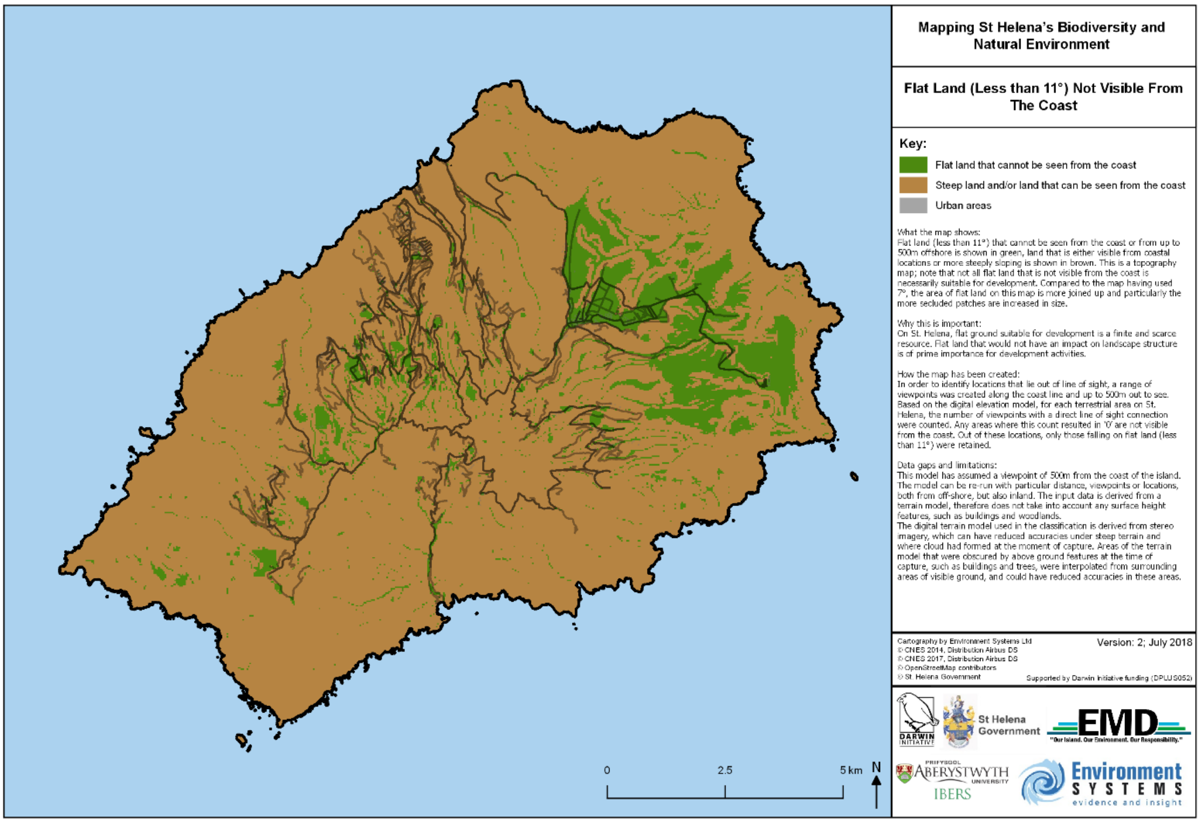
0
2.5
5 km
N


Mapping St Helena's Biodiversity and Natural Environment
Flat Land (Less than 11°) Not Visible From The Coast
Key:
Flat land that cannot be seen from the coast
Steep land and/or land that can be seen from the coast
Urban areas
What the map shows:
Flat land (less than 11°) that cannot be seen from the coast or from up to 500m offshore is shown in green, land that is either visible from coastal locations or more steeply sloping is shown in brown. This is a topography map; note that not all flat land that is not visible from the coast is necessarily suitable for development. Compared to the map having used 7°, the area of flat land on this map is more joined up and particularly the more secluded patches are increased in size.
Why this is important:
On St. Helena, flat ground suitable for development is a finite and scarce resource. Flat land that would not have an impact on landscape structure is of prime importance for development activities.
How the map has been created:
In order to identify locations that lie out of line of sight, a range of viewpoints was created along the coast line and up to 500m out to see. Based on the digital elevation model, for each terrestrial area on St. Helena, the number of viewpoints with a direct line of sight connection were counted. Any areas where this count resulted in '0' are not visible from the coast. Out of these locations, only those falling on flat land (less than 11°) were retained.
Data gaps and limitations:
This model has assumed a viewpoint of 500m from the coast of the island. The model can be re-run with particular distance, viewpoints or locations, both from off-shore, but also inland. The input data is derived from a terrain model, therefore does not take into account any surface height features, such as buildings and woodlands.
