

# Anguilla Habitat Mapping Using Earth Observation

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## Executive summary

This project has used earth observation to produce a habitat map of Anguilla and its off shore cays looking at selected plant community groups with particular functional elements. This habitat mapping has used field studies undertaken by the Government of Anguilla and earth observation classification that can be subsequently used to show how the vegetation contributes to both biodiversity and other ecosystem services.

This project builds on existing terrestrial biodiversity information for Anguilla providing spatial information which can be used for modelling and mapping to identify areas of vulnerability and work towards sustainability and the development of green economy thinking on the island.

The techniques used are robust and repeatable and can therefore be used to monitor change and to input into further analysis of ecosystem features such as the regulation of surface water runoff.

<b>1</b>	<b>Introduction</b> .....	<b>4</b>
1.1	Background .....	4
1.2	Project aims.....	4
<b>2</b>	<b>Using earth observation to identify habitat features</b> .....	<b>5</b>
2.1	Understanding earth observation imagery.....	7
2.2	Earth observation data review.....	8
2.3	Earth observation and geo-informatics techniques .....	9
2.4	Image stack .....	10
2.5	Stages of rule development .....	11
<b>3</b>	<b>Field work and map validation</b> .....	<b>18</b>
<b>4</b>	<b>Using EO for green economy and modelling</b> .....	<b>21</b>
4.2	Using EO for Ecological monitoring.....	26
<b>5</b>	<b>Conclusions and Recommendations</b> .....	<b>27</b>
<b>6</b>	<b>References and Bibliography</b> .....	<b>28</b>

# 1 Introduction

## 1.1 Background

The Department of Environment (DoE) and Ministry of Home Affairs and Environment, Government of Anguilla required the production of a habitat map of Anguilla with its off-shore island reefs.

The terrestrial environments of the Anguillan archipelago are considered fragile. For the past seven years the tourism industry has fuelled the socio-economic development in the country. The tourism industry and the associated infrastructure development have led to the degradation and loss of valuable habitats in Anguilla. It is therefore pivotal to have a baseline habitat database in order to monitor the island's biodiversity.

Advances in the application of earth observation to habitat surveillance in recent years, together with the development of geoinformatic approaches mean that these techniques can now be used to give a good baseline of habitats both on land and within shallow waters. This report outlines the use of satellite imagery to map terrestrial habitats. The report will then discuss how these habitat maps can be used to consolidate and develop biodiversity information in a format whereby it can be fed into decision making to help ensure the sustainable management of the natural resources of the country.

## 1.2 Project aims

- Creation of detailed maps of habitats on Anguilla, and its off-shore islands and reefs using remote sensing and field work already undertaken by the Government of Anguilla, looking at selected plant community groups with particular functional elements.
- Modelling and mapping of this habitat data to identify areas which are particularly vulnerable to development and need protecting, along with those which are less vulnerable and can be developed with minimal disruption to the ecosystems of the island.
- This project adds to the existing terrestrial biodiversity information for Anguilla providing spatial information which can help the sustainable management of the local terrestrial natural resources, and work towards developing a green economy within the island.

## 2 Using earth observation to identify habitat features

Earth observation is the use of data, from satellite and airborne systems, for mapping and monitoring the Earth. It provides an accurate and repeatable methodology for ecological mapping particularly where vegetation is hard to survey or study areas are remote.

The most common types of earth observation used for habitat mapping include 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 for a variety of mapping requirements. Imagery at different working scales and timings can provide information from species level right through to the wider area perspective, as well as tracking cause, effect and change which are not directly possible with field methods.

Optical remote sensing techniques have been used for many years with manual interpretation of RGB (Red/green/blue or true colour) aerial photography. Satellite imagery available advances these techniques by recording information at different 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 have a close relationship to vegetation.

Figure 1 shows the reflectance curve for vegetation. The horizontal axis shows the electromagnetic spectrum with the Blue Green Red visible part of the spectrum and then the longer wavelengths into the NIR and SWIR.

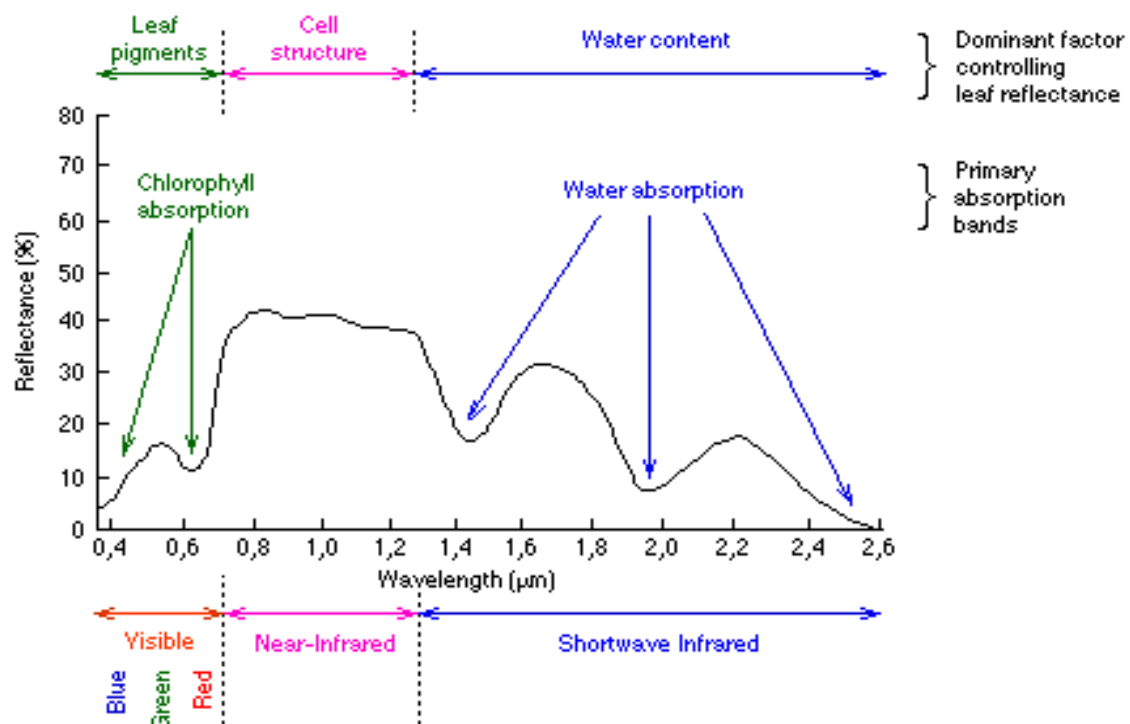


Figure 1: The spectral reflectance curve for vegetation

Green light is reflected from the top surface of the leaf, red and blue light are absorbed by the leaf and are used in photosynthesis, NIR light passes through the top surface for the leaf but is generally

reflected from the lower surface, shown in Figure 2. The near infrared signal is particularly useful for recording vegetation types as its strength is related to the leaf structure. Therefore the more open and productive the vegetation the higher the NIR signal. Species such as agricultural grasses have a much stronger signal in the NIR band than scrub species for example, even though the RGB signal could be very similar.

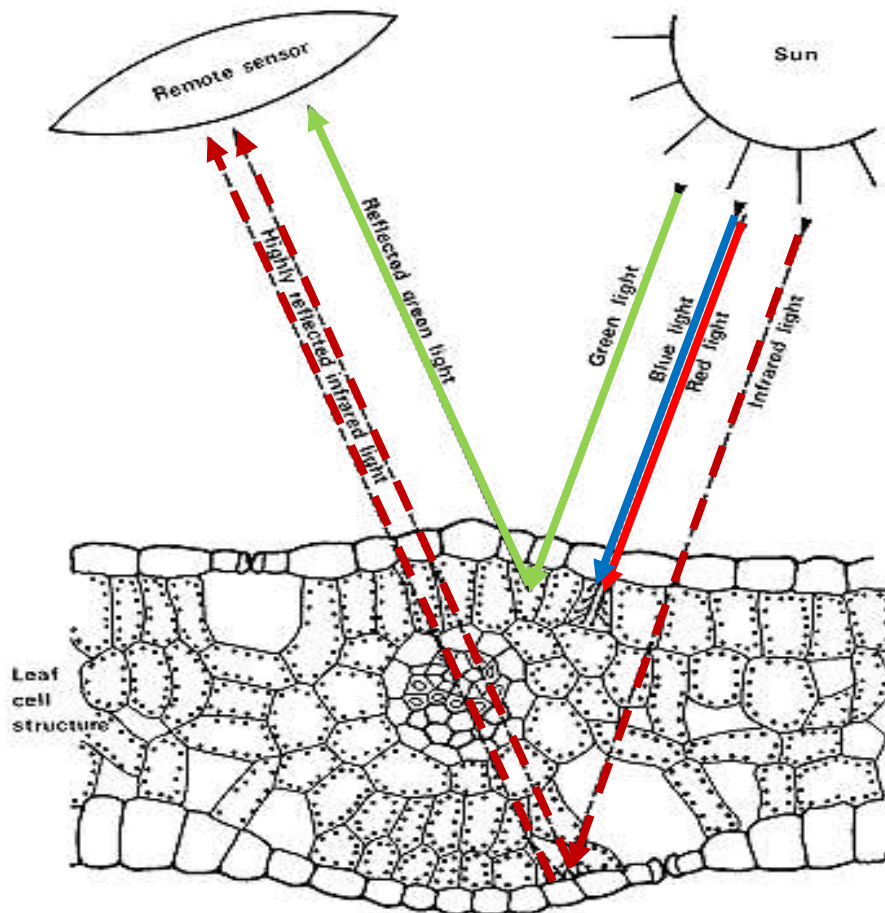


Figure 2: The profile through a leaf and how light is reflected and absorbed

Within the SWIR bands the signal is influenced by the water content of the vegetation and the soil and therefore can be useful for separating wet habitats such as mangrove from those with similar species but on a drier soil type such as limestone scrub.

Earth observation images are gathered from above and therefore are best at identifying plant communities which have a distinctive appearance from above, either as an even cover of one or a range of canopy forming species. It struggles to find communities that are distinguished by the presence of small sized plants which occur in low frequency hidden by the over-storey canopy. The classification provided by remote sensing will therefore not completely equate to that which a botanist may record on the ground. However, as earth observation can quantify other bio-physical features of the vegetation such as productivity, it enables mapping of ecological functions which have a range of effects in terms of the ecosystem services than an area provides.

