Use of satellite data for the monitoring of species on Saba and St. Eustatius.

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Summary

On 10 October 2010 Bonaire, Saba and St. Eustatius became 'special municipalities' of the Netherlands, making the Dutch government responsible for the implementation and adherence to several international conventions that apply to these islands (e.g. Convention of Biological Diversity, Ramsar convention), including the protection of nature.

Knowledge on the whereabouts of endangered and key species or habitats is essential to ensure their protection against the negative effects of activities such as uncontrolled socio-economic developments (e.g. construction works, harbour expansion, expansion of residential areas) and natural phenomena (e.g. hurricanes, Sea Level Rise). This necessitates early identification of risk locations where future expected activities may collide with species/habitat presence. To determine these whereabouts, monitoring is necessary. Monitoring in the field, however, is often costly and time-consuming. A more effective and quicker approach is desired to obtain a realistic overview of key habitat distributions and associated key species.

At the request of the Dutch Ministry of Economic Affairs the present study examines the possibility to identify the different land cover types (natural and artificial) on Very High Resolution[1] satellite images of the Caribbean islands Bonaire, Saba and St. Eustatius, using remote sensing[1] analysis. In addition, the possibility to link key species with specific land cover types was assessed by identifying the species' habitat requirements. Linking species habitat requirements with associated land cover types allows for the identification of their potential occurrence on the islands. It was expected that with niche-modelling potential distribution maps could be developed for different species and habitats. Such maps are valuable to determine risk locations where species/habitat occurrence and planned activities may conflict in the future. This would allow for the proper and early implementation of protective measures.

Worldview-2 satellite images of Saba and St. Eustatius (acquired on 3 December 2010 and 18 February 2011, respectively) were analysed. Analysis of the satellite image of Bonaire was not possible, due to time constraints. From the results of Saba and St. Eustatius it can be concluded that identification of land cover types using satellite images is possible. At present, the results are limited due to a) heterogeneous land cover types and b) the lack of ecological knowledge (e.g. baseline studies).

The identification of artificial features[1] (e.g. infrastructure) is not a problem. The challenges encountered are mainly related to the largely mixed heterogeneous vegetation found on Saba and St. Eustatius. Due to the high level of mixing, spectral overlap between different vegetation types is high. Consequently, separating the different vegetation types is difficult. Corrections can be made based on visual interpretation and expertise in the field. This requires time and expert knowledge of the different vegetation types. In addition, both Saba and St. Eustatius exhibit strong differences in altitude, resulting in numerous shadowed areas that impede the identification of the land cover types underneath. Such terrain effect can be corrected using a Digital Elevation Model (DEM). Unfortunately, a sufficiently good DEM (with a high spatial accuracy of around 1 meter) was not yet available[2].

Analysis of satellite images resulted in land cover maps with good fit to the distribution of the different land cover types on Saba and St. Eustatius. The produced land cover maps (Figures 4 to 7) give a coarse representation of the distribution of Forest, Shrub, Pasture and Artificial surface on the islands. In addition, it was possible to identify the extent and location of invasive vegetation (e.g. Corallita and other species), although identification to species-level was not possible. At present, these maps provide insufficient detail for biodiversity monitoring, because of the lack of connection with species. They could, however, be used to monitor different land cover development (e.g. forestation, artificial surfaces, shrub and pastures) on the long term (e.g. in years) or to gain a quick overview on the location of invasive

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[1] See Glossary for definitions, Appendix I.
[2] High resolution DEMs are being constructed in a new project. This will help future mapping and spatial analyses.

vegetation. A distinctive land cover classification based on the available satellite images during the present study, however, was only achieved for the coarser vegetation types.

Ecoprofiles were developed for various species and habitats, describing their habitat requirements. With sufficient detail, these requirements link the species to habitats and thereby allow for the creation of species specific maps. The level of available data on habitat requirements varies per species. Overall knowledge on habitat requirements is generally not sufficient, associating species with multiple habitat types, and making it difficult to pinpoint essential habitat types. The amount of knowledge on habitat requirements has direct influence on the success of niche modelling. This illustrates the necessity of detailed knowledge on species biology, ecology and life history characteristics even when using advanced techniques such as remote sensing.

The production of maps through niche-modelling meant to show the expected geographical distribution of species was not possible due to the limited level of detail within the identified land cover types, and the restricted data on the habitat requirements of the species occurring on Saba and St. Eustatius, in combination with time constraints. Before such maps can be developed several issues need to be solved first. These include specific knowledge on species biology, ecology and life history characteristics of the target species (baseline studies); the collection of more training samples (ground truthing data) in the field; a high quality DEM of Saba and St. Eustatius (and Bonaire as well). This will lead to further adaptation of the chosen classification scheme and aid in separating spectral overlap between the different vegetation types.

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1 Introduction

1.1 The Caribbean Netherlands

The Caribbean Netherlands concerns three islands of the Lesser Antilles island chain, namely, Bonaire, Saba and St. Eustatius. The Lesser Antilles is subdivided into the Leeward islands (northern islands starting east from Puerto Rico to Dominica in the south), the Windward islands (south-eastern islands including Dominica up to and including Grenada) and the Leeward Antilles (southern islands including Aruba, Bonaire, Curacao and the islands of the Venezuelan archipelago). Bonaire is part of the Leeward Antilles, while St. Eustatius and Saba belong to the Leeward islands. St. Eustatius and Saba differ climatologically from Bonaire, as the annual rainfall and susceptibility to hurricanes of these two islands is much higher (Debrot & Sybesma, 2000). Below a short description is given of the three islands. Figure 1. shows the locations of the islands.

1.1.1 St. Eustatius

St. Eustatius belongs to the Leeward islands and is situated between 17°28' and 17°32' N latitude and between 62°56' and 63°0' W longitude (De Freitas *et al*., 2012). It is a volcanic island with a total area of 21 km^2. St. Eustatius has a tropical climate with an annual rainfall of 986 mm, and with the majority of precipitation falling between August and November (Collier & Brown, 2006). The wind blows predominantly from the northeast to southeast (more than 80% of the time), with typical wind speeds at levels 3 and 4 on the Beaufort scale. Monthly mean temperature is about 26.7°C with a maxima of 30°C and a minima of 24°C. Annual sea surface water temperature varies from 24.7°C (February) to 27.9°C (September) (Debrot & Sybesma, 2000). The vegetation on St. Eustatius consists primarily of thorny woodland and grassland, with evergreen and elfin forest on The Quill (Collier & Brown, 2006). The island has two volcanos, an old denuded volcano in the northwest and a younger dormant volcano, The Quill, in the southeast (Collier & Brown, 2006). The highest point of St. Eustatius is 600 m above sea level and found on The Quill (STENAPA, 2012). The island is surrounded by relatively shallow bank waters and the coasts of the island are dominated by steep cliffs, while sandy beaches are rare (Debrot & Sybesma, 2000).

1.1.2 Saba

Saba, like St. Eustatius, belongs to the Leeward islands and it too, is a volcanic island of the geologically younger inner arch of the Lesser Antilles. Saba is situated between 17°36' and 17°39' N latitude and between 63°15' and 63°12'W longitude. The island lies approximately 21 km west of St. Eustatius. Its tropical climate is therefore similar to that of St. Eustatius. The annual mean temperature is 27°C and the average rainfall is 1667 mm (World Travel Guide, 2012). Saba is the smallest of the three Dutch Caribbean islands, with a total area of 13 km^2. The island is a steep dormant volcano rising from depths of 600 m extending to 870m above sea level (Debrot & Sybesma, 2000). The shores are steep and inaccessible. The plant communities found on Saba range from Croton thickets to (secondary) rainforest and elfin woodland (Rojer, 1997b).

1.1.3 Bonaire

Bonaire lies in front of the Venezuelan coast and is situated between 12°2' and 12°19' N latitude and between 68°11' and 68°25' W longitude (De Freitas *et al*., 2005). It has a total area of 288 km^2. In front of the leeward coast of Bonaire, approximately 6 km^2 and opposite from the main town Kralendijk, lies the small island Klein Bonaire (De Freitas *et al*., 2005). Bonaire lies in an arid region of the Caribbean with an annual rainfall of 532 mm (STINAPA, 2011). The wind blows from the northeast to southeast direction more than 95% of the time, predominant with wind speeds at levels 4 and 5 of Beaufort scale.

The monthly mean temperature average is about 27.5°C, with monthly maxima of 31°C and minima of about 25.5°C. Annual sea surface water temperature varies from 25.4°C (February) to 28.1°C (September) (Debrot & Sybesma, 2000).

Figure 1 The Dutch Caribbean; Bonaire, St. Eustatius and Saba (Google Earth, Digital Globe 2013. Scale arbitrary.)

1.2 Background

The global biodiversity is declining, due to habitat destruction and degradation. These are caused mainly by changes in human land use which remains, next to climate change, the most important driver of biodiversity loss (Hansen *et al*., 2004; Mücher, 2009). Therefore, there is an increasing need for reliable, up-to-date, data on land use, land cover and habitats to inform current environmental policies and nature conservation planning (Stanners and Bourdeau, 1995). The impact of land use change is widely recognised and has forced national and international agencies to take policy measures to afford a higher degree of protection to our landscapes and habitats, as well as to conduct monitoring and identification of potential sites for nature conservation.

Bonaire, Saba and St. Eustatius became special municipalities of The Netherlands in 2010. Consequently, the Dutch government became responsible for the implementation and adherence to several international conventions that apply to those islands (e.g. Ramsar, CITES, SPAW etc.). For proper implementation, monitoring of key habitats and species is essential. The Dutch Caribbean harbours a wide variety of keystone habitats and endemic and endangered species. It is generally known which habitats and species occur on the three islands and which constitute the most important nature values. However, knowledge on the geographical distribution remains limited (Smith *et al*., 2012, Rojer, 1997a, 1997b). For Saba, Rojer (1997b) recommended a complete inventory of plants growing on the top of Mount Scenery as well as the need for further research on the island's population of endangered vertebrates. For St. Eustatius, Rojer (1997a) listed several recommendations for research, including further study on the islands rare and endangered animal species and the revaluation of the various vegetation types. For Bonaire, Smith *et al*. (2012) recommended a complete and extensive inventory on the geographical distribution of key species.

Bonaire and St. Eustatius both expect social and economic developments in the near future and have recently developed spatial or strategic development plans (R.O.B., 2010; Hoogenboezem-Lanslots *et al*., 2010). These developments focus on possible coastal development, agriculture, tourism and industrial expansion, including real estate development and urbanization (R.O.B., 2010; Hoogenboezem-Lanslots *et al*., 2010). Saba does not have a spatial development plan ready at present. However, social en economic developments can also be expected for Saba. To guide spatial developments in a sustainable matter, geographical distribution of key species and habitats is a must.

Remote sensing techniques are important tools in monitoring the environment (e.g. Davaasuren & Meesters, 2012; Helmer *et al*. 2002; Helmer *et al*. 2008; Mücher *et al*., 2000; 2001; 2009). These techniques can be applied in monitoring land cover classes, and consequentially in monitoring species. Compared to count and tracking studies in the field, remote sensing techniques require relatively low costs for data acquisition. An additional advantage of remote sensing techniques is that it is possible to acquire repeated coverage of an area, also those areas that are difficult to access in field studies (Davaasuren & Meesters, 2012).