The digital terrain model used in the classification is derived from stereo imagery, which can have reduced accuracies under steep terrain and where cloud had formed at the moment of capture. Areas of the terrain model that were obscured by above ground features at the time of capture, such as buildings and trees, were interpolated from surrounding areas of visible ground, and could have reduced accuracies in these areas.
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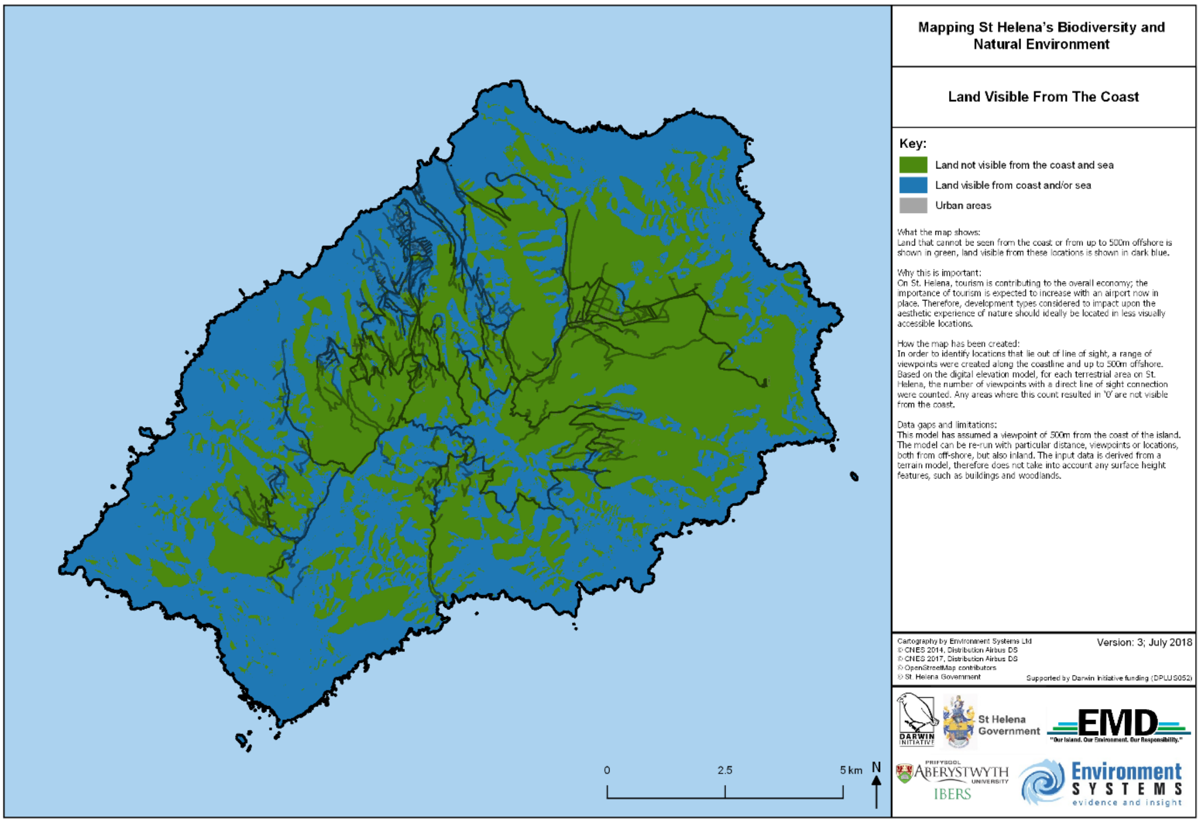
Mapping St Helena's Biodiversity and Natural Environment
Land Visible From The Coast
Key:
Land not visible from the coast and sea
Land visible from coast and/or sea
Urban areas
What the map shows:
Land that cannot be seen from the coast or from up to 500m offshore is shown in green, land visible from these locations is shown in dark blue.
Why this is important:
On St. Helena, tourism is contributing to the overall economy; the importance of tourism is expected to increase with an airport now in place. Therefore, development types considered to impact upon the aesthetic experience of nature should ideally be located in less visually accessible locations.
How the map has been created:
In order to identify locations that lie out of line of sight, a range of viewpoints were created along the coastline and up to 500m offshore. Based on the digital elevation model, for each terrestrial area on St. Helena, the number of viewpoints with a direct line of sight connection were counted. Any areas where this count resulted in '0' are not visible from the coast.
Data gaps and limitations:
This model has assumed a viewpoint of 500m from the coast of the island. The model can be re-run with particular distance, viewpoints or locations, both from off-shore, but also inland. The input data is derived from a terrain model, therefore does not take into account any surface height features, such as buildings and woodlands.
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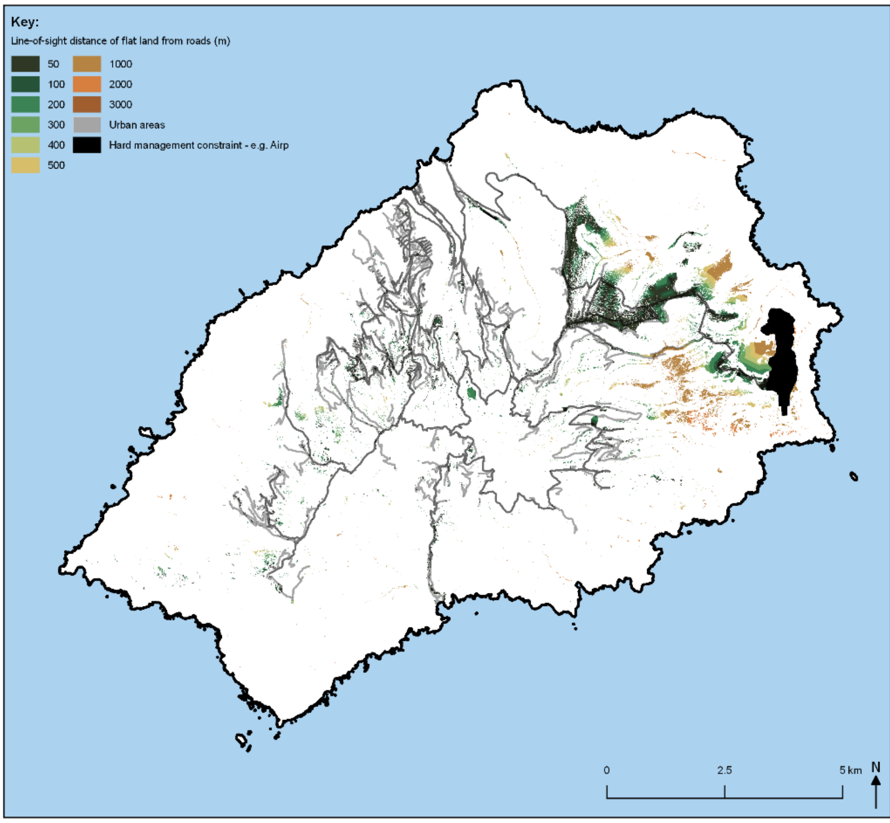