## 2.1 Understanding earth observation imagery

It is common to observe satellite images and aerial photography in what can be referred to as ‘true colour’ where by the way in which humans perceive the world is similarly represented. Green light is represented by the green channel, red by red and blue by blue. However, in order to visually interpret the information beyond the visible, images are often displayed in what might seem to be strange colour combinations.

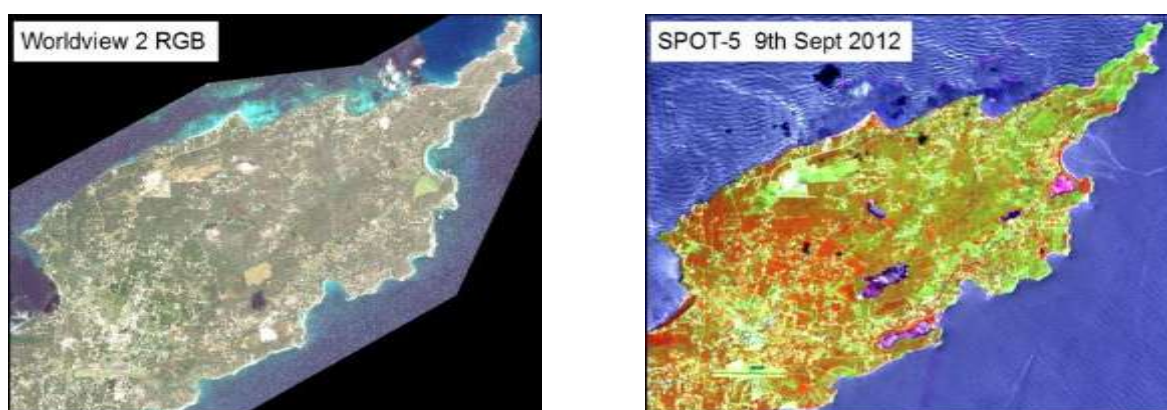


Figure 3: Worldview and SPOT satellite imagery

Many satellites do not record information in the blue band, only green, red, NIR and SWIR. In order to show the maximum differences in the vegetation the imagery can be coloured up as shown in the SPOT image in Figure 3, viewing the NIR band as red, SWIR as green and green band as blue. Since plants reflect greatest in the NIR portion of the electromagnetic spectrum areas of productive vegetation appear as red. Green is the next colour that the human eye is sensitive to and thus is linked with the next most significant reflectance with regards to the vegetation curve, the SWIR portion of the spectrum. Finally, the green band is displayed as blue.

Satellites and their sensors vary in terms of spatial, spectral and temporal resolutions (examples shown in Table 1, spatial resolution is the size of the area on the ground represented by each image pixel. The image extent is the area covered by a single image and can range from a few kilometres to hundreds of kilometres. Higher spatial resolution typically means a smaller image extent. However wider area coverage can be achieved by mosaicing several scenes together taking any timing differences into account. Spectral waveband refers to the number of colours or discrete spectral samples that are recorded for each image pixel satellite imagery affords the opportunity to map surface features over a variety of geographical and temporal footprints using different parts of the electromagnetic spectrum.

Table 1 - Differences in spatial and spectral detail available across different satellite EO platforms

Mission	Spatial Resolution (m)	Spectral Resolution <sup>1</sup>	Coverage (km)	Revisit	Cost
Worldview	1.8 m	Visible & NIR	16 x 16	1-5 days	\$\$\$\$
SPOT	10-20	Green-SWIR	60 x 60	2-3 days	\$\$
Landsat	30	Visible, NIR, SWIR & TIR	180 x 175	16 days	Free

<sup>1</sup> NIR = Near InfraRed, SWIR = ShortWave InfraRed & TIR = Thermal InfraRed

Typically more spectral wavebands increases the ability of the imagery to discriminate between landcover types. Temporal resolution is related to the repeat frequency with which a system can acquire images of the same location. Although this may be fixed for an acquisition system, environmental factors such as cloud cover have an overriding impact on the availability of usable images. Within this study we have concentrated on the use of optical sensors. However, there are other sensors becoming available including microwave, or synthetic aperture RADAR, systems. These systems are being actively researched in their role for vegetation mapping and will become increasingly useful for understanding vegetation and cover types.

## 2.2 Earth observation data review

When considering the mapping of Anguilla with remote sensing data it was necessary to conduct a review of available data taking into account the scale of the vegetation features present on the island.

A desk based review of the vegetation of Anguilla (Government of Anguilla, 2011) and a study into the zonation of *Rondeletia anguillensis* (Samuel, 2009) identified 12 main land cover types, as shown in Figure 4. These covered areas from a quarter of a hectare to many hectares in extent for an individual class. Most were dominated by shrub and small tree species with a canopy of a metre or two in diameter. Based on this work the ideal spatial scale for considering remote sensing images, would be between 1m and 20m per pixel. This would allow each vegetation community to be made up of at least five pixels of information which then allows an adequate statistical description in the rule base analysis that is undertaken.

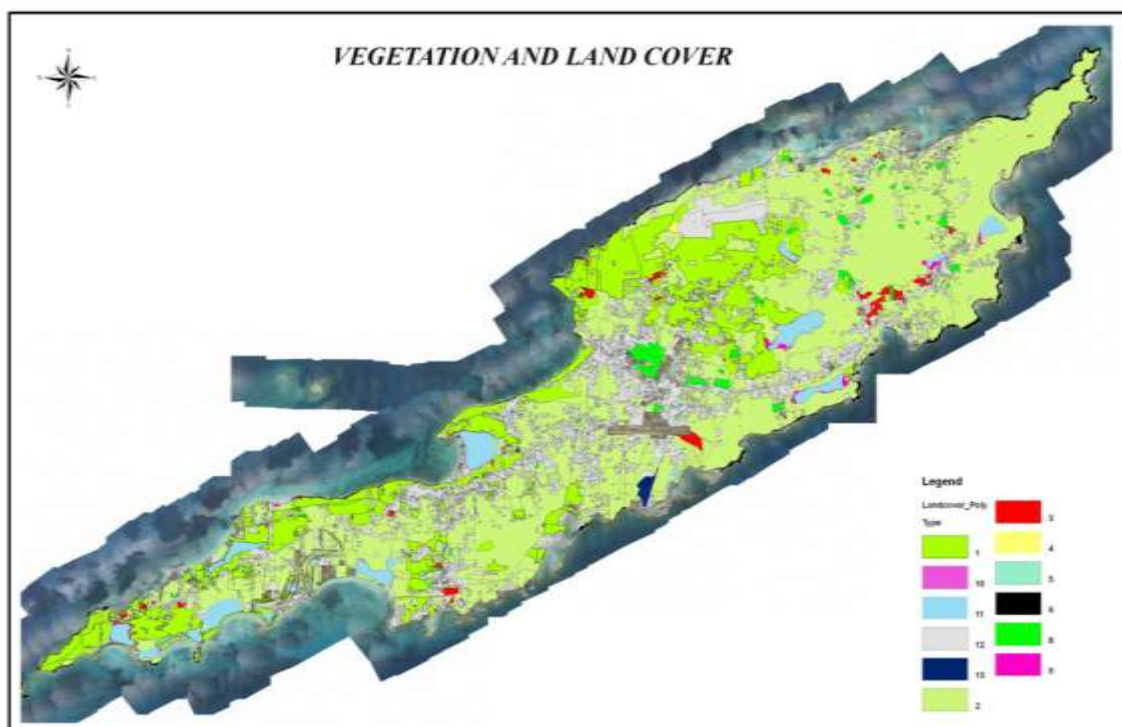


Figure 4: Vegetation and land cover of Anguilla from the desk based study

The field data available related to specific species which may have generated specific signatures Worldview was an ideal choice. This has a fine spatial resolution and a number of bands along the red

edge where different species can be separated from each other with more ease, because of the effect of their leaf structure on the NIR reflectance. Originally it was thought that the Government of Anguilla held the full wave length dataset of Worldview but unfortunately it transpired that only the red/green/blue bands were available.

Plants of different species are visually different in all wavelength regions, especially those beyond the visible spectrum, the rule base allows the separation of object based upon these differences and variation with features such as:

- Moisture content
- Surface roughness (manifested as shade)
- Productivity
- Proportions of live and dead material
- Amount of woody material (i.e., biomass)

Vegetation can have very different spectral signature in the wet and dry season when the leaves are senescent or in full growth, it was decided to look for two SPOT images that would cover the island and off shore keys that were from different seasons. Although the spatial and spectral resolution of SPOT is not as fine as World view the imagery is affordable and does show communities to a sufficient degree to achieve a vegetation map. Figure 5 shows the SPOT image for the north of the island and the clear signal given by *Coccoloba krugii*.

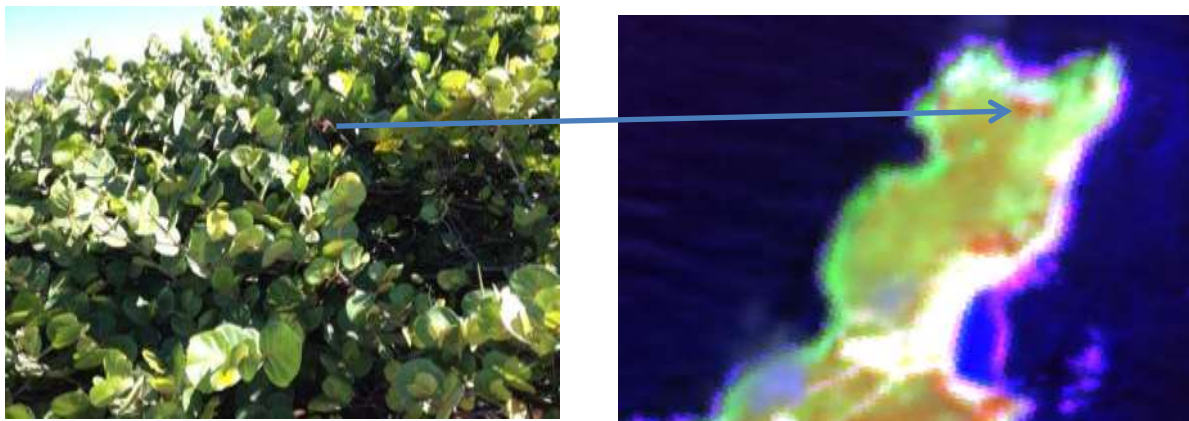


Figure 5: How the *Coccoloba krugii* (left) show up in the SPOT image (right)

## 2.3 Earth observation and geo-informatics techniques

Vegetation communities form where conditions are favourable for the plant species that they comprise. As well as spectral information about the surface of the land, contextual data can be incorporated into a rule base using geo-informatics techniques to give additional information about the location within the landscape.