Because of insufficient specific distribution data and because a full inventory of the occurrence of a species on an island is costly and time-consuming another approach is explored. The present study focuses on an approach using remote sensing techniques and Very High Resolution (VHR) satellite data to estimate the geographical distribution of key species and habitats.

1.3 Approach

To determine to what extent Very High Resolution (VHR) satellite imagery and remote sensing techniques can provide in biodiversity monitoring on the Caribbean Netherlands, land cover maps were produced from VHR satellite images of Saba and St. Eustatius using remote sensing. Worldview-2 satellite imagery of Saba and St. Eustatius were acquired. The images were analysed to produce basic land cover maps that cover the entire islands. Unsupervised[1] and supervised classification[1] of the images was performed, using a land cover typology based on CORINE[1] land cover expanded with land cover types found in the Caribbean Netherlands. A short literature review was done to determine the habitat requirements of the chosen key species and habitats, resulting in Ecoprofiles[1], with the aim to connect these species to land cover types.

1.4 Acknowledgements

The collection of information and analysis of the data in this report would not be possible without valuable contributions from different people and organisations. In this respect, we would like to thank the following people: Sabine Engel, Ineke Willemse, Fernando Simal, Ramon de Leon from STINAPA, Hannah Madden and Jessica Berkel from STENAPA, Sam Williams, Peter Montanus; Steve Geelhoed, Hans Verdaat and Rob van Bemmelen from IMARES, for their contribution on species habitat requirements. Martha Walsh-McGehee, Diana Slijkerman, Erik Meesters, Dolfi Debrot and Hans Verdaat supplied the photos that have been used in this report.

2 Assignment

The Dutch Ministry of Economic Affairs (EZ) requested IMARES and Alterra to assess the extent to which remote sensing techniques can be applied in biodiversity monitoring on the islands Bonaire, Saba and St. Eustatius.

The assignment had the following main objectives:

- To determine to what extent satellite imagery and remote sensing techniques provide in a distinctive land cover classification.
- To determine to what extent satellite imagery can be used for geographical distribution monitoring (expected distribution) of key species and habitats.
- To determine expected threats and risk locations based on species' habitat requirements and satellite imagery.

For this purpose satellite images of St. Eustatius and Saba were purchased, processed and classified. In addition, habitat requirements were determined for key species and habitats of the three islands.

3 Materials

3.1 Species and habitats

Thirteen animal species, one plant species and three habitats were chosen to examine in the present study (Table 2 and Appendix A).

3.1.1 Habitat types

Coral reefs, mangroves and sea grass meadows were the three habitats for which the specific requirements were explored. All three are appointed key habitats, as they support important biodiversity. In addition, these habitats provide a variety of ecosystem services which are of great importance for the islands and its inhabitants (e.g. coastal protection, nutrient cycling and recreation) (Costanza *et al.*, 1997). For coral reefs general requirements were investigated. For mangroves and sea grasses habitat requirements of various species were explored.

The two seagrass species Turtle grass (*Thalassia testidinum*) and Manatee grass (*Syringodium filiforme*) were chosen. For the mangroves, four species were explored; Red mangrove (*Rhizophora man gle*), White mangrove (*Laguncularia racemosa*), Black mangrove (*Avicennia germinans*) and Buttonwood (*Conocarpus erectus*).

Table 1. The species and habitats chosen to analyse in the present study.

Common name	Latin name
Sea turtles	
Green turtle	*Chelonia mydas*
Hawk's bill	*Eretmochelys imbricata*
Leatherback	*Dermocelys coriacea*
Reptiles	
Red-bellied racer	*Alsophis rufiventris*
Lesser Antillean green iguana	*Iguana delicatissima*
Mollusc	
Queen Conch	*Strombus gigas*
Bird species	
Caribbean coot	*Fulica caribaea*
American Flamingo	*Phoenicopterus ruber*
Northern Caracara	*Polyborus plancus*
Yellow shouldered parrot	*Amazona barbadensis*
Least tern	*Sterna antillarum*
Common tern	*Sterna hirundo*
Audubon's shearwater	*Puffinus iherminieri*
Plant species	
Morning glory	*Ipomoea sphenophylla*
Habitat types	
Coral reefs	-
Mangroves	-
Seagrass beds	-

3.1.2 Animal and plant species

The thirteen animal species consist of three sea turtle species (*Chelonia mydas*, *Dermochelys coriacea*, *Eretmochelys imbricata*), one snake species (*Alsophis rufiventris*), one lizard species (*Iguana delicatissima*), one marine mollusc (*Strombus gigas*) and seven bird species (3 seabirds: *Sterna hirundo*, *Sterna antillarum*, *Puffinus Iherminieri*, 2 waterbirds: *Fulica caribaea, Phoenicopterus ruber*, 1 bird of prey: *Polyborus plancus* also known as the *Caracara cheriway* and 1 parrot: *Amazona barbadensis*).

The animal species have been chosen due to their unique, endemic or protected status on one, two or all of the three islands.
The three turtles are either endangered or critically endangered (Seminoff, 2004; Sarti Martinez, 2000; Mortimer & Donnelly, 2008). The small snake, Red-bellied racer, is endangered, while the population of the Queen conch (marine mollusc) is declining due to high fishing pressures.

The Lesser Antillean Green Iguana population is decreasing and is endangered. Both the Northern Caracara (*Polyborus plancus*) and the American Flamingo (*Phoenicopterus ruber)* are included in Appendix II of the CITES convention[3]. The Caribbean coot (*Fulica caribaea*), the Audubon's Shearwater (*Puffinus iherminieri)* and the Least tern (*Sterna antillarum*) are considered threatened (BirdLife International, 2012b, c, d; CAR-SPAW-RAC, 2012), the Common tern *(Sterna hirundo*) is included in Appendix II of the Bonn convention[4] (CMS, 2012). The Yellow shouldered parrot (*Amazona barbadensis*) is considered vulnerable as its population numbers is decreasing (BirdLife International, 2012f).

The Morning glory (*Ipomoea sphenophylla*, a creeper of the family *Convolvulaceae*), is a plant species that is only found on St. Eustatius. It was presumed extinct, but was rediscovered.

3.2 Satellite images

For both Saba and St Eustatius Worldview-2 single date multi-spectral[1] and panchromatic images[1] were acquired. The image for Saba was acquired on 3 December 2010 and the image for St. Eustatius on 18 February 2011. Figure 2 shows the purchased satellite images. For a short description on Worldview-2 see Appendix C.

Table 2 Satellite image specifications.

Sensor	Area	Resolution	Acquisition data	Max angle	Sun elevation
WorldView-2	Saba	0.5 m (pan) 2 m (ms)	03/12/2010	8.22	48.09
WorldView-2	St. Eustatius	0.5 m (pan) 2 m (ms)	18/02/2011	0.42	55.14

Further satellite image specifications:

- WorldView-2 Data: Panchromatic with 0.5 meter spatial resolution1 and 8-band Multispectral image data with 2.0 meter spatial resolution
- WorldView-2 Standard Ortho-Ready Standard Image Data with geolocation accuracy specification of 6.5 m CE90 at nadir, excluding terrain and off-nadir effects
- Projection, date, and measurement units will be UTM, WGS84, metric
- Image file format will be GeoTIFF format
- Image data will be provided in 16-bit1 dynamic range
- Projection UTM zone 20 N (WGS84)

3.3 Ancillary data[1]

The landscape ecological vegetation maps generated for Bonaire (scale: 1: 50.000; de Freitas *et al*., 2005), St. Eustatius (scale: 1: 37.000; de Freitas *et al*., 2012; after Stoffers, 1956) and Saba (de Freitas *et al*., in press) were used as additional references for setting up the land cover legend and during the classification itself.

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[3] *Appendix II of the CITES convention includes species not necessarily threatened with extinction, but trade in these species must be controlled to avoid utilization incompatible with their survival (CITES, 2012).*

[4] *Appendix II of the Bonn convention includes migratory species that need or would significantly benefit from international co-operation.*

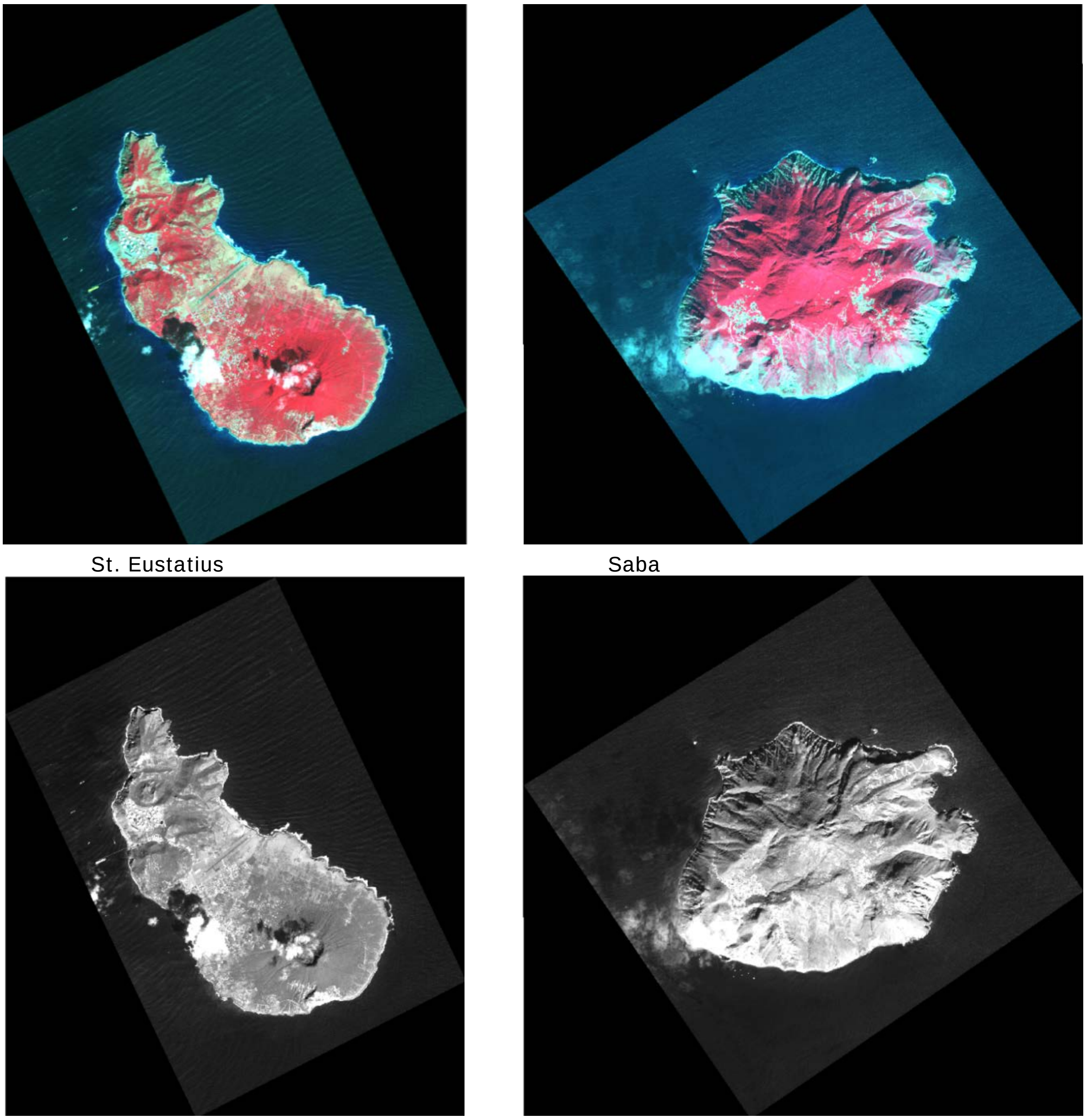

Figure 2. Screenshot of complete Worldview-2 imagery acquired for St Eustatius and Saba. Above in false-color the multi-spectral imagery with 8 bands[1] (RGB:7/5/3) and a spatial resolution of 2 m. Below the additional black & white panchromatic images for St. Eustatius and Saba with a 0.5 m spatial resolution.