Mapping St Helena's Biodiversity and Natural Environment

Distance Of Roads From Flat Land (Less Than 7°) That Cannot Be Seen From The Coast

What the map shows:
On a gradient from dark green to orange, the maps shows the distance from roads, measured as line of sight, of accessible flat land that cannot be seen from the coast. Dark green land is located in direct proximity to existing roads, while orange land is over 2000m away from the nearest road. As distance from roads is a factor mostly important for development considerations, rather than just a topographical consideration, the airport and other restricted areas are displayed in solid black to highlight the hard constraint it presents to other types of development. Other constraints to development, such environmentally sensitive and protected sites or planning constraints, can exist and need to be taken into consideration during any planning process for development.
This map is based on gentle slope being defined as less than 7° degrees; the map showing flat land (less than 11°) that cannot be seen from the coast illustrates how the area coverage could change for development types less sensitive to steeply sloping ground.
Why this is important:
On St. Helena, tourism is contributing to the overall economy; the importance of tourism is expected to increase with an airport now in place. Therefore, development types considered to impact upon the aesthetic experience of nature will ideally be located in less visually accessible locations. Many types of development will also require land to only slope gently. Distance to roads is important as development in proximity to existing roads is logistically easier and, consequently, cheaper.
How the map has been created:
In order to identify land meeting all criteria for development, the distance to the nearest road was calculated for each area of land identified as both 'gently sloping' (less than 7°) and out of sight from the coast.
Data gaps and limitations / possible refinements:
The distances to the road network are calculated as line of sight; however, in some cases the actual distance to the site might be larger, for example if steeply sloping land needs to be circumnavigated.
The digital terrain model used is derived from stereo imagery, which can have reduced accuracies under steep terrain and where cloud had formed at the moment of capture. Areas of the terrain model that were obscured by above ground features at the time of capture, such as buildings and trees, were interpolated from surrounding areas of visible ground, and could have reduced accuracies in these areas.

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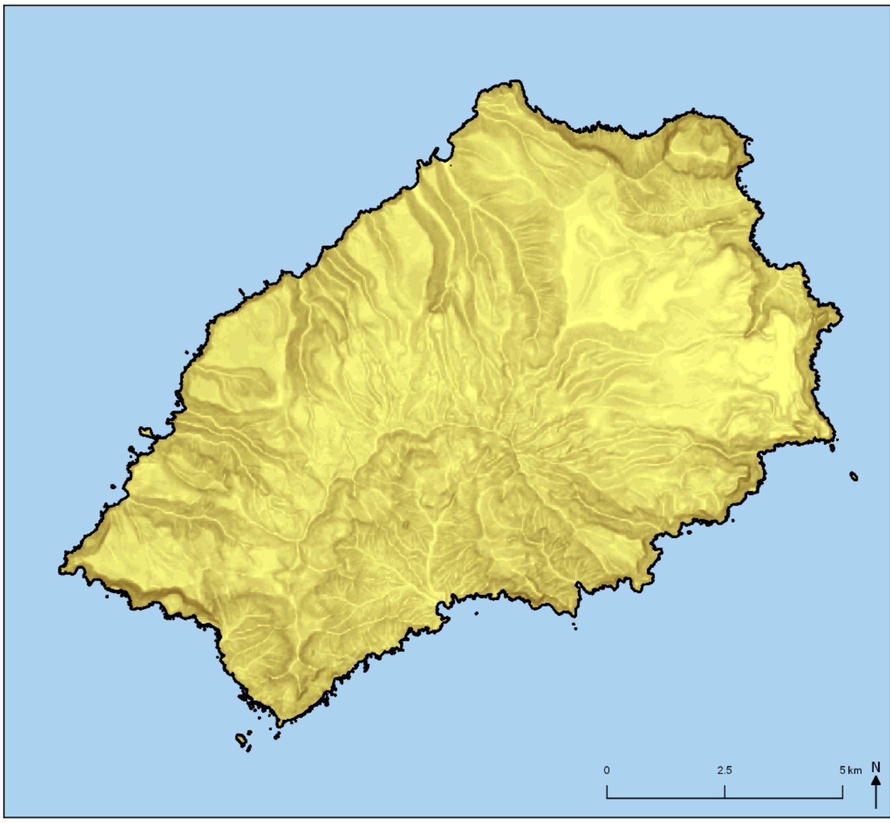

Mapping St Helena's Biodiversity and Natural Environment

Steepness Of Slope In 5 Degree Intervals

Key:

0 - 5 degrees	40 - 45 degrees
5 - 10 degrees	45 - 50 degrees
10 - 15 degrees	50 - 55 degrees
15 - 20 degrees	55 - 60 degrees
20 - 25 degrees	60 - 65 degrees
25 - 30 degrees	65 - 70 degrees
30 - 35 degrees	70 - 75 degrees
35 - 40 degrees	75 - 80 degrees

What the map shows:
The map shows the steepness of the terrain on St. Helena when classified into 5° bands. The steepest land is shown in brown, whilst flat land is shown in light yellow.