In Anguilla, dry forest is found in the steepest most sheltered valleys where soil has built up to a greater depth and moisture is trapped, conversely cacti dominated scrub is only found on the north of the island where the vegetation is exposed to the strong trade winds. This sort ecological contextual information can therefore be incorporated to confirm and help separate out plants which have similar spectral characteristics but are different habitat types, occurring in different settings.

## 2.4 Image stack

The image stack used in the development of the rule base for Anguilla can be seen in

Figure 6. It includes:

- Landform data derived from Lidar, giving a DTM, slope and aspect layers.
- Urban and roads layer created during this work
- Soils related data as the soil type is pivotal to the vegetation growing above.
- Aerial photography
- Satellite imagery

This imagery and derived contextual data was loaded into eCognition and a rule base was developed using segmentation and classification of the objects produced to give the habitat map.

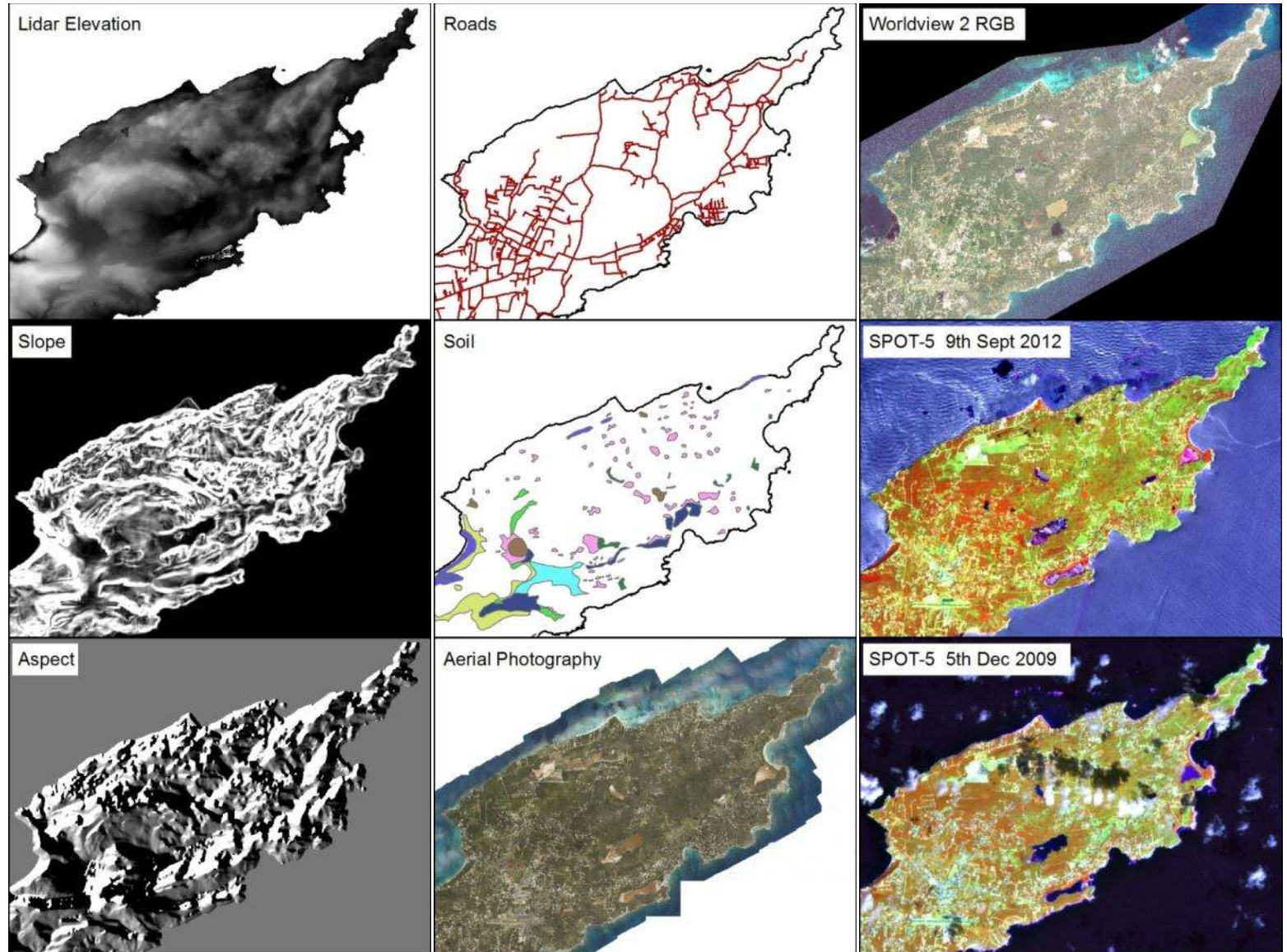


Figure 6: Data used in the image stack for the rule base

## 2.5 Stages of rule development

The following describes the processes undertaken during rule development:

### 2.5.1 Thorough image preparation

#### Radiometric image preparation

In order to allowing comparison of images acquired on different dates, from different sensors, and also over different regions, radiance calibration and atmospheric correction is necessary. This not only removes the effects of atmospheric dust and water vapour, but also provides image data in units of surface reflectance (%). This standardises the images to allow direct comparison and analysis, ensuring that the images from the different dates, sensors and also spatial areas could be incorporated together within the image stack.

#### Orthorectification

It is essential that all imagery falls in exactly the correct geographic space, taking into account the effect of topography, otherwise imagery taken from different dates and look angles will be mismatched in the image stack. To facilitate this all imagery was orthorectified using the LiDAR DTM which provided the most accurate topographic model for Anguilla. This allows for sub-pixel positional accuracy for data layers within the image stack.

### 2.5.2 Creation of derived image products and indices

In order to extract the maximum amount of ecologically useful information from the data, it is desirable to produce a number of derived products from the imagery. Vegetation indices are one of these derived products and are combinations of surface reflectance at two or more wavelengths used to highlight various properties of vegetation. They include the Normalised Difference Vegetation Index (NDVI) which is derived from visible red and near infrared bands. While there are over 150 vegetation indices that can be generated, many of which have been published within scientific literature, only a small subset have a substantial biophysical basis, or have been systematically tested. Linear spectral unmixing can also be used to give an estimate of the relative amount (fractions) of features of the image. These features can include shade or moisture, photosynthetic (green) vegetation (PV) and non-photosynthetic (dead or senescent; NPV) vegetation (Lucas *et al* 2011).

The performance and suitability of a particular index or fraction can generally be determined by the sensitivity of the index to a characteristic of interest. NDVI is the most widely used index and separates green vegetation from other surfaces because the chlorophyll of green vegetation absorbs the red light for photosynthesis, and reflects in the near infrared wavelengths due to scattering when the incoming radiation is forced to deviate from a straight trajectory through interaction with different elements of the leaf structure. A high NDVI value will therefore indicate high leaf biomass, canopy closure, or leaf area.

#### Cloud masks

The 2009 SPOT image contained some small clouds and their associated shadows, these needed to be masked from the rule base to avoid confusions in the classification as they change how the features on the ground appear in the imagery.

### **2.5.3 Separation of the landscape into distinct units**

In any area of land, the landcover will be a function of land use influenced by topography, soil, geology and hydrology. The first stage of rule development is separating the landscape out into its major contributing elements. Each of these elements has distinct land cover associated with them. By separating out the landform elements confusion is avoided between habitats with similar reflectance that occur in different locations.

#### **Urban**

The urban features, including buildings, roads, tracks, as well as gardens and recreation areas, must be identified and can then be removed from subsequent analysis in the rule base. To create this layer, existing road datasets were used together with spectral rules which separated tracks and buildings. These were then manually checked in a quality assurance (QA) step, formed into an individual layer and put back as a mask into the analysis.

#### **Agricultural land**

Agricultural land on Anguilla occurs in a number of different forms, such as; actively managed with row crops or tree crops, fallow with grazing, reverting to scrub or bare awaiting the next crop. Because each of these forms for each of the different crops will have a distinct spectral signature, agriculture has a very diverse appearance in the imagery. Therefore it was necessary to focus analysis using the agricultural soil layer before further analysis was undertaken.

Once the agricultural land has been classified, it can then be removed from subsequent analysis and therefore confusion is avoided between habitats which appear similar in terms of their reflectance but occur in different locations.

### **2.5.4 Development of specific rules for each vegetation class**

Once the heavily managed aspects of the landscape have been identified and separated out, as described above, the natural areas of the landscape can then be analysed and classified. Understanding the landscape ecology is vital in this step including the identification of any biogeographical effects and understanding how the vegetation appears in the satellite imagery in this setting. The most effective way to understand these natural features and how they appear in the satellite imagery is to annotate them in the field, seeing which images and bands separate each of the communities.

For Anguilla the island's ecology is dominated by the effect of the north easterly trade winds, a biogeographic zone mask was created based on exposure to prevent confusion between cacti dominated scrub and other scattered shrub communities.

### **2.5.5 Imagery segmentation**

The level of detail it is possible to pick up depends upon the pixel size of the image demonstrated by Figure 7. The dark purple area may represent a region of dune scrub within a wider environment of turquoise limestone scrub and green thicket. With the finest pixel size the exact edge of each of the features can be picked up. With the medium pixel size the edge pixels of the purple area fall half into one pixel and half into another leading to a mixed single and a less accurate delineation. With the largest pixel size the purple area is such a small part of one pixel that is unlikely to be distinguished at all.