3.4 Ground truthing data

Ground truth data was collected during November 2012 on St. Eustatius and Saba, by A.O. Debrot and students. Beforehand, 90 GPS points on St. Eustatius and 57 GPS points on Saba were selected as potential training samples for the classification. The GPS points corresponded with the central point of those areas chosen for ground truthing. The areas were selected based on the spectral classes that resulted from the unsupervised classification (see 4.3.2), their homogeneity and size (minimum of 5 x 5 pixels). In the selection process of possible useful training samples also the expertise from vegetation experts was used. A large number of these potential samples were visited in November 2012.
The ground truth data in combination with the corresponding spectral signature derived from the satellite images served as trainings samples for the supervised classification (see 4.3.3.)

4 Methodology

4.1 Habitat requirements

All species need certain basic requirements or resources which are essential to their survival and enable them to thrive within an environment (healthy population status and population growth). These aspects are known as habitat requirements. The most essential habitat requirements concern (Yarrow, 2009):

a) Nourishment - such as food and water;
b) Cover or shelter - against the weather or predators and;
c) Space - to obtain food and water and to attract a mate for reproduction.

Habitat requirements may concern biotic (e.g. particular vegetation, prey etc.) and abiotic aspects (e.g. light, acidity, rocky substrate etc.).

Based on the habitat requirements of a species, two approaches are possible to estimate the geographical distribution.

i. By determining the habitat requirements found in those areas where the target species has actually been observed in the field. Additional areas of expected occurrence, that facilitate the same requirements, may be pin pointed by extrapolation. For this approach, actual field observations on the islands are necessary.
ii. By applying a modelling approach (e.g. niche modelling) based on land cover or habitat maps and other environmental data sources. With knowledge on the specific habitat requirements of the target species and knowledge on the areas that may provide these requirements, its geographical distribution on the islands can be estimated. For this approach, it is therefore necessary to determine the habitat requirements of the chosen species and habitats.

In the present study, a short literature review was performed to determine the available distribution data (presence and absence) and to identify the (habitat) requirements of the selected key species and habitats. In addition, experts on the specific species and habitats were contacted. Ecoprofiles were developed for each species and habitat describing the species or habitat, its requirements and the threats that may endanger its presence or cause its absence.

4.2 Land cover and vegetation typology

The major objective in the present study, was to produce basic land cover maps that cover the entire islands. Before land cover classification of satellite data is started, it should be clear which land cover classes are selected. The objective here was to create a typology that is a hierarchical nomenclature with different levels that can be used flexibly and extended when needed, and which covers the major natural vegetation types of interest, in addition to other land cover types (e.g. urban areas and agriculture). Another consideration was to keep a common link with the national land cover classifications of the Netherlands (see Hazeu *et al*., 2011), in addition to continental (e.g. CORINE land cover, see Heymann *et al*., 1994, Büttner *et al*., 2004, Feranec *et al*., 2007) and global land cover classifications.

Table 3 shows the classification scheme used to designate the different land cover classes. The classification typology developed was a comprehensive, hierarchical and flexible nomenclature with land cover and vegetation classes that are mutual exclusive. Level 4 was the most detailed level. Not all level 2 and 3 classes were subdivided up to level 4, and not all classes would be discerned on the Worldview-2 imagery that was used for the classification (estuaries are not found on Saba and St. Eustatius for example).

Table 3. The classification scheme (typology) used to designate the different land cover classes.

Proposal BO-BES land cover /habitat map		coming from DOM legend	
Level 1	Level 2	Level 3	Level 4
1 (CLC 1) Artificial surfaces	1.1 Urban fabric (CLC 11)	1.1.1. Continuous urban fabric	
		1.1.2 Discontinuous urban fabric	
		1.1.3 Informal housing	
	1.2 Industrial, commercial and transport units (CLC 12)	1.2.1 Industrial and commercial units (CLC 121)	
		1.2.2 Road and rail networks and associated land (CLC 122)	1.2.2.1 Tarmac
			1.2.2.2. Concrete
		1.2.3 Port areas (CLC 123)	
		1.2.4 Airports (CLC 124)	
	1.3 Mine, dump and construction sites (CLC 13)		
	1.4 Artificial non-agricultural vegetated areas (CLC 14)	1.4.1. Corallita	
		1.4.2. Caesalpinia buondoc	
		1.4.3. Leucaena	
		1.4.4. Philodredron giganteum	
		1.4.5 Cryptostegia grandiflora	
		1.4.6. Elephant grass	
		1.4.7. Tamarind	
2 (CLC 2) Agricultural areas	2.1 Arable land (CLC 21)	2.1.1 Non-irrigated arable land (CLC 211)	
		2.1.2 Permanently irrigated land (CLC 212)	
	2.2 Permanent crops (CLC 22)	2.2.1 High level of management	
		2.2.2 Low level of management	
	2.3 Pastures (CLC 23)	2.3.1 Seasonal	
3 (CLC3.2) Range land	3.1 Herbaceous rangeland (CLC 321)		
	3.2 Shrub and bush rangeland (CLC 322+323+324)	3.2.1 Evergreen bushland	
		3.2.2 Cactus scrub	
		3.2.3 Thorn scrub	
		3.2.4 Strand shrub community	
	3.3 Mixed rangeland		
4 (CLC3.1) Forest land	4.1 Broadleaved evergreen (CLC 311)	4.1.1 Seasonal	4.1.1.1 Evergreen seasonal forest
			4.1.1.2 Montane thicket
			4.1.1.3 Elfin forest or mossy forest
			4.1.1.4 Seasonal Thorny woodland
			4.1.1.5 Leucaena thicket
			4.1.1.6 Croton thicket
		4.1.2 Dry	4.1.2.1 Dry evergreen forest
			4.1.2.2 Dry rain forest
			4.1.2.3 Littoral woodland
			4.1.2.4 Dry Thorny woodland
			4.1.2.5 Hippomane woodland
			4.1.2.6 Croton thickets
	4.6 Broadleaved semi-evergreen	4.6.1 Seasonal	4.6.1.1 Semi evergreen seasonal forest
		4.6.2 Dry	
	4.2 Broadleaved deciduous (CLC 311)	4.2.1 Seasonal	4.2.1.1 Deciduous seasonal forest
		4.2.2 Dry	
	4.3 Needleleaf evergreen (CLC 312)	4.3.1 Seasonal	
		4.3.2 Dry	
	4.4 Needleleaf deciduous (CLC 312)		
	4.5 Mangroves		

Proposal BO-BES land cover /habitat map (2)					
5 Water (CLC5)	5.1 Inland waters (CLC 51)	5.1.1	water courses (CLC 511)		
		5.1.2	water bodies (CLC 512)		
		5.1.3	artificial water bodies/temporary water bodies		
		5.1.4	inland fresh and brackish water		
	5.2 Marine waters (CLC 52)	5.2.1	coastal lagoons (CLC 521)	5.2.1.1	seagrass
				5.2.1.2	unvegetated
		5.2.2	estuaries (CLC 522)		
		5.2.3	sea and ocean (CLC 523)	5.2.3.1	seagrass
				5.2.3.2	coral reefs
				5.2.3.3	algal beds
				5.2.3.4	unvegetated
6 Wetland (CLC4)	6.1 Inland wetlands (CLC 41)	6.1.1	inland marshes (CLC 411)		
		6.1.2	peatbogs (CLC 412)		
		6.1.3	wet grasslands (new from DOM legend)		
	6.2 Coastal wetlands (CLC 42)	6.1.1	salt marshes (CLC 421)		
		6.1.2	salines (CLC 422)		
		6.1.3	intertidal flats (CLC 423)		
		6.1.4	salt flats	6.1.4.1	vegetation of the salt flats
Barren land	Beaches, sand, dunes				
7 (CLC3.3)	7.1 (CLC 331)	7.1.1	Sand		
		7.1.2	Rubble		
	7.2 Bare rocks (CLC 332)				
	Sparsely vegetated		Rock pavement		
	7.3 (CLC 333)	7.3.1	vegetation		
		7.3.2	Rocky slopes vegetation		
		7.3.3	Desert		
	7.4 Glaciers and perpetual snow (CLC 335)				

4.3 Satellite image analysis

Multispectral classification, in this case, is the analysis of reflected energy from an object or an area of interest in multiple bands or regions of the electromagnetic spectrum[1] (Jensen, 2005). The main purpose of multispectral imaging is the potential to classify the image into the classes of interest (e.g. vegetation, roads etc.) using multispectral classification. This is in general a much faster method of image analysis than is possible by human interpretation, especially when it concerns large areas. In principle there are two main approaches to explore the multispectral domain, namely unsupervised and supervised classification. Both approaches are preceded by pre-processing[1] of the satellite images and followed by post-processing of the resulting images.

4.3.1 Pre-processing

Pre-processing involves radiometric (e.g. atmospheric, topographic) and geometric (proper location) corrections of the satellite imagery, with the aim of improving the quality of the images before analysis. In addition, pan-sharpening[1] was performed for better visual interpretation.

4.3.2 Unsupervised classification

An unsupervised classification or clustering methodology does not require a-priori knowledge of the field situation and is usually used to explore the satellite image and divides the image into clusters, based on natural groupings of the spectral properties of the pixels. Those pixels that have similar values are assigned to the same cluster. Each cluster might represent one or more thematic classes, also depending on the number of classes defined. A cluster needs to be interpreted afterwards in terms of its thematic content (e.g. meaningful labels such as buildings, vegetation types, bare rock etc.).

In the present study, the unsupervised classification (or clustering) was performed using ERDAS IMAGINE (2011 version), applying the ISODATA algorithm[5].

[5] ISODATA stands for "Iterative Self-Organizing Data Analysis Technique".

4.3.3 Supervised classification

A supervised classification provides a tool for categorizing pixels using interactive supervised techniques (confirmation of categorization based on known reference points). To perform a supervised classification a number of training samples (ground truth data) of the defined thematic classes (section 4.2.) are needed. A prerequisite is that these training samples are selected with care and are as homogenous as possible in the spectral domain so that they really represent the thematic class of interest. In the present study, training samples were provided (section 3.4) of how particular classes look like in the multispectral domain, which were then used by the software algorithms to derive rules for mapping all other pixels into the class value[6].

Training samples were identified as small polygons (with a minimum area of 9 pixels) before and during the fieldwork using the original satellite image and the clusters from the unsupervised classification. In the field the polygon was checked on its homogeneity and interpreted according to one of the labels of the nomenclature (section 4.2). If the polygon was not homogeneous or did not belong to one class of the nomenclature it was not labeled. No specific GPS equipment was used in the field, besides the widely used GARMIN GPS devices. These devices have an accuracy of around 5-8 meters and might in some cases lead to a wrongly identified training sample.