Why this is important:
Topography affects the type of land use that is possible in any one area. Flat land is easier to use for agriculture, as well as construction works. Due to its overall steep topography, flat land is an important resource on St. Helena.

How the map has been created:
This data uses the Airbus DTM model supplied by Saint Helena Government, and modelled to form slope, in degrees, using open source GIS software. The continuous slope model was reclassified 5° bands to form categories representable as a shapefile, from the gentles sloping class (less than 5° slope) to the steepest class (75° to 80° or more slope).

Data gaps and limitations / possible refinements:
The input terrain model is derived from stereo imagery, which can have reduced accuracies under steep terrain, and where cloud had formed at the moment of capture. Areas of the terrain model that were obscured by above ground features at the time of capture, such as buildings and trees, were interpolated from surrounding areas of visible ground, and could have reduced accuracies in these areas.

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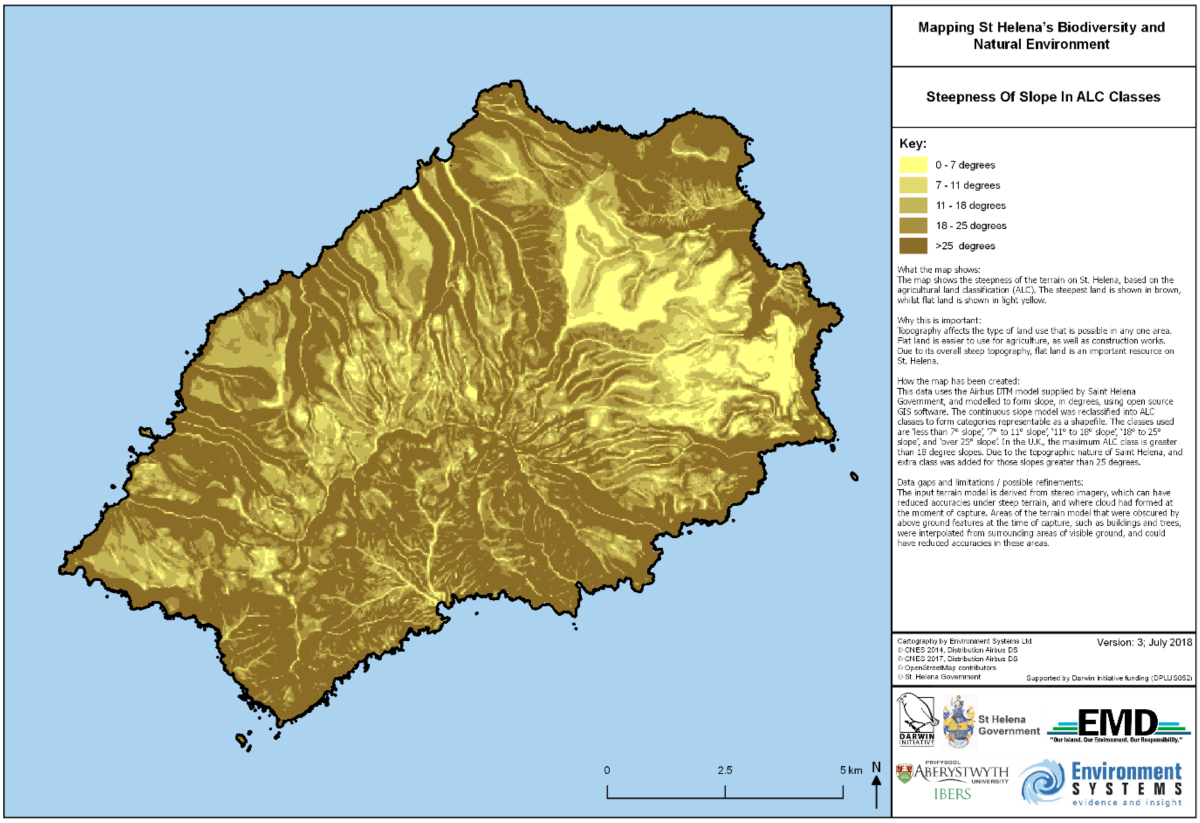
Mapping St Helena's Biodiversity and Natural Environment
Steepness Of Slope In ALC Classes
Key:
0 - 7 degrees
7 - 11 degrees
11 - 18 degrees
18 - 25 degrees
>25 degrees
What the map shows:
The map shows the steepness of the terrain on St. Helena, based on the agricultural land classification (ALC). The steepest land is shown in brown, whilst flat land is shown in light yellow.
Why this is important:
Topography affects the type of land use that is possible in any one area. Flat land is easier to use for agriculture, as well as construction works. Due to its overall steep topography, flat land is an important resource on St. Helena.
How the map has been created:
This data uses the Airbus DTM model supplied by Saint Helena Government, and modelled to form slope, in degrees, using open source GIS software. The continuous slope model was reclassified into ALC classes to form categories representable as a shapefile. The classes used are 'less than 7° slope', '7° to 11° slope', '11° to 18° slope', '18° to 25° slope', and 'over 25° slope'. In the U.K., the maximum ALC class is greater than 18 degree slopes. Due to the topographic nature of Saint Helena, and extra class was added for those slopes greater than 25 degrees.
Data gaps and limitations / possible refinements:
The input terrain model is derived from stereo imagery, which can have reduced accuracies under steep terrain, and where cloud had formed at the moment of capture. Areas of the terrain model that were obscured by above ground features at the time of capture, such as buildings and trees, were interpolated from surrounding areas of visible ground, and could have reduced accuracies in these areas.