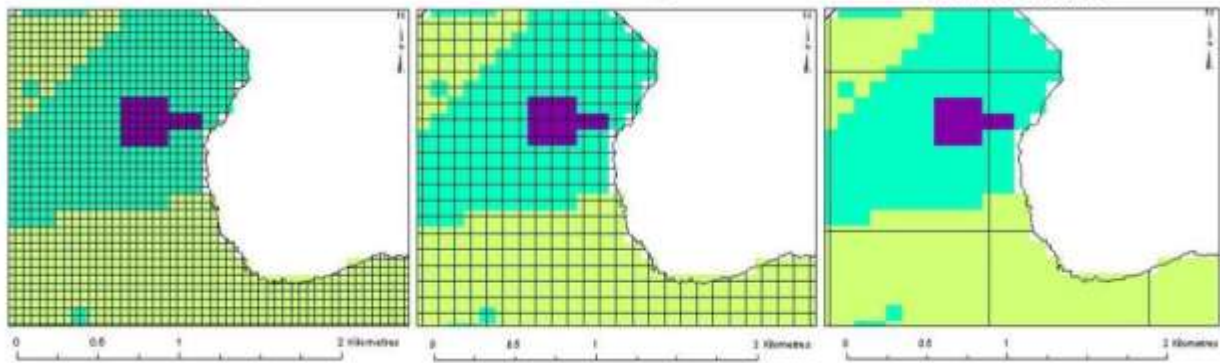


Figure 7: Pixel size and the relationship with habitat scale

Segmentation is an earth observation technique where the computer examines every part (pixel) of an image and groups those which are similar in colour and 'texture' together into an object. It is possible to use any spatial data from the image stack to base the segmentation upon. It is important to choose a scale that is suitable for the habitat of interest as shown in Figure 7. This does not always need to be a compromise, it is possible to use more than one image and/or one scale for the segmentation, allowing one part of the image, for example the agricultural fields, to use one set of criteria (e.g. a large sized object with a high, even, NIR signal) from natural habitats (e.g. a smaller object with high green values). This technique of introducing different scaled segmentation is very useful for dealing with habitats which are very common and form large objects in conjunction which occur with some habitats which are rare and form long thin objects.

The initial rule base used a single, simple segmentation which used all the bands and the altitude information from the DTM to produce a medium sized object. This approach was used in the pilot to give an initial view of the data and identified the scope for the development of a more sophisticated segmentation based on the ecological manifestations of the habits within the landscape context.

### 2.5.6 Classification

Once each object has been segmented, classification rules can be used to separate out the different components of the landscape. Rule development attempts to codify our understanding of vegetation spectral signatures and landscape context. For example, as discussed earlier Cacti dominated limestone scrub is known to be a sparsely vegetated habitat that occurs mainly on the exposed north eastern tip of the mainland. Investigating objects in areas known to contain this habitat shows that the habitat presents moderate NDVI values typical of scattered vegetation, combined with high NIR and SWIR reflectance typical of dry rocky soils. However, as these characteristics are also largely true of the scattered scrub on limestone pavement habitat class, we need to use additional landform (aspect) and location (distance from NE tip of mainland) rules to define this class.

In addition to using expert habitat knowledge, field points were also used to identify spectral features that may separate classes. This was done by taking field observations collected in previous vegetation studies and extracting the reflectance values from the image stack for each field point. Reflectance values were grouped by the observed habitat class and presented in box and whisker plots, examples of which can be seen in Figure 8. Box and whisker plots present a large volume of information regarding the distribution of classes for each reflectance value, with the boxes containing 50% of samples for the class, and the whiskers drawn to encompass values within 1.5 interquartile ranges of the top and

bottom of the box. Figure 8 shows that the cacti dominated scrub box has little overlap with either limestone scrub or thicket for SWIR and NDVI, confirming that using a combination of these spectral characteristics will allow for the classification of this class. Note, however, that the thicket and scrub boxes overlap more for both SWIR and NDVI indicating that further rules are required to successfully classify these two habitats.

Using evidence from field observations, box plots and prior habitat knowledge, those spectral signatures that gave the maximum separation between classes were built into the rule base. The functional land cover types identified in the rule base are shown in Figure 9. This figure also contains a summary of the spectral information and any contextual information used in the rules for separating each habitat.

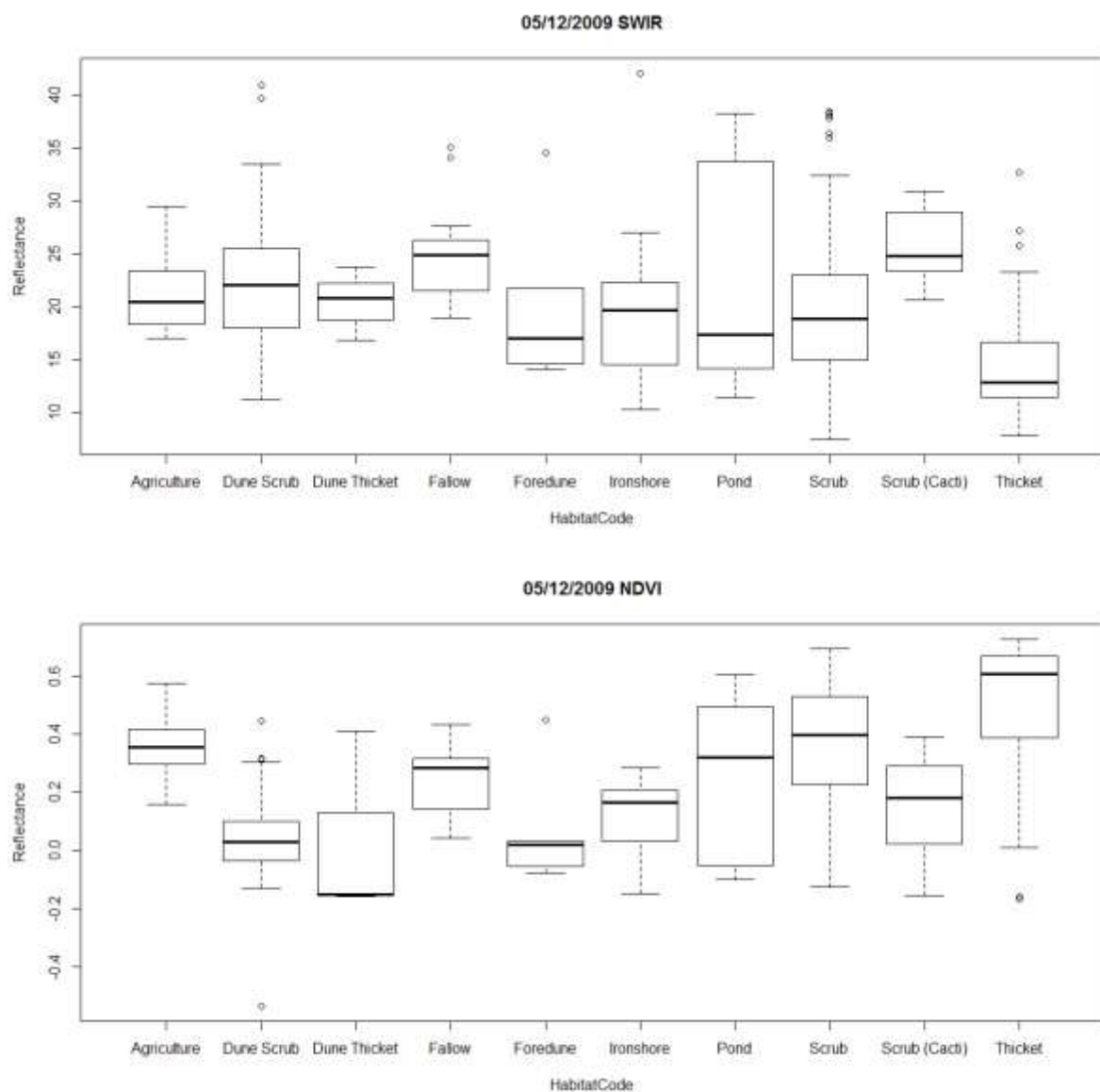


Figure 8: Box and whisker plots for the 05/12/2009 SPOT-5 image showing class distribution for SWIR reflectance and NDVI.

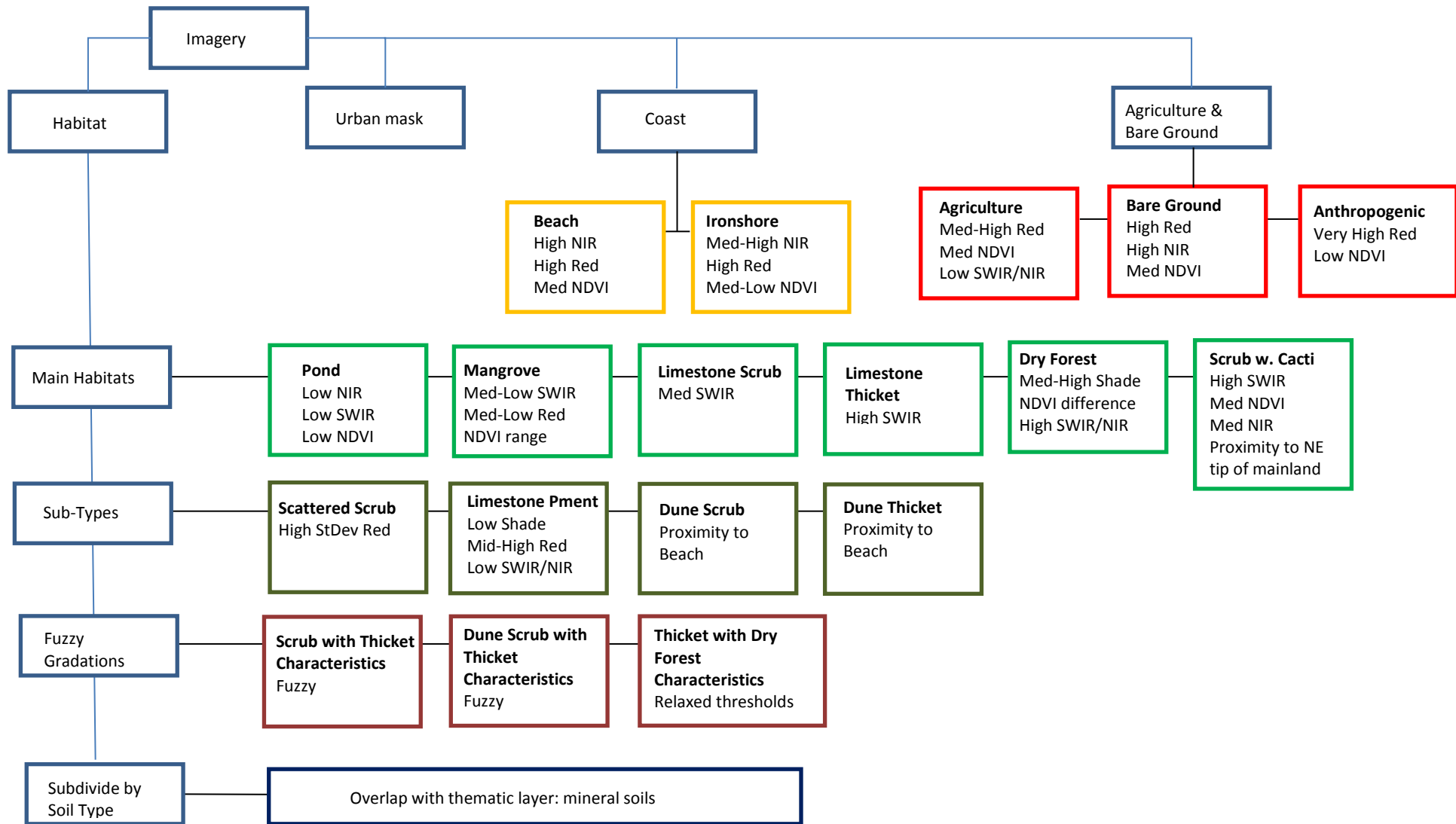


Figure 9: Functional rule base showing features of communities pertinent to green economy modelling