Spectral overlap between some of the thematic classes is often unavoidable. A big advantage of a supervised classification is that the output classes are directly linked to a thematic class and need less interpretation afterwards.

4.3.4 Post-processing

During the post-processing the training sample labels were aggregated to the classes of the nomenclature at hierarchical level 3 (section 4.2) in ERDAS (using the recode function; raster > thematic). For each class a colour label and a class name was appointed. The result was checked through visual inspection. If necessary, recoding of specific areas using AOIs (Area of Interest) was performed. For example it became clear that too many pixels were labelled as arable fields. Since most arable fields were next to urban areas and had a rectangular shape, all other pixels with this label were recoded to herbaceous rangeland. Another example is that many bare rocky areas on the coast were classified as urban while it was clear that no built-up area or individual houses were there. Those areas were recoded to bare rocks (class. 7.2.1) using the AOI tool.

When all classes were revised a recoding was performed to the land cover classes at level 2 (section 4.2). Land cover maps up to Level 2 and up to Level 3 were maintained as results. In addition, a 3 x 3 majority filtering[1] was performed on the separate level 2 and 3 classification to reduce the “salt-and-pepper’’ effect[1].

Final classification was a result of the supervised classification and post-processing.

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[6] During the supervised classification the maximum likelihood algorithm (a Bayesian rule) was used.

5 Results

5.1 Occurrence on the islands.

An inventory was made to determine which of the chosen species and habitats were found on the three islands. Table 4 shows which of the chosen species and habitats occur on the islands.

Bonaire, Saba and St. Eustatius
The three sea turtles are found on all three islands, as is the Queen Conch. The Least tern and the Common tern are present on all the three islands, however, they have not been documented as breeding species for St. Eustatius and Saba, whereas on Saba these two species are only found on the small rocky islands in front of the coast of Saba. The Caribbean coot is known to occur on Bonaire and Saba, and is expected to occur on St. Eustatius, but is only known to breed on Bonaire. Audubon's Shearwater may occasionally nest on Bonaire, but proof is lacking (Voous, 1983). Likewise for St. Eustatius. All three islands possess coral reefs. Even though small patches of sea grass are found on Saba and St. Eustatius, the surface area present is limited. Bonaire, however, does harbour sea grass meadows.

Bonaire
The American Flamingo, the Yellow shouldered parrot and the Northern Caracara are only present on Bonaire. Northern caracaras (*Polyborus plancus*) are heavily persecuted and their numbers are diminishing rapidly (Voous, 1983). Whereas the flamingo (*Phoenicopterus ruber*) is a breeding species on Bonaire. Mangroves are also only found on Bonaire.

Table 4. *An inventory on the occurrence of the target species and habitats on the three Dutch Caribbean islands. * this species is considered a key species on the island due to its protected, endangered or breeding status.*

Inventory on the presence or absence of target species and habitats.				
Species and habitats		**Caribbean Netherlands**		
Common name	**Latin name**	**Bonaire**	**Saba**	**St. Eustatius**
Sea turtles				
Green turtle	*Chelonia mydas*	x*	x*	x*
Hawk's bill	*Eretmochelys imbricata*	x*	x*	x*
Leatherback	*Dermocelys coriacea*	x*	x*	x*
Reptiles				
Red-bellied racer	*Alsophis rufiventris*		x*	x*
Lesser Antillean green iguana	*Iguana delicatissima*			x*
Mollusc				
Queen Conch	*Strombus gigas*	x*	x*	x*
Bird species				
Caribbean coot	*Fulica caribaea*	x*	x	x
American Flamingo	*Phoenicopterus ruber*	x*		
Northern Caracara	*Polyborus plancus*	x*	x?	x?
Yellow shouldered parrot	*Amazona barbadensis*	x*		
Least tern	*Sterna antillarum*	x*	x	x
Common tern	*Sterna hirundo*	x*	x	x
Audubon's shearwater	*Puffinus iherminieri*	x*?	x	x*?
Plant species				
Morning glory	*Ipomoea sphenophylla*			x*
Habitat types				
Coral reefs	-	4372 ha.	14 ha. (Saba bank: 40 x 60 km)	180 ha.
Mangroves	-	79 ha.		
Sea grass beds	-	104 ha.	56 ha.	82 ha.

Saba & St. Eustatius
The Red-bellied racer is found on Saba and St. Eustatius.

St. Eustatius

The Lesser Antillean Green Iguana is found only on St. Eustatius. The Morning glory is endemic to St. Eustatius, and therefore only found on this island.

5.2 Eco-profiles

The Eco-profiles and an overview of the available geographical distribution data (field observations) of the different species and habitats are respectively found in Appendix A and B.

For most species and habitats, basic habitat requirements could be determined. However, for the unique and endemic Morning Glory, sparse information was available, resulting in a limited Eco-profile. For the habitats sea grasses, corals and mangroves explicit abiotic habitat requirements were sought (e.g. light, salinity, depth, temperature), in particularly regarding the three islands. In general, different ranges (salinity range, depth range) were found, which will help in determining possible areas of occurrence.

For the different species habitat requirements ranged from vegetation types (e.g. xeric scrub, mangroves, littoral woodland, fruit and flowering trees), vegetation characteristics (e.g. vegetation density or biomass), ecosystem components (e.g. sea grasses, corals, mangroves, cliffs), sediment characteristics (e.g. sand, clay, bare rock, gravel), abiotic characteristics (e.g. turbidity, salinity, temperature, water depth, light penetration, altitudes), and characteristics concerning proximity (e.g. open sea, sea grasses or fresh water in the vicinity).

In general, most habitat requirements can, to some extent, be determined using remote sensing (Guisan and Zimmerman, 2000; Guisan and Thuiller, 2005); e.g. turbidity (Moore, 1980), salinity (Lagerloef *et al*., 1995), temperature (Garcia-Santos *et al*., 2010), water depth (Ceyhun & Yalcin, 2010), light penetration (Schroeder *et al*., 2009), sediment characteristics (Sternlicht & de Moustier, 2003), ecosystem components, such as sea grasses (Dahdouh-Guebas *et al*., 1999), mangroves (Davaasuren & Meesters, 2012) and vegetation types (Helmer *et al*., 2002; 2008, Martinuzzi *et al*., 2007, Xie *et al*., 2008). Mapping of coral reef, sea grasses and algae using remote sensing is more challenging as they present similar spectral information (Mumby *et al*., 1997). It is beyond the scope of this research to want to determine the geographical ranges of these habitat requirements on the islands, other than land cover classes (e.g. salinity, etc.).

Data on the absence or presence of the different species on all three islands is limited and patchy. This coincides with earlier findings on Bonaire (Smith *et al*., 2012). Table 5 shows an overview of the threats that are associated with the different species and habitats, while table 6 shows the threats that may occur on the three islands.

Table 5. An inventory on the threats associated with the different target species and habitats.

Common name	Latin name	Coastal development / habitat loss	Human disturbances (recreation, use of the same area e.g. shipping)	Human hunting pressure (incl. egg consumption, trade, killing out of fear)	Overfishing	Litter/debris	Flooding	Logging	Roaming and (over)grazing cattle	Predation/ competition by introduced species.	Road casualties	Light sources (unnatural)	Pollution (chemical)	Sedimentation	Eutrophication	Storm & hurricanes	Acidification	Climate change (e.g. sea level rise, drought)
Sea turtles																		
Green turtle	*Chelonia mydas*	x	x	x		x	x					x	x					
Hawk's bill	*Eretmochelys imbricata*	x	x	x		x	x					x	x					
Leatherback	*Dermocelys coriacea*	x	x	x		x	x					x	x					
Reptiles																		
Red-bellied racer	*Alsophis rufiventris*	x	x	x		x				x	x							
Lesser Antillean green iguana	*Iguana delicatissima*	x		x		x			x		x							
Mollusc																		
Queen Conch	*Strombus gigas*				x	x							x		x	x		
Bird species																		
Caribbean coot	*Fulica caribaea*	x		x		x				x			x					
American Flamingo	*Phoenicopterus ruber*		x	x		x	x									x		
Northern Caracara	*Polyborus plancus*	x	x			x												
Yellow shouldered parrot	*Amazona barbadensis*	x		x		x			x	x								x
Least tern	*Sterna antillarum*	x	x	x		x	x			x			x					x
Common tern	*Sterna hirundo*	x	x	x		x	x						x					x
Audubon's shearwater	*Puffinus iherminieri*	x	x			x	x			x								x
Plant species																		
Morning glory	*Ipomoea sphenophylla*	x	x			x							x					
Habitat types																		
Coral reefs	-	x	x		x	x			x				x	x	x	x	x	x
Mangroves	-	x	x			x		x	x				x	x	x	x	x	x
Seagrass beds	-	x	x			x			x				x	x	x	x	x	x

Table 6. An inventory on the threats present on the three Dutch Caribbean islands

	Coastal development / habitat loss	Human disturbances (recreation, use of the same area e.g. shipping)	Human hunting pressure (incl. egg consumption, trade, killing out of fear)	Overfishing	Litter/debris	Flooding	Logging	Roaming and (over)grazing cattle	Predation/ competition by introduced species.	Road casualties	Light sources (unnatural)	Pollution (chemical)	Sedimentation	Eutrophication	Storm & hurricanes	Acidification	Climate change (e.g. sea level rise, drought)
Bonaire	x	x	x	?	x	x	?	x	x	x	x	x	x	x	x	?	x
Saba	x	x	x	?	x	x	?	x	x	x	x	x	x	x	x	?	x
St. Eustatius	x	x	x	?	x	x	?	x	x	x	x	x	x	x	x	?	x

5.3 Land cover classification

The landscape ecological vegetation (de Freitas *et al*., 2005, 2012, in press) distinguished vegetation types based on geology, geomorphology and vegetation. The distinguished classes, however, are heterogeneous, meaning that vegetation classes are based on the most dominant vegetation that occurs in the area, even though other vegetation types may be present. The landscape ecological vegetation maps do not include land cover classes other than vegetation. In the present study, the focus was to obtain land cover classification of the entire islands, including urban areas and agriculture.

5.3.1 Pre-processing

Pre-processing resulted in the removal of clouds and their shadows from the satellite imagery (cloud masking). This was done by a visual delineation using Area Of Interest (AOI). Cloud masking was performed to mitigate negative influences, as they negatively influence the interpretation of satellite imagery and limit land cover classification. Clouds affect atmospheric correction, limit valid land surface information, compromise the estimation of biophysical parameters, obstruct the training selection process and hinder interpretation of results (Sedano *et al*., 2011).

Land-sea masking (separating land from sea in the satellite imagery), was created from ancillary data, but needed to be improved by visual interpretations since the coastline was sometimes too coarse or wrong due to new manmade constructions on the coast (e.g. the pier in the harbour of St. Eustatius).

Atmospheric correction was performed to allow for the removal of the atmospheric effects on the measured values and to obtain the at-surface reflectance values. This resulted in a clearer and sharper satellite image. For more information on and the effect of the Atmospheric correction, see Appendix D.