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St Helena Government
EMD
Aberystwyth University
IBERS
Environment Systems
evidence and insight
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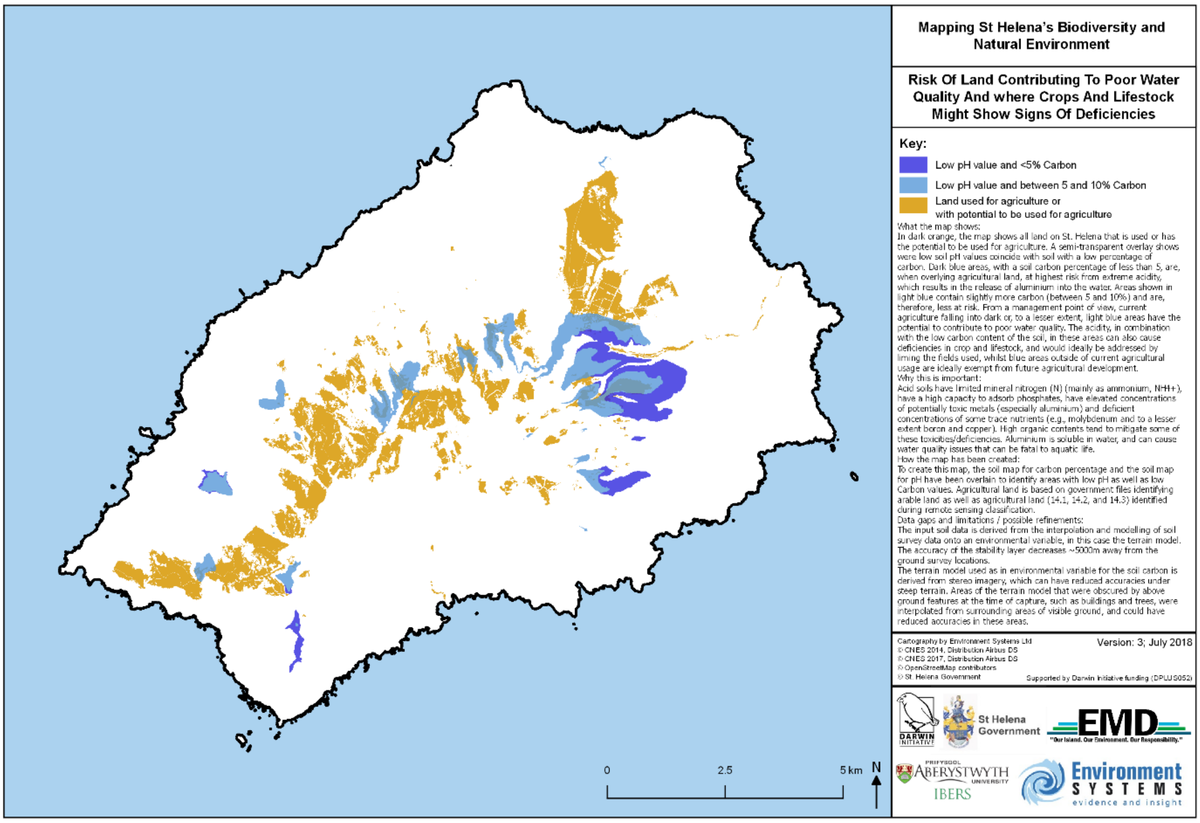
Mapping St Helena's Biodiversity and Natural Environment
Risk Of Land Contributing To Poor Water Quality And where Crops And Lifestock Might Show Signs Of Deficiencies
Key:
Low pH value and <5% Carbon
Low pH value and between 5 and 10% Carbon
Land used for agriculture or with potential to be used for agriculture
What the map shows:
In dark orange, the map shows all land on St. Helena that is used or has the potential to be used for agriculture. A semi-transparent overlay shows were low soil pH values coincide with soil with a low percentage of carbon. Dark blue areas, with a soil carbon percentage of less than 5, are, when overlying agricultural land, at highest risk from extreme acidity, which results in the release of aluminium into the water. Areas shown in light blue contain slightly more carbon (between 5 and 10%) and are, therefore, less at risk. From a management point of view, current agriculture falling into dark or, to a lesser extent, light blue areas have the potential to contribute to poor water quality. The acidity, in combination with the low carbon content of the soil, in these areas can also cause deficiencies in crop and lifestock, and would ideally be addressed by liming the fields used, whilst blue areas outside of current agricultural usage are ideally exempt from future agricultural development.
Why this is important:
Acid soils have limited mineral nitrogen (N) (mainly as ammonium, NH4+), have a high capacity to adsorb phosphates, have elevated concentrations of potentially toxic metals (especially aluminium) and deficient concentrations of some trace nutrients (e.g., molybdenum and to a lesser extent boron and copper). High organic contents tend to mitigate some of these toxicities/deficiencies. Aluminium is soluble in water, and can cause water quality issues that can be fatal to aquatic life.
How the map has been created:
To create this map, the soil map for carbon percentage and the soil map for pH have been overlain to identify areas with low pH as well as low Carbon values. Agricultural land is based on government files identifying arable land as well as agricultural land (14.1, 14.2, and 14.3) identified during remote sensing classification.
Data gaps and limitations / possible refinements:
The input soil data is derived from the interpolation and modelling of soil survey data onto an environmental variable, in this case the terrain model. The accuracy of the stability layer decreases ~5000m away from the ground survey locations.