This classification then translated into the functional classification shown in Figure 10. This classification equates with the field work classification developed by the Government of Anguilla, however instead of the sub-classes being identified by individual species they are different functional components based on the density and productivity of the vegetation layers.

Primary Habitat	Secondary (Functional) Habitat	Remote sensing features
Dry forest	→ Dry forest	Densest vegetation with strongest NIR signal due to multiple layers of vegetation being present on the ground
Thicket	→ Thicket with dry forest characteristic	Strong vegetation signal with many layers of vegetation due to the occurrence of dry forest species within the thicket – although these not reaching the height of dry forest itself
	→ Thicket on limestone	Strong NIR signal indicating taller thicket habitat
	→ Dune Thicket	Strong NIR signal indicating taller thicket habitat on sandy subsoil
Scrub	→ Scrub with thicket characteristics	Stronger NIR signal than limestone scrub coincident with the occurrence of some taller thicket species
	→ Scrub on limestone pavement	Using current values from RS data and soil layer to type subsoil
	→ Scrub on mineral soil	Using current values from RS data and soil layer to type subsoil
	→ Dune Scrub	Using current values from RS data and soil layer to type subsoil
	→ Scattered scrub on limestone	This is short (less than 1m high) sparse vegetation which occurs on limestone pavement and is not cacti dominated
	→ Scattered scrub on mineral soil	This is short (less than 1m high) sparse vegetation which occurs on mineral soil and is not cacti dominated
	→ Scattered scrub cacti dominated	This is short (less than 1m high) sparse vegetation which occurs on limestone pavement with wind exposure and is cacti dominated
	→ Scrub dominated by <i>Thrinax morrisii</i>	This species is associated with an endemic gecko and may have a unique signal in RS layers
Mangrove	→ Mangrove	Use existing RS rule
Other	→ Fallow and agricultural	Use existing RS rule and attempt will be made to see if invasive agricultural species can be identified separately from RS data
	→ Roads and buildings	Use existing RS rule if possible separate buildings from roads spectrally
	→ Iron shore, coral and sand beaches	Use existing RS rule

Figure 10: Functional classification of the land cover of Anguilla

The created habitat map using this classification can be seen in Figure 11. These features will in turn affect the ecological functioning of the areas in the number of niches they provide, the interception of water features shown and the carbon stored. This classification is therefore a good starting point to highlight features of pertinence to the ecosystem in general and the green economy.

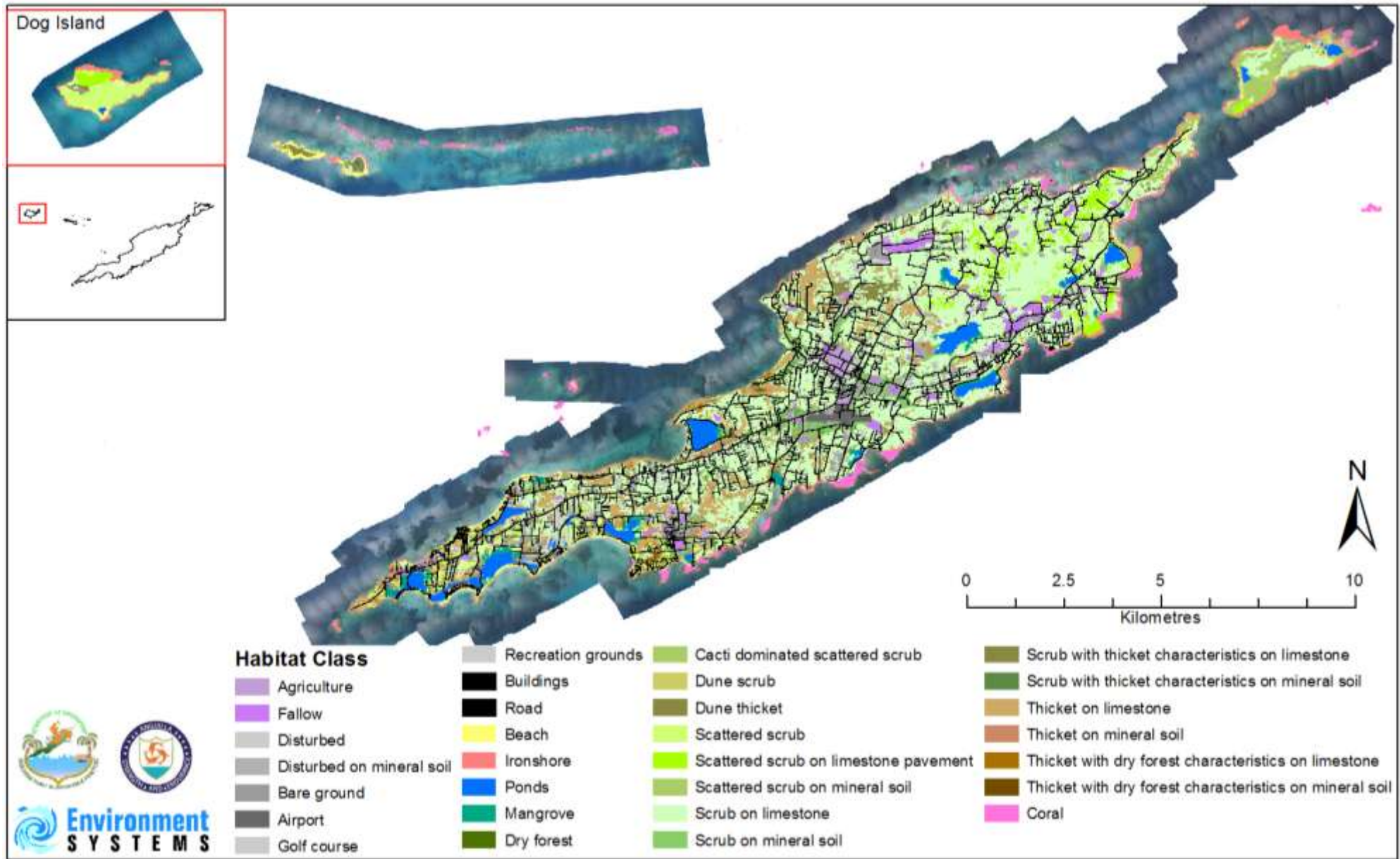


Figure 11: Created habitat map of Anguilla

### 3 Field work and map validation

The classification produced was validated during a field visit. This fieldwork analysis had two main purposes; the first was to check the initial remote sensing classification and the second to collect data to allow enhancements of the rule base. This visit resulted in the formulation of the functional groupings, based on observed community features and features that remote sensing recorded well. Some habitat types were confused in the original classification, particularly cacti dominated scrub and other forms of low level scattered scrub. Understanding the bio-physical characterises of the island and introducing a mask to mirror the exposure to the north easterly trade winds largely prevented this confusion from being an issue in the final classification.

The final classification was assessed against 265 field work points that had been previously collected from vegetation transects by the Government of Anguilla. As the fieldwork points were not originally collected with the intention of map validation they are attributed with a different classification and are not directly compatible with the created habitat map. This should be considered when drawing conclusions from the following accuracy work. The following data preparation steps needed to be undertaken prior to the accuracy assessment:

1. Some habitat map classes, such as scattered scrub and scrub with thicket characteristics, needed to be aggregated as field points did not identify many of the different functional classes used in the final classification
2. Classes with fewer than 10 field observations were removed from the analysis. Classes with very small numbers of field samples will tend to skew accuracy figures unrealistically due to the small size of sample population. Typically 50 well spread out observations are needed for a reliable accuracy assessment (Congalton and Green 1993), however as this would leave only scrub and thicket classes for the accuracy assessment a pragmatic figure of 10 samples per class was used.

For the remaining 229 points the observed habitat class for each point was compared against the mapped habitat. An example of this comparison and how there can be errors at the boundary of habitats is shown in Figure 12.