Geometric accuracy of the satellite images was determined by comparing the images with the topographic information of the ancillary data (see 3.3). The satellite images fitted reasonably well, although some shifts of a few meters were sometimes visible. It should be noted, that the ancillary data itself already appears to show major geometric shifts between other sources. For example common data from vegetation maps do not match with cadastral data. In Appendix D. the geometric accuracy of the satellite data is illustrated.

Pan-sharpening resulted in a clearer presentation of the different structures on the satellite images and a better spatial resolution, making it possible to distinguish more details. This will contribute to a better identification of objects (or classes) during visual interpretation of the land cover classification. In Appendix D pan-sharpening is illustrated.

Terrain (topographic) corrections of the satellite images were not possible due to lack of a High Resolution Digital Elevation Model (HR DEM, with a high spatial accuracy of around 1 meter). A DEM is a digital representation of the terrain elevations found on the islands and enables to have a better understanding of the terrain. For example, to distinguish which areas lie downstream from other areas. During the present study two DEMs were considered (ASTER DEM and DOTKA Data). However, these turned out not to be sufficient. For more information on the two DEMs see Appendix D.

Both Saba and St. Eustatius exhibit strong differences in altitude. As a result, a lot of shadowing effects are visible on the satellite images. Satellite imagery often contain shadows, due to the topography of the terrain or the sun's angle. Similar to clouds and their shadows, shadowed areas due to topographic features display reduced values of reflectance compared to non-shadowed areas with similar surface cover characteristics (Giles, 2001). The shadows impede the identification of the land cover types underneath. By removing or reducing the shadow in a terrain correction model, a more precise identification of the land cover types can be obtained. Due to the lack of an appropriate HR DEM, the negative influences as a result of strong differences in altitude were not mitigated. As a result, shadowed areas on the satellite images impeded the proper classification of land cover types in those areas.

5.3.2 Unsupervised classification

The unsupervised classification of the multispectral WV-2 images of Saba and St. Eustatius yielded output images with a number of 20 and 50 classes identified and each pixel of the image assigned to a class.

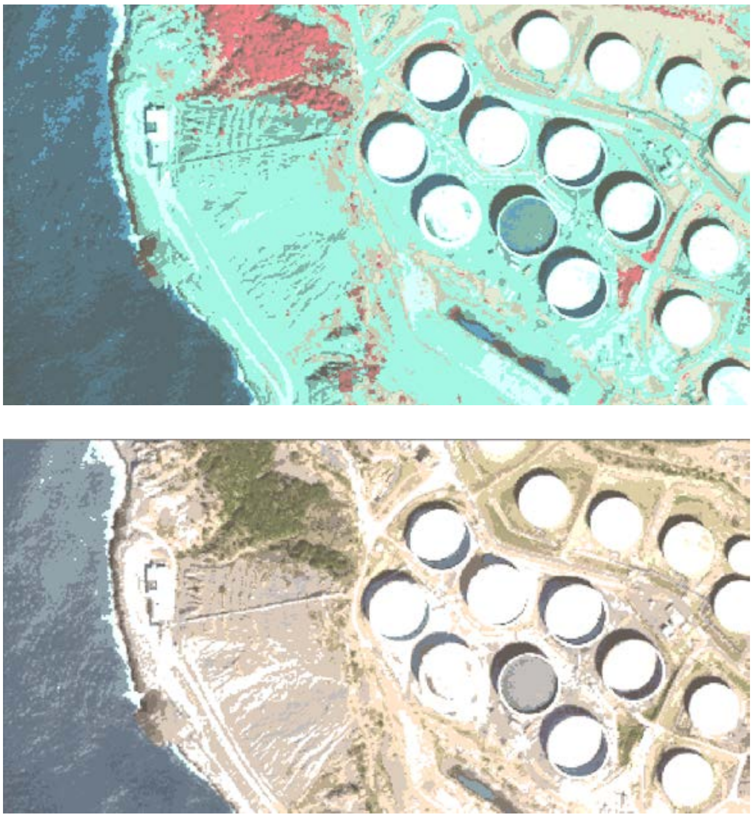


Figure 3. The unsupervised classification of a part of St. Eustatius (zoomed in) with 20 classes (above) and with 50 classes (below).

The unsupervised classification with 50 classes shows more spectral detail than the unsupervised classification with 20 classes (figures 3). Twenty classes represented more or less the number of thematic classes (e.g. vegetation types, buildings, bare rock etc.) which might be distinguished for each island. However, due to a strong spectral variation in each thematic class, especially due to strong shadowing effects in each targeted class caused by strongly undulated terrain, 50 cluster seems to be a better output. Each of the 50 cluster was interpreted in terms of its thematic content, e.g. vegetation types, buildings, bare rock etc. Many classes showed a strongly dispersed character (not characterised by one typical reflectance), or had spectral overlap with other thematic classes.

For example, the white tops of breaking

waves and the white storage tanks on St. Eustatius are classified/grouped into the same land cover type/class. Even though these are completely different thematic classes, water vs. industrial material, pixels related to these object were assigned to the same classes because of spectral overlap (both highly reflective, figure 3). Also bare rock and gravel pavement do not show difference in thematic detail on the imagery, compared with heavily shadowed areas due to strongly undulated terrain.

Appendix E. gives the thematic interpretation of the 50 clusters for Saba and St. Eustatius. This exploration phase was necessary to explore what range of thematic classes would be feasible for the nomenclature as defined in section 4.2. The spectral clusters were used as the spatial domains in which individual training samples needed to be identified for the supervised classification.

5.3.3 Final classification

Trainings samples

For St. Eustatius, 90 polygons were selected for ground truth data. An additional 14 areas were selected in the field, where specific homogeneous land cover or vegetation classes were encountered. This resulted in a total of 104 areas to identify. However, 33 areas were not possible to visit for identification due to the roughness and inaccessibility of the terrain. In addition, GPS points with uncertain identification were discarded. In the end, 74 areas were labeled in the field and used in the signature file during supervised classification. The signature file shows the subset of cells that are representative of a class or cluster (signature). See Appendix G for the used training samples. Often more than 1 training sample was used for a specific thematic class.

For Saba, 57 polygons were initially chosen for ground truth data. An additional 11 areas were selected in the field, resulting in a total of 68 areas to identify. The roughness and inaccessibility of the terrain or uncertainty concerning the correct location prohibited the identification of 21 areas. For Saba, 45 areas were used as training samples in the signature file during the supervised classification (Appendix G).

The signature files were used to run a maximum likelihood supervised classification for both Saba and St. Eustatius. The output is a thematic raster file with respectively 74 labels for St. Eustatius and 45 labels for Saba. During post-processing the labels were regrouped according to the nomenclature (section 4.2), because many labels belonged to the same class. Often the different training samples for one land cover class or vegetation class are grouped already in the signature editor. However, grouping should only be done when all training samples have the same quality. For this reason it was decided to do the grouping of the samples according to the legend in the post-processing stage.

Land cover maps

The final classification (supervised classification combined with post-processing) resulted in a land cover map for each island (see figures 4 to 7). The chosen classes in the legends correspond to the nomenclature at hierarchical level 2 and 3 (section 4.2.).

During the present study, a rough distribution of land cover classes can be identified using remote sensing techniques and satellite data. Subsequently, visual interpretation and correction is needed for fine-tuning. The land cover maps give a reasonable approach of the present field situation, in particular for the classes Forest (broadleaved evergreen, broadleaved semi-evergreen and deciduous), Rangeland (herbaceous rangeland and thorn scrub) and Agricultural areas (pastures). The extent of these three classes correspond with the field situation. For all classes at Level 2, the surface and percentage across the islands were calculated (Tables 7 and 8). The location and extent of invasive species (Artificial non-agricultural vegetated areas) correspond reasonably well with the field situation. However, identification to species level was not possible due to spectral overlap. The identification of invasive species in Figure 4 and 6 are therefore not correct and can therefore represent several invasive vegetation species. To determine which specific invasive species is found on location, identification in the field is necessary.

During the present study, it was not possible to distinguish specific land cover types related to vegetation (e.g. Montane thicket, Elfin forest, Thorny woodland etc.) as a result of spectral confusion. More trainings samples are necessary, to distinguish between the different vegetation types. Unfortunately, only a limited number of trainings samples were available during this study.

Table 7. The surface area (ha.) and percentage representing the island of the different classes of St. Eustatius satellite image. (Note: Sea and Nodata are included resulting in a higher surface area than the surface area of the island, approx. 2100 ha.)

Class	Legend Nr.	Class Names (Level 2)	Histogram	Area (ha)	Perc (%)
1	11	Urban fabric	68779	27.5	0.2
2	12	Industrial, commercial and transport units	200754	80.3	0.7
3	14	Invasive species	145810	58.3	0.5
4	21	Arable land	9026	3.6	0.0
5	23	Pastures	350246	140.1	1.2
6	31	Herbaceous rangeland	141600	56.6	0.5
7	32	Shrub and bush rangeland	1595726	638.3	5.3
8	41	Forest broadleaf evergreen	351423	140.6	1.2
9	42	Forest broadleaf deciduous	919	0.4	0.0
10	46	Forest broadleaf semi-evergreen	1483850	593.5	4.9
11	51	Inland waters	1749	0.7	0.0
12	52	Sea	24908459	9963.4	82.5
13	71	Beaches, sand, dunes	31446	12.6	0.1
14	72	Bare rocks	299360	119.7	1.0
15	73	Sparsely vegetated	46159	18.5	0.2
16	99	No data	546688	218.7	1.8
			30181994	12072.8	100

St. Eustatius
St. Eustatius has a land surface area of 2100 hectares, however due to cloud cover only 1890.7 ha was classified during this study (12072.9 ha includes 'No data' and 'Sea'). According to the land cover map 166.1 ha (1.4% of the satellite image, 8.8% of the classified area (1890.7 ha)) consists of artificial surfaces such as road, buildings and invasive species, 143.7 ha (1.2%; 7.6%) out of agricultural areas (pastures and arable land), 694.9 ha. (5.8%; 36.8%) out of range land, 734.5 ha. (6.1%; 38.8%) out of forest land and 150.8 ha. (1.2%; 8.0%) out of barren land, such as bare rock, beaches etc. 9964.1 ha (82.5 %; 0.0%) consisted of waters (sea and inland waters).

Helmer *et al.*, 2008 estimated the extent of land cover and how it changed over the second half of the 20th century for four islands of the Lesser Antilles, including St. Eustatius. During this study, they calculated the surface area of the different classes they found. Appendix H. compares the classes and surfaces area of that study with the present study. The table also shows which land cover classes from the previous study coincide with the present study. High-medium and low density urban or built-up land represent areas that consist > 15% of manmade structures, which reasonable coincides with the land cover classes *Discontinuous urban fabric*, *Industrial and commercial units*, *Road and rail networks and associated land* and *Airport*, in the present study. More of a challenge was matching the vegetation cover classes. As the land cover classes *Herbaceous rangeland* and *Thorn scrub,* in the opinion of the authors, related more to grassy/shrubby areas, these land cover classes were matched with the land cover class *Pasture, Hay and Grassy areas* of Helmer *et al*., 2008.

As mentioned before, during the present study it was not possible to distinguish different forest types from each other. Therefore, al forest land cover classes were matched as a group with the forest land cover classes of Helmer *et al*., 2008. The invasive species were included as they often occur in forest areas. The *No vegetation* class of Helmer *et al*., (2008) coincided with the *Barren land* class of this study.