The terrain model used as in environmental variable for the soil carbon is derived from stereo imagery, which can have reduced accuracies under steep terrain. Areas of the terrain model that were obscured by above ground features at the time of capture, such as buildings and trees, were interpolated from surrounding areas of visible ground, and could have reduced accuracies in these areas.
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EMD
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evidence and insight
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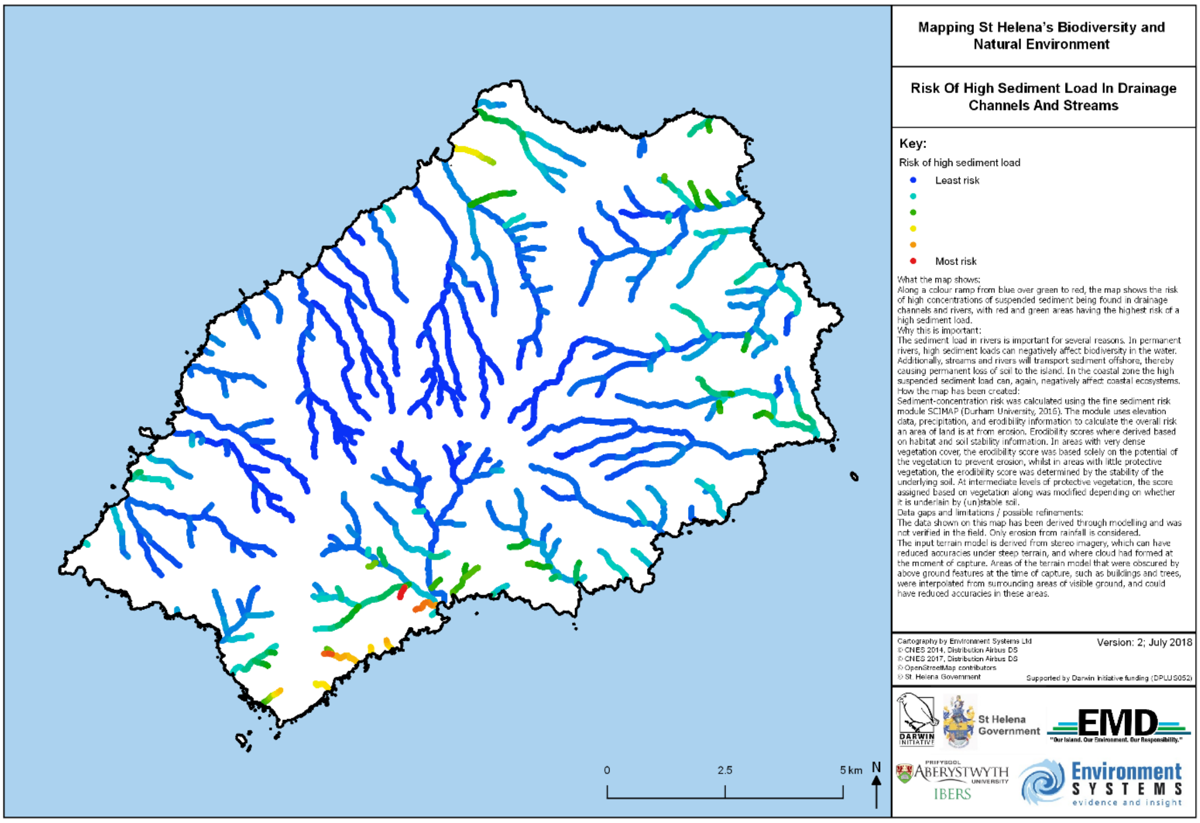
Mapping St Helena's Biodiversity and Natural Environment
Risk Of High Sediment Load In Drainage Channels And Streams
Key:
Risk of high sediment load
Least risk
Most risk
What the map shows:
Along a colour ramp from blue over green to red, the map shows the risk of high concentrations of suspended sediment being found in drainage channels and rivers, with red and green areas having the highest risk of a high sediment load.
Why this is important:
The sediment load in rivers is important for several reasons. In permanent rivers, high sediment loads can negatively affect biodiversity in the water. Additionally, streams and rivers will transport sediment offshore, thereby causing permanent loss of soil to the island. In the coastal zone the high suspended sediment load can, again, negatively affect coastal ecosystems.
How the map has been created:
Sediment-concentration risk was calculated using the fine sediment risk module SCIMAP (Durham University, 2016). The module uses elevation data, precipitation, and erodibility information to calculate the overall risk an area of land is at from erosion. Erodibility scores where derived based on habitat and soil stability infomation. In areas with very dense vegetation cover, the erodibility score was based solely on the potential of the vegetation to prevent erosion, whilst in areas with little protective vegetation, the erodibility score was determined by the stability of the underlying soil. At intermediate levels of protective vegetation, the score assigned based on vegetation along was modified depending on whether it is underlain by (un)stable soil.
Data gaps and limitations / possible refinements:
The data shown on this map has been derived through modelling and was not verified in the field. Only erosion from rainfall is considered.
The input terrain model is derived from stereo imagery, which can have reduced accuracies under steep terrain, and where cloud had formed at the moment of capture. Areas of the terrain model that were obscured by above ground features at the time of capture, such as buildings and trees, were interpolated from surrounding areas of visible ground, and could have reduced accuracies in these areas.
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2.5
5 km
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Appendix H. Erodibility scores