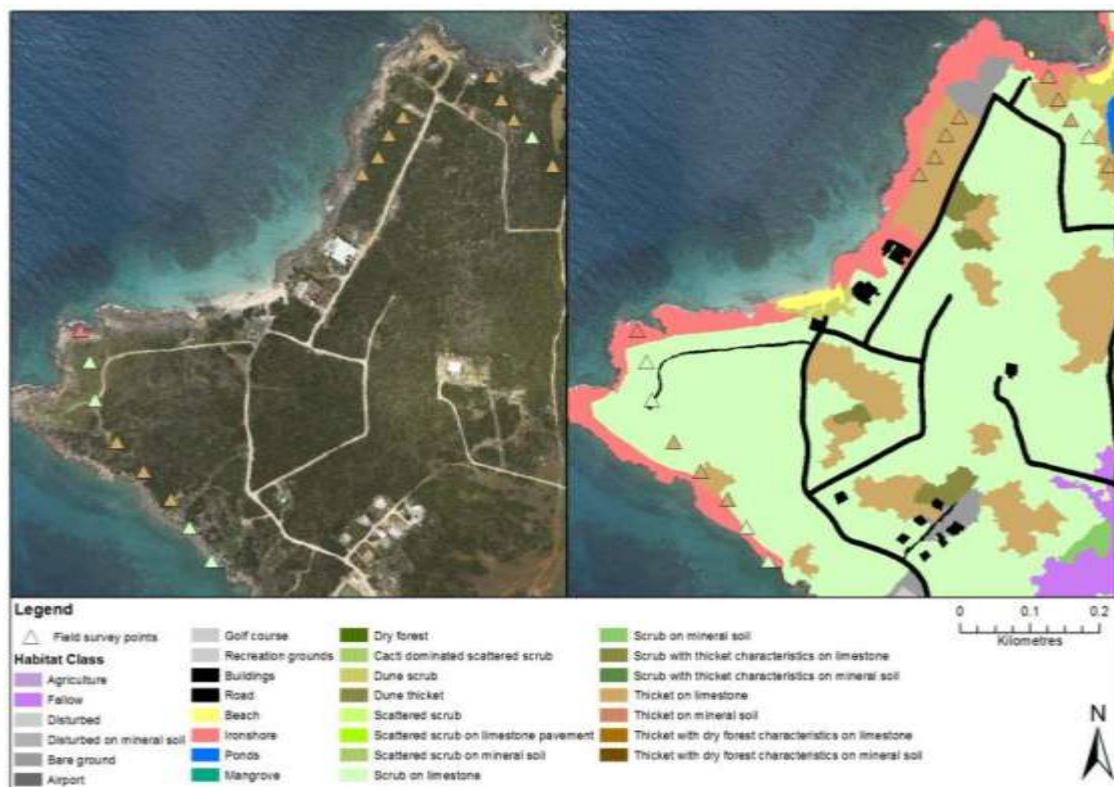


Figure 12: Comparison of fieldwork points against mapped habitats.

The comparison between field and map habitat class is shown as a confusion matrix in Table 2. This compares field observed classes across the top against map classes along the side. Correctly classified habitats fall along the diagonal, with the total map accuracy evaluated by summing the number of observations that fall along the diagonal and dividing by the total number of observations. This shows an overall map accuracy of 80%. Within earth observation projects there are two possible types of errors; over-recording of a habitat or missing areas of habitat. These are called user and producer accuracies and are shown for each class.

Table 2: User producer accuracy table for the habitat mapping using EO compared with field data points

	Field data							Total	User accuracy
	Abandoned Agriculture	Agriculture	Dune Scrub	Ironshore	Limestone Scrub	Limestone Scrub [Cacti dominated]	Limestone Thicket		
EO Classification	15							15	100%
Abandoned Agriculture	3	10						13	77%
Agriculture			3					3	100%
Dune Scrub			4	7	2	3	3	19	37%
Ironshore	1		4	5	104	4	6	124	84%
Limestone Scrub					2	11		13	85%
Limestone Scrub [Cacti Dominated]				1	6		35	42	83%
Limestone Thicket									
<b>Total</b>	<b>19</b>	<b>10</b>	<b>11</b>	<b>13</b>	<b>114</b>	<b>18</b>	<b>44</b>	<b>229</b>	
Producer accuracy	79%	100%	27%	54%	91%	61%	80%		80%

The main errors relate to habitats which occur at a fine spatial scale, as very thin habitats such as ironshore and dune, where within a short distance (approximately 10m) several different habitats occur. These habitats are too fine to be well identified in a SPOT based classification system but could be improved by incorporating higher resolution imagery for a finer image segmentation such as Worldview. In addition the field point recording needs to be suitably accurate to confirm these areas. Another noticeable source of error was a misclassification of very tall and vigorous scrub species being classified as thicket and likewise the less dense forms of thicket being classified as scrub.

These errors are not randomly distributed throughout an earth observation map, they tend to form in specific circumstances for example:

- Shaded areas on steep slopes where the spectral signature differs. In the current habitat map thicket is slightly over recorded on northern slopes of the islands where the cliffs are slumping into the sea. This could be overcome by introducing an imagery dataset with a finer spatial resolution into the coastal zone such as Worldview which would provide more pixels per object and therefore more information for the rules to evaluate.
- Where the habitat has a different appearance because of an added species, for example mimosa plants invading a scattered scrub area may cause it to appear differently from above, changes in soil type can also cause the spectral signal to change enough to fall outside the rule parameter.
- Because of management/ anthropogenic influence (e.g. accidental burn), habitats have an unusual phenotypic appearance.
- Misclassification of habitats along ecotones or within mosaics.

There is also a degree of spatial autocorrelation within the field points that will affect map accuracy results. Spatial autocorrelation reflects the fact that geographical phenomena are related in space; therefore points that are near to each other will tend to be similar. From a map accuracy perspective, recording points along a transect can mean that a number of points fall within a single object in the map as Figure 12 illustrates. Misclassifying a single object can introduce an unrealistically high error score as 4-5 observations are scored as misclassified, when in reality it is a single object. However, the converse is also true as a single polygon that contains a number of correct field points will positively skew results. Furthermore a transect or point based validation strategy does not allow for the accuracy of object boundaries to be evaluated. Figure 13 shows an area from above and from the ground.



*Figure 13: How the imagery relates to what is seen on the ground*

## 4 Using EO for green economy and modelling

The biodiversity of the island of Anguilla is in a delicate balance reliant on sediment and water cycles. Understanding the threats and pressures on the island are important in planning for the future. Figure 14 shows the land use character on the islands, divided into natural, anthropogenic, roads and buildings. It shows that development is concentrated around the Valley and the coasts. These areas, particularly around the salt ponds, are some of the most vulnerable habitats on the island needing monitoring and to be mapped in consideration of the different ecosystem services provided for the island.

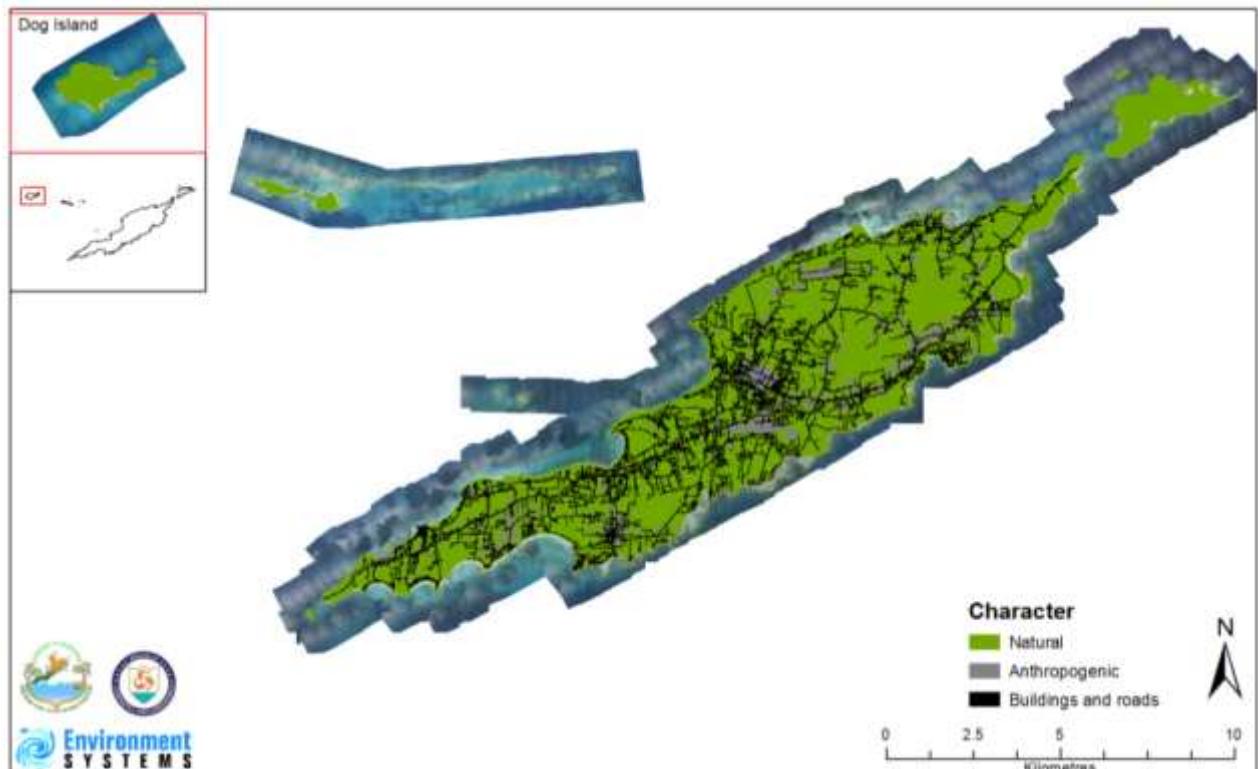


Figure 14: The anthropogenic and natural split of land cover on Anguilla

Coral reef habitats, seagrass beds and mangroves provide important goods and services both individually and through functional linkages. A range of anthropogenic factors are threatening the ecological and economic importance of these habitats and it is vital to understand how ecosystem processes vary across seascapes (Harborne *et al* 2006). Mangrove forests are important within the ecosystems on Anguilla and serve many purposes including:

- Forming the basis of the marine food chain; mangrove leaf litter is an important food source for crabs and small crustaceans, which in turn are predated by fish.
- A habitat for species; many fish require mangrove forest to complete their life cycle using the root systems as refugia and as a spawning ground. This includes many species of commercially important fish.
- Protection against wave action; the complex, dense root structure is crucial to prevent erosion, by absorbing heavy wave impact and dissipating wave energy from severe storms and hurricanes.

- Flood Control; mangroves and their associated salt water ponds are a significant part of the flood plain where they act as buffer systems absorbing excess water during periods of heavy rain.
- Sedimentation and water quality; fine particulate and contaminants are precipitated out of the salt water by an increased rate of sedimentation in the areas protected from wave action by the mangrove roots, therefore improving the water quality of the lagoons. Much of the particulate is carbon based, and therefore the process also acts as an important mechanism for carbon sequestration into the sediment.

There has been inadvertent clearing of mangrove as part of a development due to a lack of understanding of their importance. This is a fragile resource that needs to be understood and valued as part of the green economy. The new habitat map shows the distribution of mangrove across the island Figure 16.