Compared to Helmer *et al*., (2008) it appears that the surface area for the land cover classes Urban, Forest, and Barren land have decreased since 2008. While the surface area for Pastures has increased. However, multiple factors may explain this situation. It is possible that Forest areas gradually made a transition to Pastures due to overgrazing or other causes, however, the transition of Urban or Barren land into Pastures is unlikely. More likely, it is the influence of cloud cover in the satellite images, prohibiting the classification of these areas. The clouds in the satellite image of St. Eustatius cover a part of Oranjestad (Urban) and it's coast (Barren land) and a large part of the Quill (forest), which may explain the decreased surface area of the land cover classes Urban, Forest and Barren land. Another cause, can be the slight mismatch of the land cover classes of the two studies. For example, in the present study, the barren soil found within the industrial area of the oil storage drums was included in the land cover class *Urban fabric* and not within the class *Barren land*.

Figure 4a shows the land cover map for St. Eustatius at level 3. Figure 4b. shows a part of St. Eustatius for more detail (zoomed-in, at level 3). Figure 5 shows the land cover map for St. Eustatius at level 2. The 74 labels were regrouped into 21 different classes (Level 3) or 16 different classes (Level 2) including a class 'No data'. The land cover map covers the entire island, except for the areas influenced by clouds or their shadows (the four black areas).

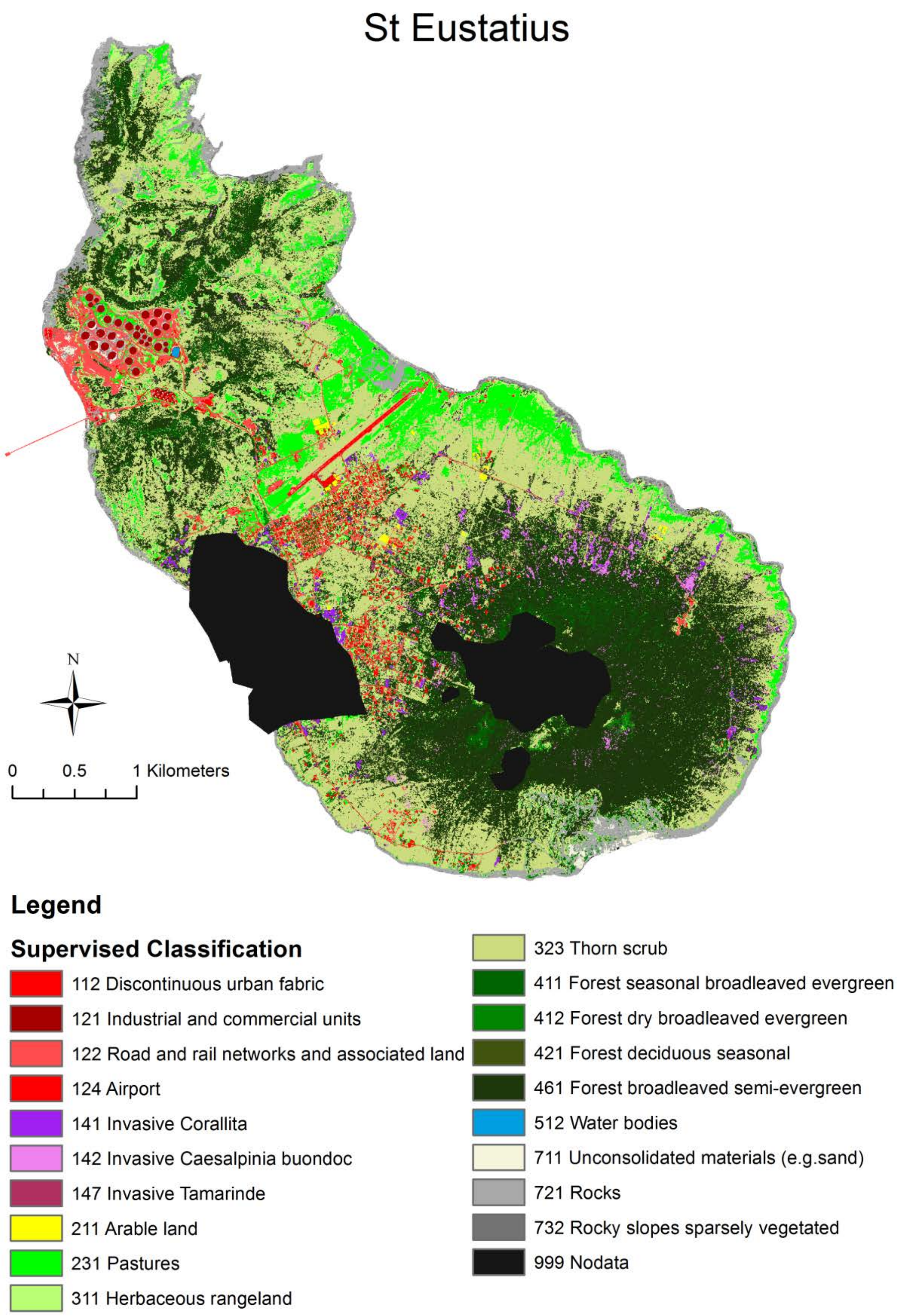


Figure 4a. A land cover map for St. Eustatius (Level 3).

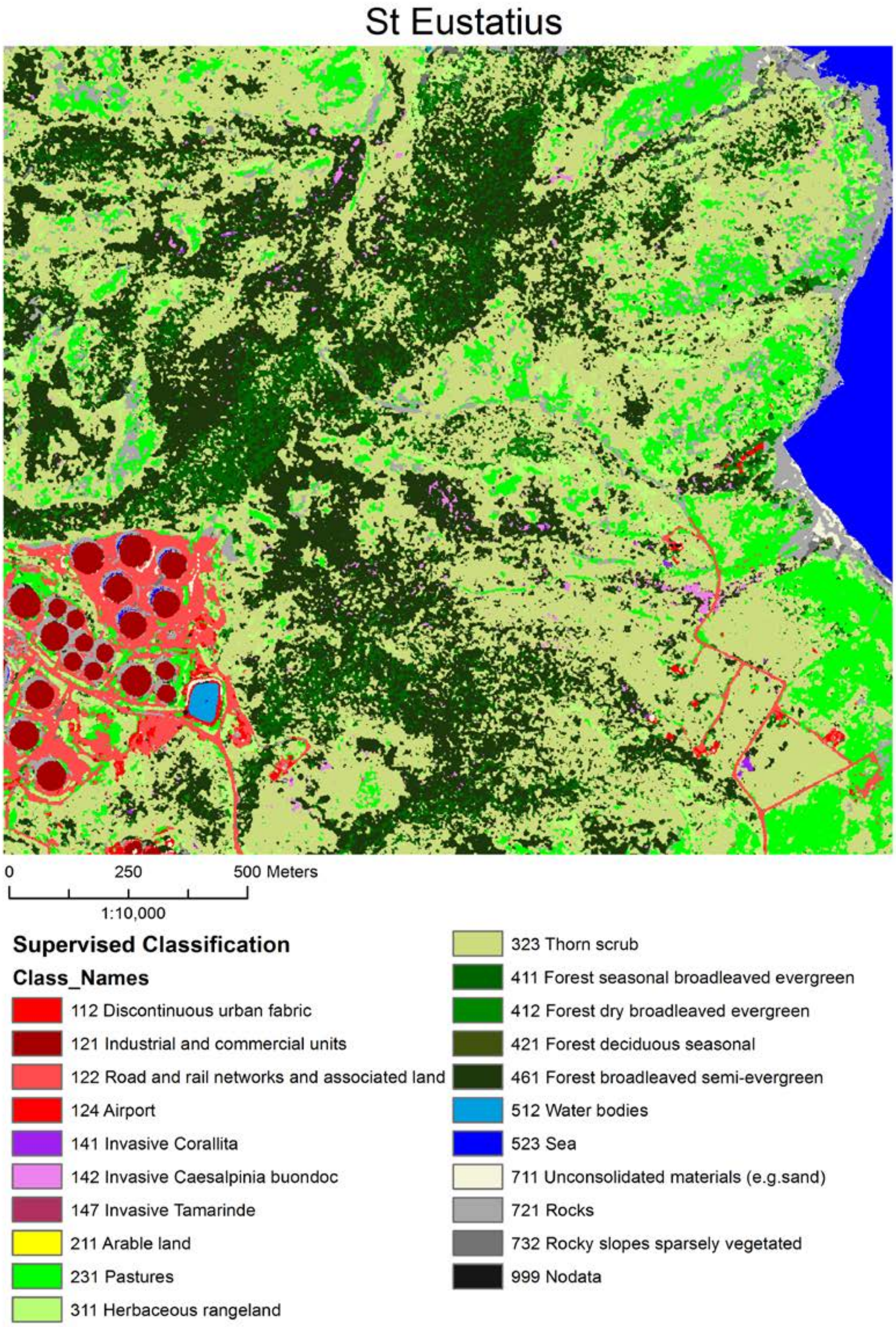


Figure 4b. Detail of the land cover map for St. Eustatius (Level 3)

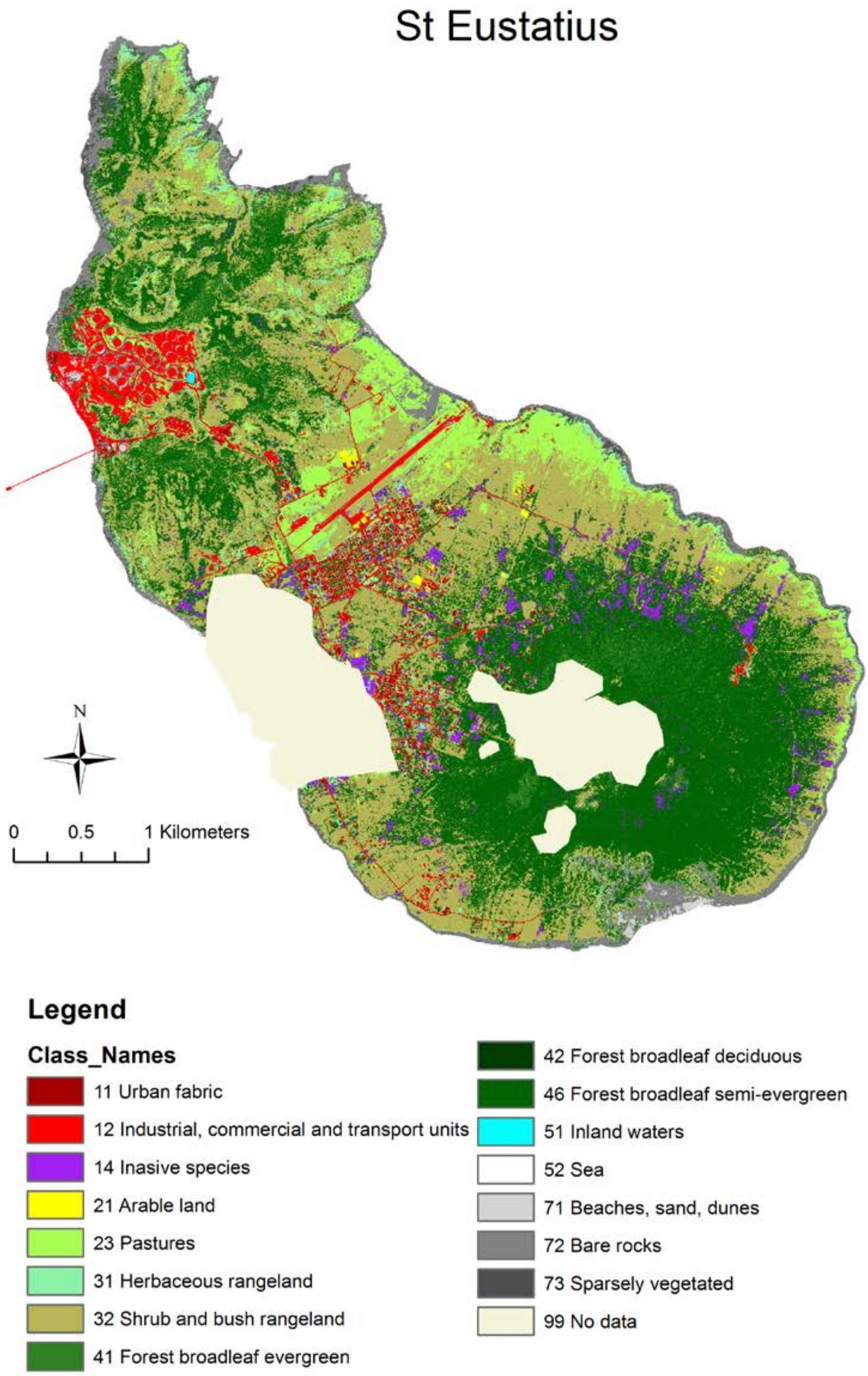


Figure 5. A land cover map for St. Eustatius (Level 2).