Erodibility scores were based both on vegetation cover and the stability of the underlying score. Both factors were scored separately. Erodibility scores range from 0 (most stable / hardly any risk of loss to erosion) to 1 (least stable/erodes very easily). The vegetation cover is considered in addition to the soil stability, as the root network and canopy cover can protect even unstable soils from weathering effects.

To create a combined erodibility score, habitat and soil stability information was unioned spatially. For each resulting vegetation cover – soil combination, erodibility scores were derived according to a set of rules:

- If no soil information is available (coastal slivers, where habitat and soil don't fully overlap), the habitat erodibility score was used
- If the habitat is scored < 0.3 (e.g., a habitat type that offers very high protection to the soil), the habitat erodibility score was used, to express that the protective cover is so good that even very unstable soils won't erode easily
- If the habitat is scored > 0.7 (e.g., a habitat that offers very little protection to the soil), the soil erodiblity score was used, to express that in these areas the erosion risk is primarily determined by the inherent stability of the soil
- If the habitat is scored between 0.3 and 0.7, the proportional influence of the soil score increases, as vegetation offers less protection. For example, if the habitat is scored between 0.5 and 0.6, the *soil erodibility modifier* * 0.4 is added to the habitat erodibility score. The soil contribution based on the protection offered by the land cover were:

Table 8.5: Habitat score and soil contribution

Habitat score	*Soil contribution*
0.3 - 0.4	0.2
0.4 - 0.5	0.3
0.5 - 0.6	0.4
0.6 - 0.7	0.5

Table 8.6: Soil stability, erodibility score and modifier

Soil stability		*Soil erodibility score*	*Soil modifier*
< 20%	Least stable	1.0	1.0
< 40%		0.7	0.5
< 70%		0.4	-0.5
> 70%	Most stable	0.1	-1.0

Table 8.7: IUCN Level 3 habitats and erodibility scores

IUCN3	*Final scores*
1.5.1 Gumwood Woodland	0.2
1.5.2 Eucalyptus Woodland	0.2
1.5.3 Pine Woodland	0.2
1.5.4 Bermudan Cedar Woodland	0.2
1.5.5 Wild Mango Woodland	0.2
1.5.6 Mixed Woodland	0.2

IUCN3	*Final scores*
1.5.7 Peruvian Pepper Tree Woodland	0.2
1.5.8 Acacia Woodland	0.2
1.5.9 Silky Oak Woodland	0.2
1.6.1 Thorn Tree Woodland	0.2
1.6.2 Blackwood Woodland	0.2
1.6.3 Cape Yew Woodland	0.2
1.6.4 Sclerophyllous Woodland	0.2
1.6.5 Bamboo Thicket Woodland	0.2
1.6.6 Cypress Woodland	0.2
1.6.7 White Poplar Woodland	0.2
1.6.8 Chinese Fir Woodland	0.3
1.9.1 Tree Fern Thicket	0.05
1.9.3 She Cabbage Tree Woodland	0.05
1.9.4 Jellico Stands	0.05
1.9.5 Moist Upland Species Mix	0.05
1.9.6 Dogwood & White Wood Mix	0.05
3.5.1 Shrubwood Shrub	0.2
3.5.2 Sparse Shrub Mixture	0.4
3.5.3 Mixed Leucaena Shrubland	0.2
3.5.4 Introduced Herb Mixtures	0.4
3.5.5 Succulent Shrub	0.4
3.5.6 Furze Shrub	0.3
3.5.7 Dense Shrub Mixture	0.2
3.5.8 Lantana Shrub	0.3
3.5.9 Wild Coffee Shrub	0.2
3.5.10 Acacia Shrub	0.2
3.5.11 Vegetation with Exposed Soil	0.72
3.5.12 Eucalyptus Dominated Shrub	0.2
3.6.1 Wooded Valleys	0.1
3.6.2 Bilberry	0.72
3.6.4 Blue Weed	0.2
3.6.5 Ginger Stands	0.2
3.6.6 Upland Complex Mosaic	0.2
3.6.7 Flax	0.5
3.6.8 Whiteweed	0.1
3.6.9 Arum Lily Stand	0.1
5.1.1 Permanent Stream	0.0
5.1.5 Proliferous Spike-rush	0.16
5.2.2 Semi-permanent Riparian Margins	0.2
5.2.4 Seasonal Gully	0.95
5.3.3 Rice Paper Plant	0.15
5.8.3 Chow-chow Dominated Area	0.05
5.8.4 Aracea Dominated Area	0.05
6.1.1 Rocky Areas	0.6
6.1.4 Scree	0.8

IUCN3	*Final scores*
6.1.5 Inland Rocky Cliffs	0.58
6.2.1 Succulent Native Annuals	0.72
6.2.2 Inland Sand Deposits	1.0
6.2.3 Barren Soil	1.0
6.2.4 Sparse Shrub	0.72
8.4.1 Fountain Grass and Prickly Pear Semi-Desert Mix	0.58
8.4.2 Agave Shrub Semi-Desert	0.8
8.4.3 Introduced Low Shrub Semi-Desert	0.72
8.4.4 Nargy Weed Low Shrubland Semi-Desert	0.8
8.4.5 Samphire Semi-Desert	0.7
8.4.6 Creeper Waste Semi-Desert	0.72
8.4.7 Sparse Prickly Pear	0.72
12.1.1 Rocky Shoreline	0.0
12.2.1 Sandy Shore	0.0
12.3.1 Shingle/Pebble Shore	0.0
12.6.1 Tidepools	0.0
12.6.2 Intertidal Beds	0.0
13.1.1 Sea Cliffs	0.05
13.1.2 Offshore Island	0.0
13.1.3 Seabird Colonies	0.0
14.1.1 Planted Crops	0.8
14.2.1 Kikuyu Grass Dominated	0.2
14.2.2 Cardinal Tussocks	0.72
14.2.5 Mixed Grass Areas	0.2
14.2.7 Cow Grass Dominated Area	0.2
14.2.8 Thatching Grass Meadow	0.3
14.2.9 Neglected Alien Herb Areas	0.58
14.2.10 Bull Grass Dominated	0.2
14.2.11 Bamboo Grass Patches	0.3
14.3.1 Clearfells	0.8
14.3.2 Plantation	0.3
14.4.1 Rural Gardens	0.25
14.5.1 Urban Areas & Buildings	0.0
14.5.4 Tarmacadam	0.0
14.5.5 Unsurfaced Tracks	0.5
14.5.7 Earth Banks	0.5
14.5.10 Open Grass Field	0.3
15.1.1 Reservoir	0.0
15.2.1 Pond	0.0
15.5.1 Quarry	0.0
15.11.1 Dock/Jetty	0.0