Figure 15: an area of mangroves in Anguilla

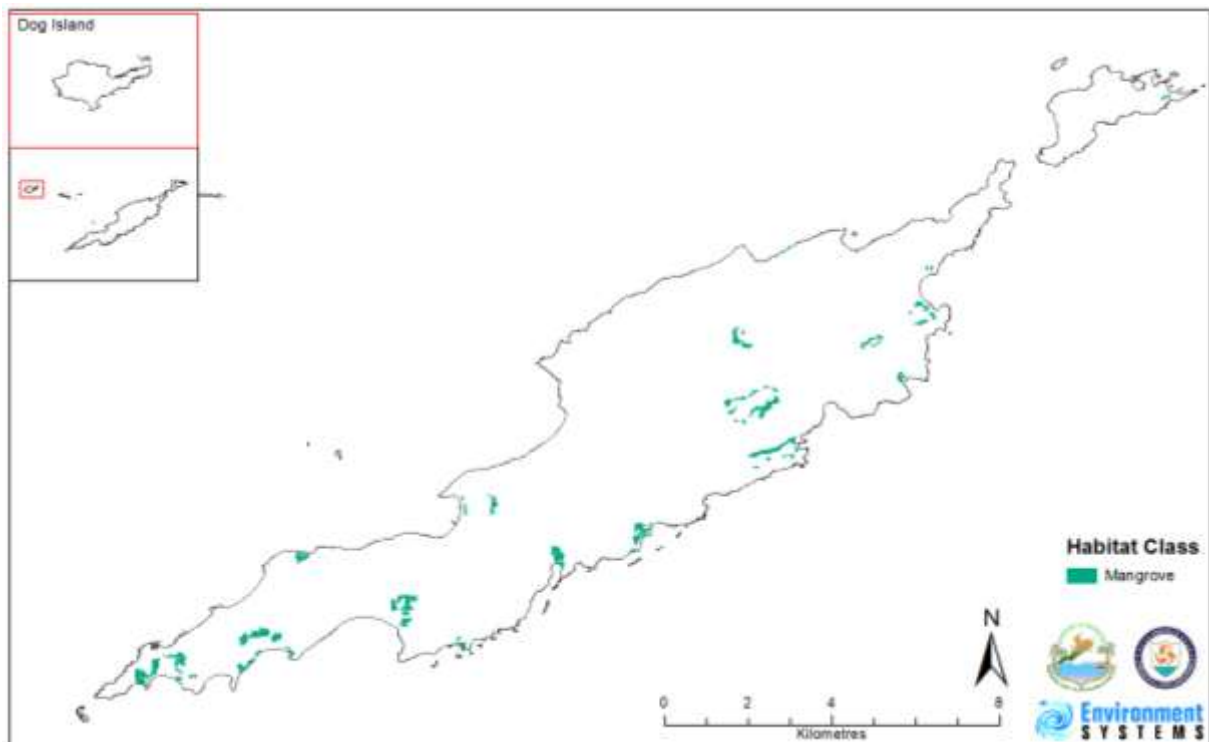
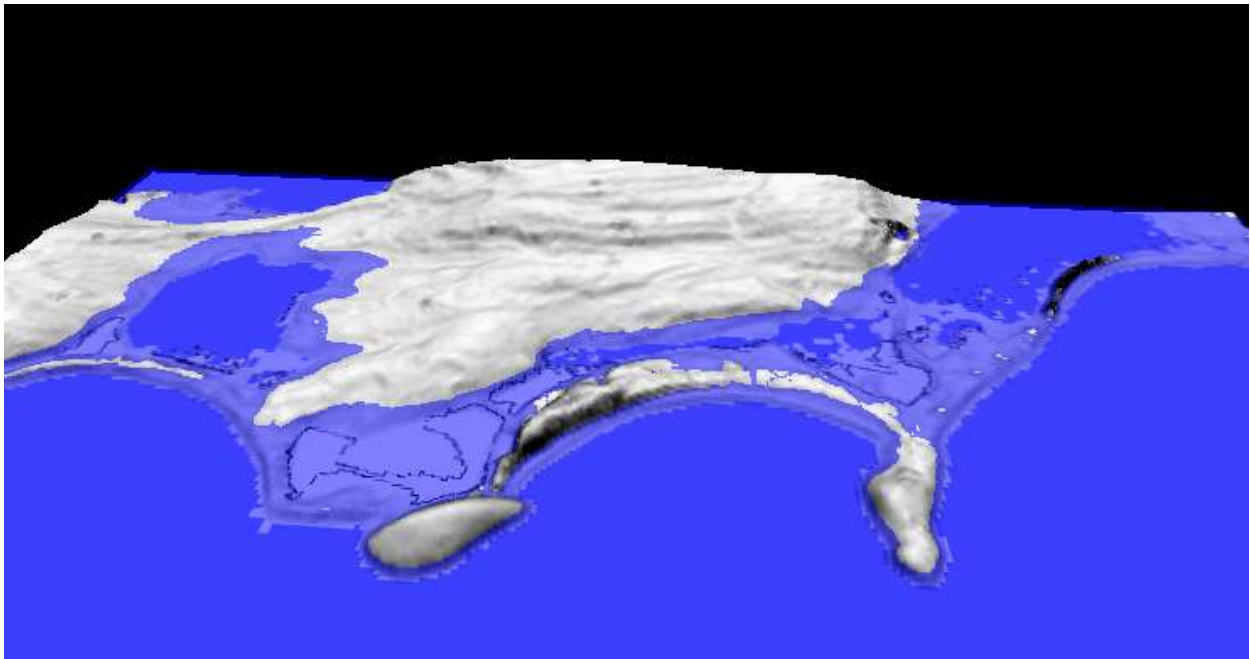


Figure 16: The distribution of mangrove across Anguilla

Using the mapping data and the contextual layers showing slope and flood plains developed in this project, it is possible to provide illustrative maps such as Figure 17 where a 3m storm surge has been modelled on part of the south of the island.



*Figure 17: Representation of the effect of a 3m storm surge on Anguilla*

The beaches, one of Anguilla's prime tourist attractions, are particularly vulnerable to destructive land use types. Illegal sand mining has left an area in the north of the island significantly depleted in sand and therefore with lessened natural defences, particularly vulnerable to damage from hurricanes. This area is also heavily grazed by goats which can further exasperate erosion and subsequently large reduction in the presence of sand. Because the tourism industry relies on the white sandy beaches surrounding the coast of Anguilla and loss of sand could also equate to a reduction in tourist potential.

Apart from those anthropogenic pressures already identified, changes in beach extent and shape can also be exacerbated by natural events, including sea level rise, increasing hurricane frequency and intensity, and lessening of the natural sea defences with climatic coral reef decline.

The following, Figure 18, is an example of how remote sensing could be used to track changes in beach sand over time using existing data, in this case Worldview satellite imagery and the aerial photography. This can allow for hindcasting as well as creating a baseline which can be compared with future data.

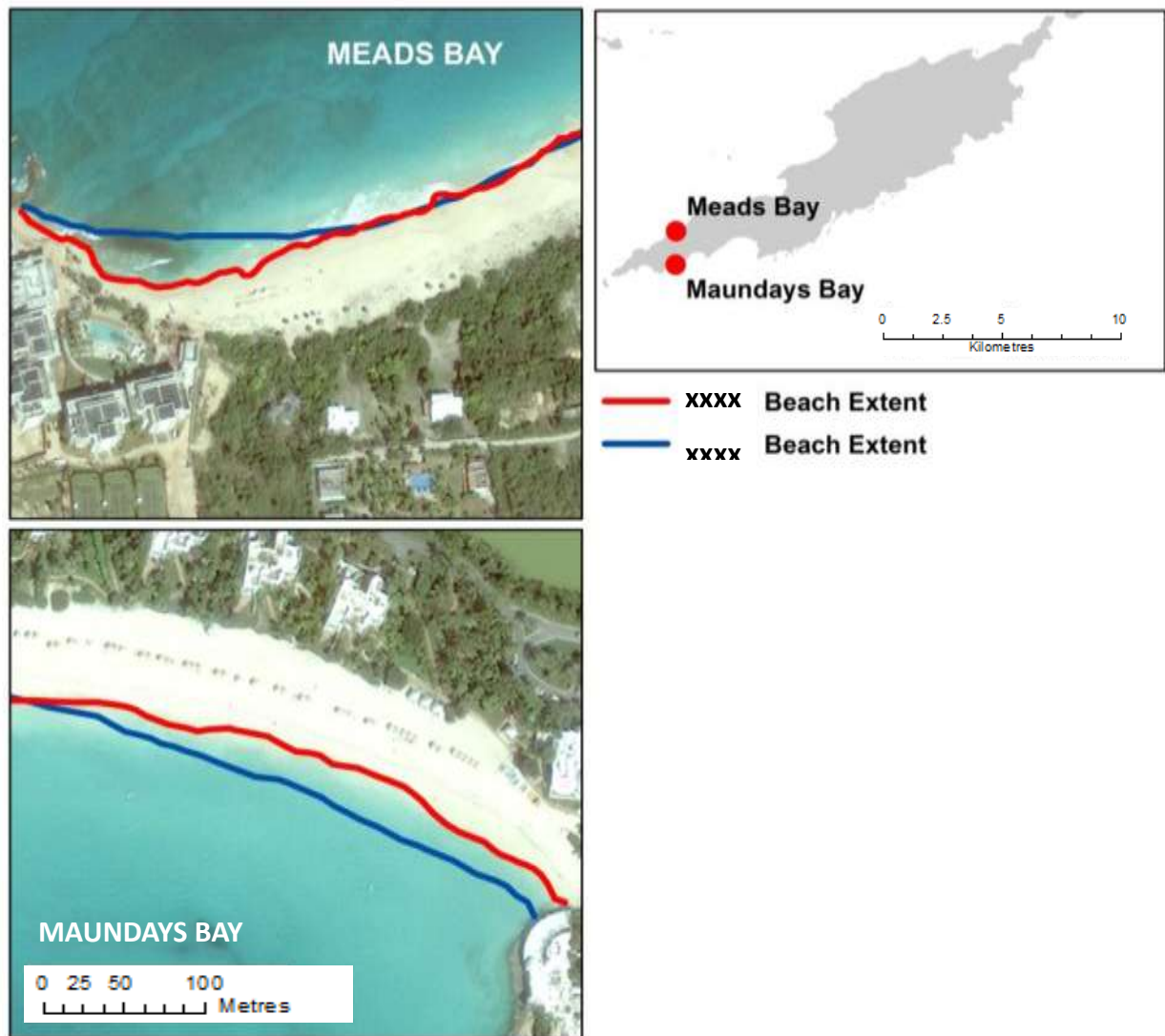


Figure 18: Change in beach extent between the aerial photography (blue line) and the Worldview satellite imagery (red line)