Saba

Figure 6a. shows the land cover map for Saba according to the nomenclature at hierarchical level 3, with Figure 6b. showing a part of Saba (zoomed-in). Figure 7 shows the land cover map of Saba at Level 2. The 45 labels, that resulted from the supervised classification, for Saba were regrouped into 16 classes (Level 3) or 14 classes (Level 2). In the below left corner of the image a part of the island exhibits No data as a result of cloud cover.

Table 8. The surface area (ha.) and percentage representing the island of the different classes of Saba at Level 2, including 'Sea' and 'No data'.

Class	Legend Nr.	Class Names Level 2	Histogram	Area (ha.)	Perc. (%)
1	11	Urban fabric	85413	34.2	0.4
2	12	Industrial, commercial and transport units	25654	10.3	0.1
3	13	Mine, dump and construction sites	53	0.0	0.0
4	14	Invasive species	978	0.4	0.0
5	23	Pastures	513940	205.6	2.7
6	31	Herbaceous rangeland	23192	9.3	0.1
7	32	Scrub and bush rangeland	189158	75.7	1.0
8	41	Forest broadleaf evergreen	109990	44.0	0.6
9	42	Forest broadleaf deciduous	97911	39.2	0.5
10	46	Forest broadleaf semi-evergreen	1566631	626.7	8.2
11	52	Sea	14654307	5861.7	76.9
12	71	Beaches, sand, dunes	29026	11.6	0.2
13	72	Bare rocks	453912	181.6	2.4
14	99	No data	1306613	522.6	6.9
			19056778	7622.7	100.0

Table 8. shows the surface area of each land cover class for Saba. The total surface area of Saba is 1300 ha. Due to cloud cover only 1238.4 ha was classified during this study (7622.7 ha includes 'No data' and 'Sea'). According to the developed land cover map 44.8 ha (0.6 % of the satellite image; 3.6 % of the classified land (1238.4 ha)) consists of artificial surfaces such as roads, buildings and invasive species, 205. 6 ha (2.7 %; 16.6 %) out of agricultural areas (pastures and arable land), 84.9 ha. (1.1 %; 6.9 %) out of range land, 709.8 ha. (9.3 %; 57.3 %) out of forest land and 193.2 ha. (2.5 %, 15.6 %) out of barren land, such as bare rock, beaches etc. 5861.7 ha (76.9 %; 0.0%) consisted of sea water.

Invasive species

During the collection of the trainings samples, a few locations were included that exhibited large patches of invasive flora species growth. On St. Eustatius, three invasive flora species were encountered; Corallita (*Antigonon leptopus*), Yellow Nicker (*Caesalpinia buondoc) and Leucaena leucocephala.* On Saba, the three invasive species Corallita (*Antigonon leptopus*), Elephant ear (*Philodendron giganteum*) and Rubber vine (*Cryptostegia grandiflora)* were encountered.

Antigonon, *Leucena* and *Caesalpinia* are creepers, that grow on top of existing vegetation. The Elephant ear (*Philodendron giganteum*) is a thicket that grows on the ground, and therefore under the canopy layer. Consequently, this invasive species may be less detectable on satellite images. On St. Eustatius, the invasive species found in the Northern hills, is mainly *Leuceana*. *Antigonon* does not occur in the northern hills. Once *Antigonon* has established, it is almost impossible to remove it (unless the area is bulldozed for construction or agriculture). It is a fast growing species and can overgrow other vegetation within several months. In addition *Antigonon* and *Caesalpinia* occur mainly where there is erosion or human disturbance (i.e. risk areas for these two species).

Based on expert judgement, the appointment of the different invasive species appear not to be correct. The spectral signature of the different invasive species do not seem to be sufficient to distinguish them from each other. The classification of different invasive species in Figures 4 and 6 (Level 3) is therefore not correct. For the invasive species it is only possible to classify up to Level 2 (Figures 5 and 7). It depends per thematic class which land cover map (Level 2 or Level 3) shows the situation closest to that found in the field.

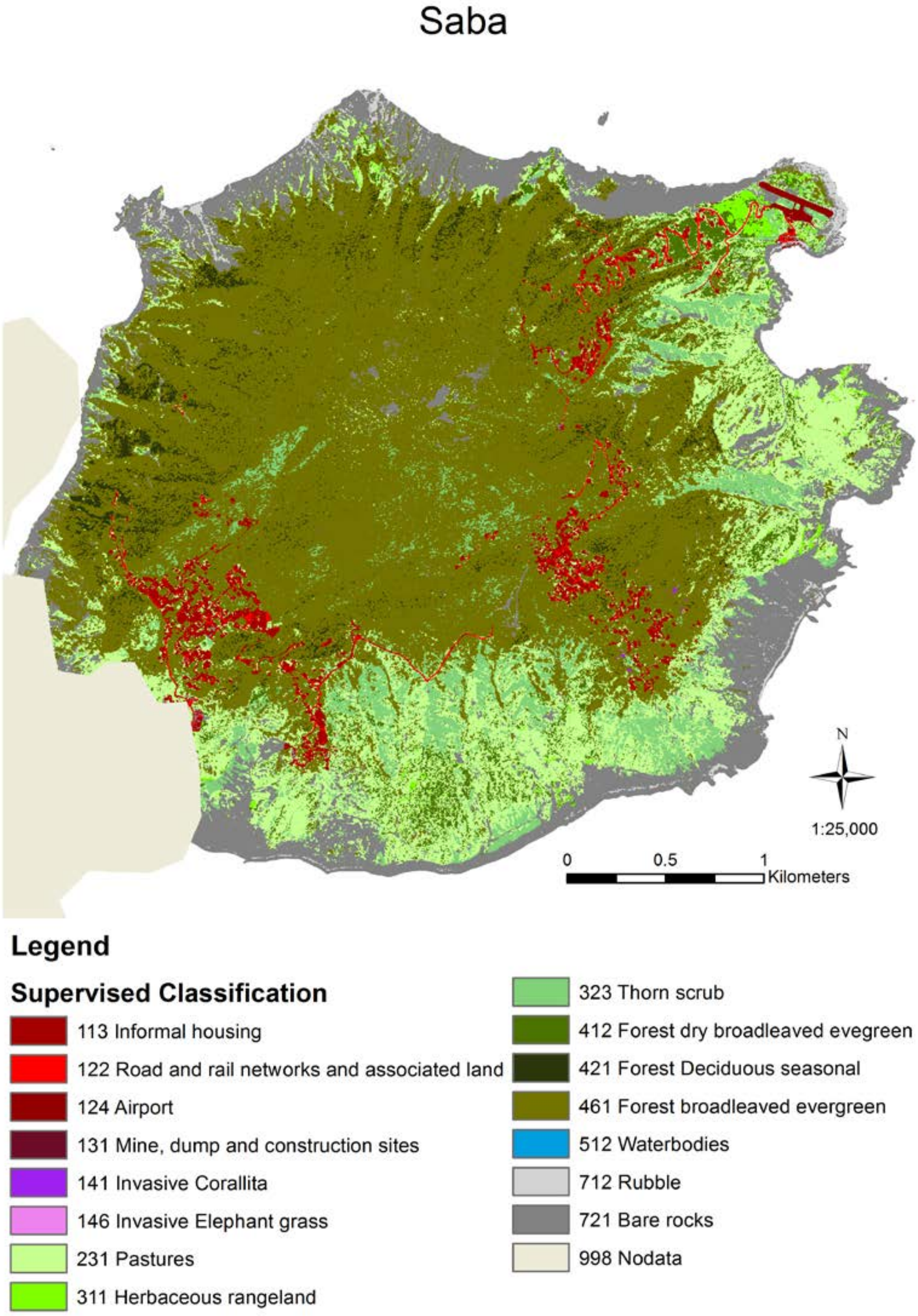


Figure 6a. A land cover map of Saba (Level 3)