Appendix I. Ascension Island soil data

The opportunity to characterise soils on Ascension Island, and provide training on how to do so, arose initially due to the need for stopovers between flights and ship sailings. Shortly prior to travelling, the ship was withdrawn so only five days were available for fieldwork on island. This necessitated a targeted sampling programme, dictated in part by logistics and accessibility, and partly by on-island interest (e.g., Euphorbia sites). The disruption experienced made it possible to train parties from Ascension Island on their own soil, rather than spending the time and resources for them to travel to St Helena.

Samples were prepared on Ascension (sieving to remove large stones and weighing for calculation of water content) prior to shipment to Aberystwyth University (subject to export permits and under UK import licence 50791/261040/0) where further measurements were made.

All sample points were georeferenced with notes on habitats included, providing baseline soil data for the island.

Soil property means are summarised in here, classified by main habitat type. For some habitats, Cricket valley samples were recorded separately given field observations of their different character.

Soils from low elevations generally had low clay, C and N contents, mostly irrespective of habitat type. Soils at higher elevations, mostly on Green Mountain, had higher values for these parameters. Soils in Cricket valley in addition to having low content, also had very few stones in comparison to other low elevation soils.

Targeted sampling was undertaken on Euphorbia sites to investigate soil factors that might explain the large decline in abundance of the species. Soils formerly supporting Euphorbia showed very high variability in properties, particularly for pH and Ec; the soils were generally very low in clay and C. Investigations for root fungal pathogens on unhealthy Euphorbia was generally inconclusive, although some samples had evidence of a genus (*Acrocalymma*) associated with root rot in agricultural crops.

Table 8.8: Summary soil data for different habitat classes on Ascension Island – means and standard deviations

Vegetation	*pH*	*Electrical Conductivity (µS/cm)*	*N [%]*	*C [%]*	*C:N ratio*	*Clay %*	*Silt %*	*Sand %*
bare ground	7.72±0.71	1792±2228	0.02±0.01	0.17±0.04	8.75±3.27	2.3±2.06	19.2±13.6	78.6±15.34
juniper	6.89±0.53	1733±1661	0.23±0.08	3.82±0.96	17.03±2.4	21.7±8.15	30.3±10.77	47.9±16.44
buttonweed	7.04±0.81	642±265	0.17±0.09	2.42±1.27	13.79±2.05	18.5±11.21	25.8±12.85	55.7±25.87
casuarina	6.89±0.12	5205±1345	0.07±0.02	1.16±0.36	16.24±1.6	6.6±3.7	14.6±8.48	79.2±45.71
euphorbia	6.71±1.93	5118±5807	0.07±0.03	0.78±0.61	11±7.23	3.1±1.81	12.5±8.43	84.4±31.48
ficus	6.85±1.03	817±180	0.31±0.24	4.85±3.33	15.98±3.81	25.9±7.6	33.3±2.6	40.8±9.58
grass	7.16±0.53	572±148	0.26±0.14	3.44±1.69	13.63±0.9	19.1±8.87	31.9±14.1	48.9±19.98
guava	7.28±0.34	854±479	0.19±0.09	3.2±1.87	16.65±3.76	23.2±8.99	35.1±13.23	41.6±16.03
guava cricket	6.95±0.39	411±111	0.08±0.01	1±0.2	11.86±0.9	5.3±1.5	31.5±18.04	63.2±18.9
lantana	6.31±0.64	1504±498	0.55±0.23	7.31±3.48	13.08±0.86	30.2±1.82	41.3±7.16	28.5±8.99
lantana cricket	7.26±0.08	499±108	0.09±0.04	1.05±0.61	12.06±2.35	8.9±2.53	24.9±10.97	66.1±13.41
lily	6.74±0.04	1056±407	0.33±0.08	4.73±1.12	14.55±0.05	18.3±6.22	28.3±7	53.4±13.21
mexican thorn	8.07±1.1	4693±1263	0.12±0.08	1.3±1.08	10.23±1.95	7.5±2.24	24.8±5.93	67.7±8
NI pine	6.86±0.64	1648±23	0.35±0.09	6.5±1.76	18.58±0.2	35.6±2.73	38.8±1.06	25.6±3.79
P.purpurensis	6.02±0.36	768±128	0.42±0.09	5.62±1.15	13.33±0.11	39.86±5.7	37.2±2.63	22.9±4.92
sedge (bare)	6.24±0	7360±0	0.09±0	0.62±0	6.9±0	3.17±0	11.2±0	85.6±0
yellow boy (cricket)	7.65±0.07	1365±769	0.18±0.09	2.35±1.32	12.68±0.69	12.77±6.25	31.4±6.45	55.8±3.51