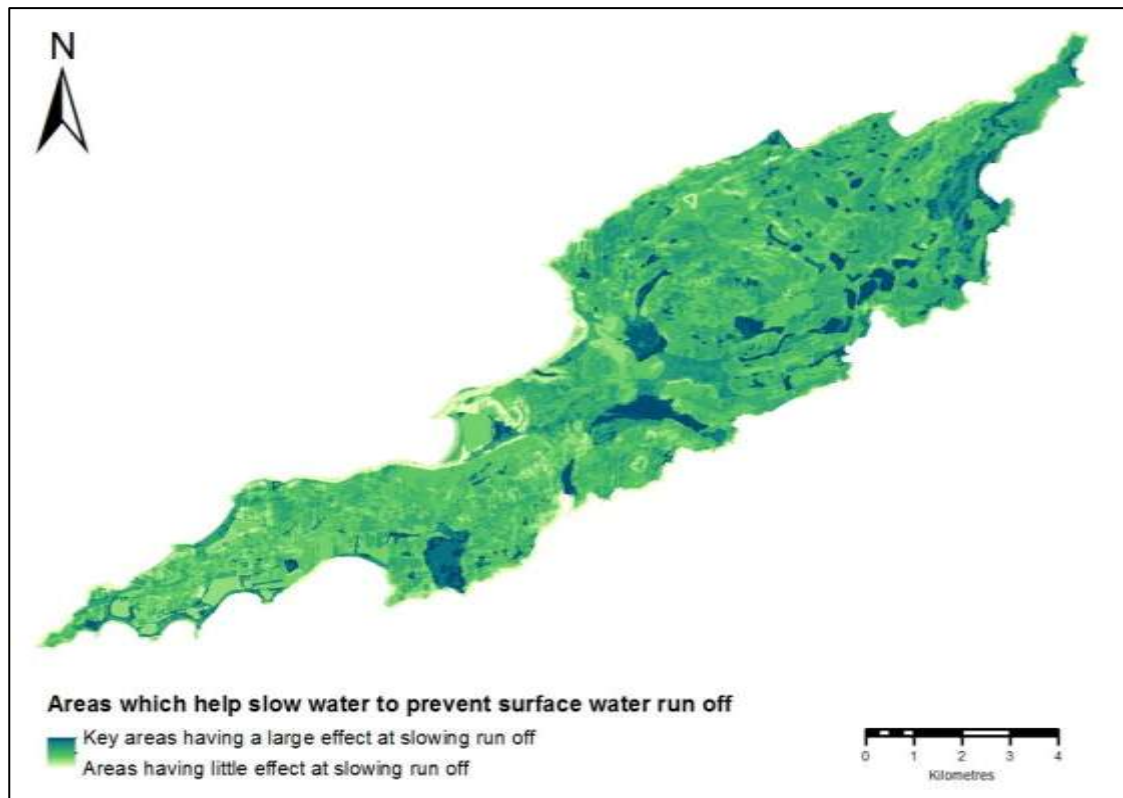
#### 4.1.1 Ecosystem service and habitat mapping

Ecosystem services can be regarded as the services we obtain from the land that are both immediately apparent such as food but also more hidden such as flood protection (MEA, 2005). These ecosystem services reflect the land cover available within an area. They are based on four factors which interact together in different ways for the services under consideration (Medcalf *et al*, 2012). These four key factors are:

- The type of habitat or land cover (e.g. thicket or mangrove)
- The soil and geology upon which the habitat has established
- The position in the landscape (e.g. on a steep slope or valley bottom)
- The management imposed upon them (e.g. intensive agriculture)

Using existing scientific understanding knowledge about how these four factors interact we can use the habitat map to begin to understand the ecosystem services and to demonstrate their efficiency.

A key role of the habitats in Anguilla is of regulating surface water run off during storm events by infiltrating the rainfall, slowing it down and therefore reducing its potential for erosion and increasing its likely hood of being absorbed into the soil rather than washed over the surface. In order to demonstrate the potential for this type of analysis a simple rule base was developed. This used vegetation type, slope, soil type and a proxy valuation of exposure to show how rainfall events differ to produce a picture of the island which highlights the existing key areas and the vulnerable areas for this service (Figure 19).



*Figure 19: Areas which help slow water to prevent surface water run off*

The ecosystem approach is about managing land in a holistic and integrated manner, considering the economic, environmental and cultural aspects together during any land use decision (SCBD, 2004). The use of the habitat map and ancillary layers produced for this project can enhance the understanding of the natural environment and raise awareness of the multi-functional benefits the green infrastructure assets under examination can provide (ECDGE, 2012; Pankhurst, 2012; TCPA and the Wildlife Trusts, 2012). An aim of green infrastructure (GI) is to enhance the health and resilience of ecosystems and the provision of ecosystem services. Multi-functional GI can be viewed as an application of an ecosystem approach, having a strong supporting role in the development of a green economy, through sustainable land and water management (ECDGE, 2012) this is represented in Figure 20.

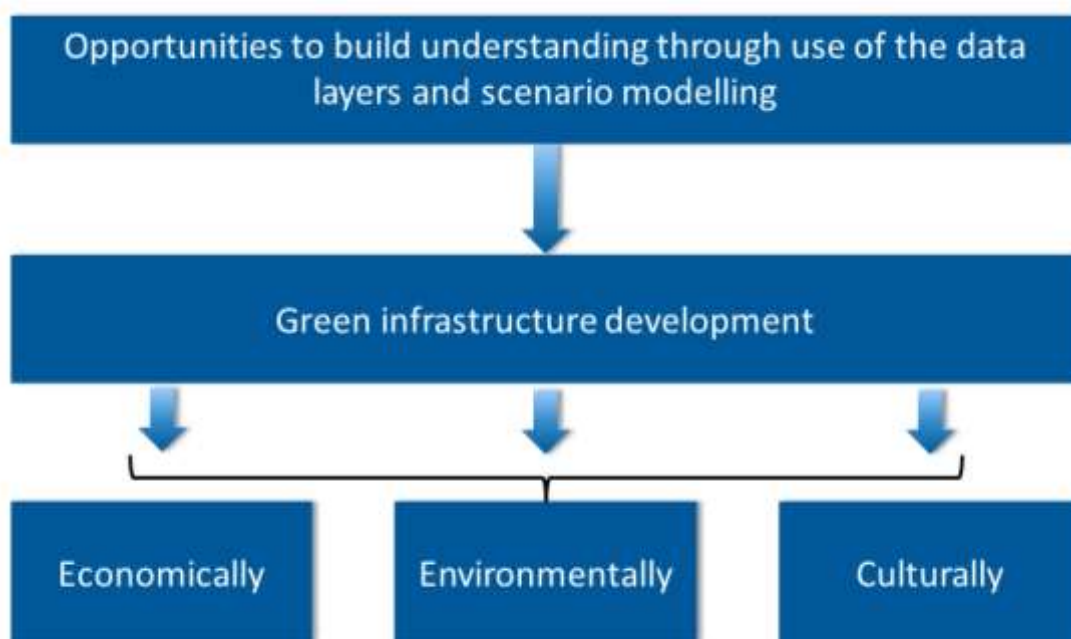


Figure 20: Application of ecosystems approach into green economy thinking

## 4.2 Using EO for Ecological monitoring

Earth observation is a powerful tool for ecological monitoring as it allows for direct measurement and boundary changes over time. It also allows other biophysical parameters to be measured that are cannot easily be measured by fieldwork. Earth Observation has the added value for monitoring habitats that it can be used to look back and forward in time if suitable existing imagery and with subsequent imagery capture.

When designing a monitoring program the following features need be considered:

1. Identification of what changes are significant
2. How to assess and measure that change
3. How to assess the effect of that change

All vegetated surfaces are changing continuously. Within a year an agricultural plot can be bare ready for planting, growing crop, fallow or even reverting to scrub but is still regarded as agricultural as these variations are part of the natural cycle of these areas. Any monitoring program needs to separate this cyclic change from substantive change pertinent to the condition of the site, such as a land use change characterised by the clearing of thicket.

The habitat map gives an ideal starting point for this sort of change evaluation. The habitat boundaries can be compared with imagery obtained both forward and backward in time and the spectral signature can be compared against what is expected for that type of habitat or whether there has been significant change. These significant changes such as vegetation clearing, should be detectable even if the spectral resolution of the data is different, older satellite data is likely to be coarser whilst newer satellite data may have a finer spatial scale. If the timing of known development is used to help establish the change in signature that is significant, the Government of Anguilla could run such an analysis both backward in time and subsequently every few years with new data to understand how the situation is changing.

## 5 Conclusions and Recommendations

This project has used earth observation to produce a satellite map of Anguilla and its off shore cays. This map has used field studies carried out by the department of Anguilla as a basis for building a biophysical earth observation classification that can be used to show how the vegetation contributes to both biodiversity and other ecosystem services.

The techniques used are robust and repeatable and can be used to monitor change and to input into further analysis of ecosystem features such as the regulation of surface water runoff.

Due to initial constraints the map was based on SPOT imagery with a 10m pixel size. This has meant that some of the very fine scale features, particularly ironshore, are quite coarsely recorded. Running the analysis again with a finer scale of imagery would significantly enhance the accuracy of the spatial representation of these areas.

The data created during this work can be used as a basis for sustainable decision making in Anguilla's planning processes by the LDCC (Land Development Control Committee) and all relevant natural resource management agencies.

### Way Forwards

- Acquire the full Worldview spectral imagery and correct it for both the land and marine environment.
- Use the Worldview with the species datasets to look at spectral differences in species and enhance the habitat map further within the terrestrial environment
- Use the Worldview to create a more detailed bathymetric dataset and also to begin to classify out the marine environment
- Development of ecosystem service layers to show how the habitat mapping can be integrated into the green economy and natural capital for the island
- Habitat change mapping
- Provide training for staff in using open-source GIS software (multi-department)

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