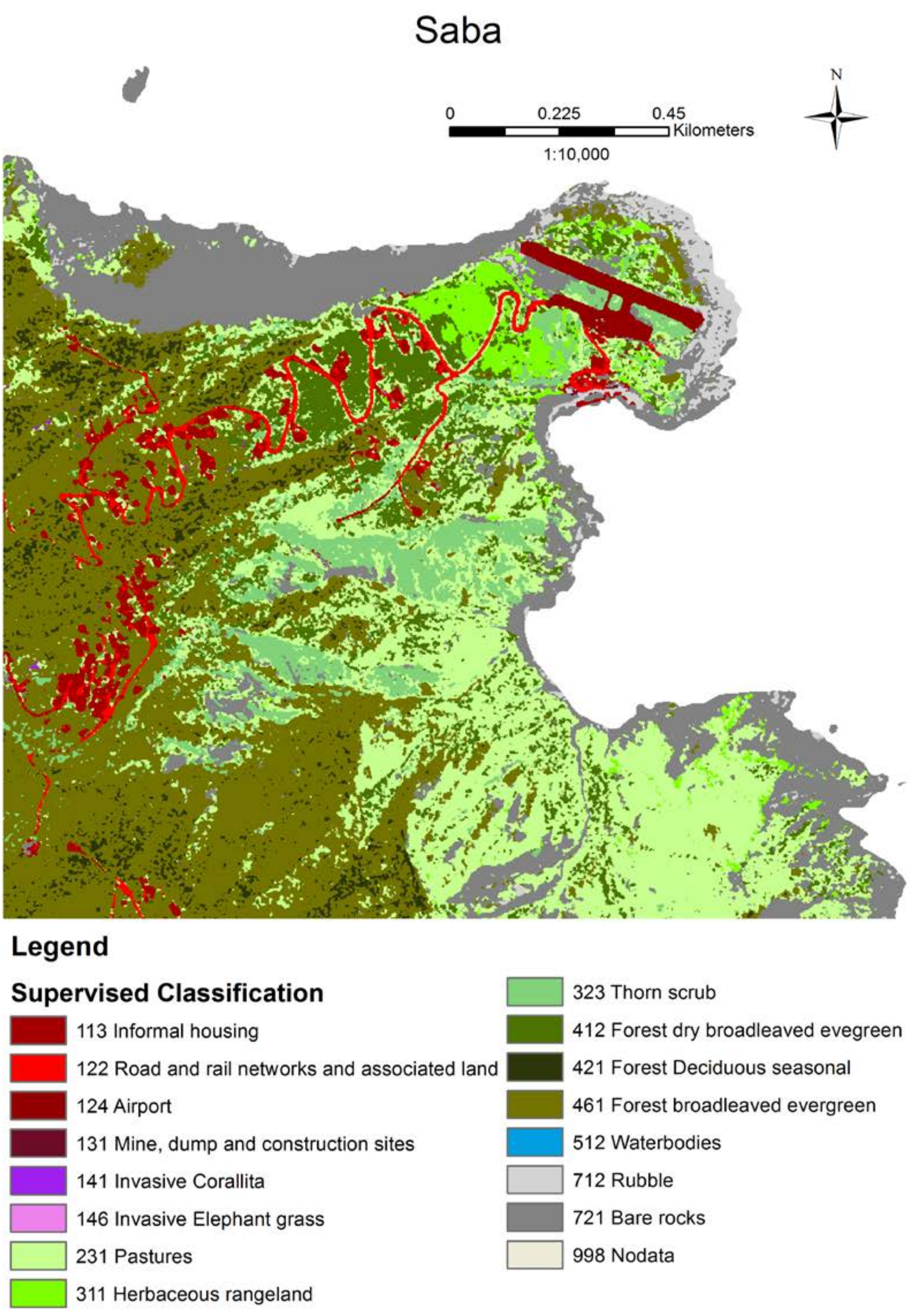


Figure 6b. Detail of the land cover map for St. Eustatius (Level 3)

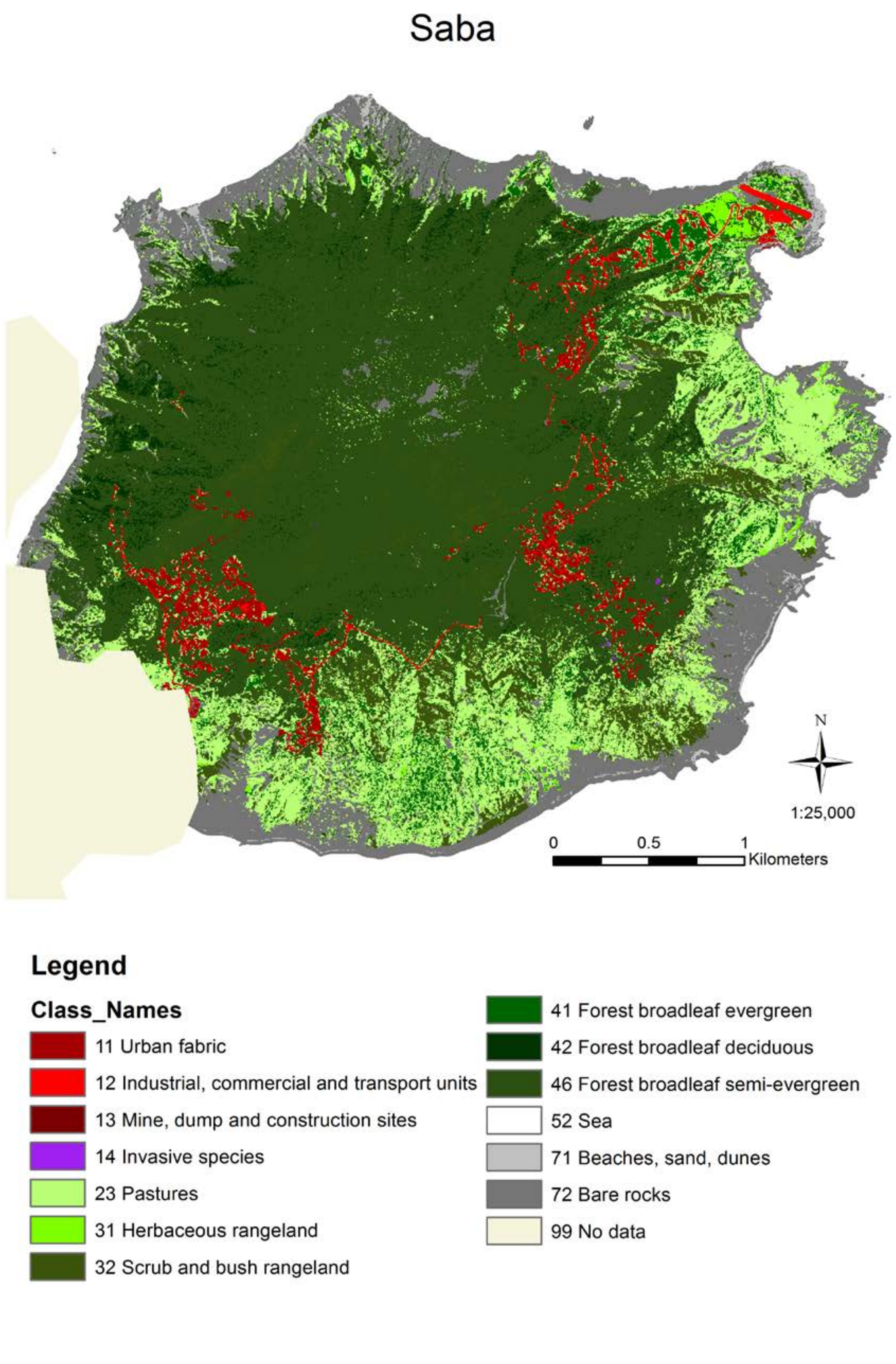


Figure 7. The land cover map of Saba (Level 2)

6 Discussion

Satellite images were successfully used to classify vegetation and urban areas on Saba and St. Eustatius. The land cover maps produced, corresponded reasonably well with the distribution of the land cover types found in the field and provided a representation of the distribution of Forest, Shrub, Pasture and Artificial surface on the islands. The maps, in particularly for St. Eustatius, provide a relatively good representation of the location of invasive species on the islands, which is useful for monitoring the expansion and trends of these invasive flora species. A more detailed classification of the vegetation types (e.g. species-level) was not possible during the present study. This corresponds with previous studies in the Caribbean (Helmer *et al*., 2002, 2008, Martinuzzi *et al*., 2007) where the identification of detailed vegetation types using satellite imagery seems to be a challenge. This is a result of the heterogeneous vegetation found on the islands. The vegetation consists of a great variety of plant communities which are very mixed and rarely homogeneous. With homogeneous vegetation it is easier to identify the various vegetation classes based on their spectral signature. The mixed vegetation (heterogeneous) results in different vegetation types having similar spectral signatures, making it difficult to distinguish one from the other. The use of Very High Resolution satellite imagery alone does not seem to be sufficient to identify different vegetation types in detail. Helmer *et al*., (2002) propose to spectrally segment images and then use the ancillary variables, such as topography, temperature, rainfall etc. to separate spectrally similar classes, to mitigate spectral confusion. Geographic data ancillary to satellite imagery is therefore important when it comes to mapping natural vegetation types in the Caribbean (Helmer *et al*., 2002). During the present study, the use of cadastral or topographic maps was missing as a basis for a good land cover classification. The geographic accuracy of the ancillary information (vegetation maps) that was available should be improved before it can be integrated with the high resolution satellite imagery. The distinction between individual species will in most cases not be realisable. But identifying dominant species could be possible if multiple satellite images are available and analysed. Multiple satellite images in a year reveal the specific phenology of the vegetation type in different seasons (tropics: before and after the rainy season).

The strong differences in altitude on Saba and St. Eustatius result in numerous shadowed areas, that impede the identification of the land cover types underneath. A Digital Elevation Model (preferably with a high spatial accuracy of around 1 meter) for Saba and St. Eustatius is essential to perform topographic correction (e.g. removal of shadows). It is expected, that with such a Digital Elevation Model, a more accurate land cover map can be achieved. Unfortunately, such a DEM was not available during the present study. A good option may be the TanDEM-X (German observation satellite). Unfortunately, the TanDEM-X is not yet completely ready. The DEM of the Earth's surface will be built up over three years of joint operations. Ultimately, it should have a vertical resolution of 1-2m and a spatial resolution of 12m - far superior to any previous global data set. It is expected that a DEM is more crucial for Saba and St. Eustatius compared to Bonaire, as Bonaire has less differences in altitude.
It should be noted that the satellite images were classified (supervised classification) based on training samples collected in the field. The satellite images were not acquired in the same period (year) as the training samples (collected in the field during the project). This difference can lead to discrepancies between the satellite images and the field situation. For example, invasive species found on a specific location in the field, may not be found on the satellite images taken a few months or years earlier.

The choice was made to focus on the islands Saba and St. Eustatius as they are the two smaller islands of the three and up to date training samples for these islands were readily available. An image of Bonaire could not be analysed due to time constraints and lack of ground truthing data. In addition, the shallow waters around the islands Saba and St. Eustatius were not included in this classification as the classification of these areas are part of an internship by a MSc. student at Alterra.

Ecoprofiles were developed for various species and habitats, describing their habitat requirements. With sufficient detail, these requirements link the species to habitats and thereby allow for the creation of species specific maps. The level of available data on habitat requirements varies per species. Overall knowledge on habitat requirements is generally not sufficient, associating species with multiple habitat types, and making it difficult to pinpoint essential habitat types. The use of satellite imagery for geographical monitoring of key species and habitats depends on:

- the available knowledge on habitat requirements of key species and habitats;
- the quality of the available imagery and land cover classification.

The amount of knowledge on habitat requirements has direct influence on the success of niche modelling. This illustrates the necessity of detailed knowledge on species biology, ecology and life history characteristics even when using advanced techniques such as remote sensing.

The production of maps through niche-modelling, to show the expected geographical distribution of species and to determine expected threats and risk locations, was not possible due to the limited level of detail within the identified land cover types and the restricted data on the habitat requirements of the species occurring on Saba and St. Eustatius.

The identification of habitat requirements does require a precautionary approach, when linking species to specific flora species or vegetation types. The high occurrence of a species within a specific vegetation type, does not automatically indicate that this vegetation type is the most preferred habitat. Possibly the most preferred vegetation type is no longer available on the island. As a result, the species is forced to choose a different (less favourable) habitat. When identifying the habitat requirements based on the habitat where it is found, it is possible that the wrong habitat requirements are identified. Therefore, habitat requirements should be based on data from the whole geographic extent where the species can be found. Likewise, when linking a species to a habitat based on its habitat requirements, it is not yet guaranteed that the species is found in all areas on the island where this habitat occurs. Other factors, e.g. anthropological and climate disturbances, may prevent their presence at a certain location. Therefore the creation of habitat maps based solely on the species' habitat requirements will generally overestimate the areas where it will occur.

When it is possible to generate probability maps for the presence of key species and habitats, they provide the 'expected' geographical distribution. Field monitoring will still be necessary for ground truthing, amongst others:

- to confirm actual presence of the species;
- to obtain data on species numbers;
- to obtain data on habitat or population quality;
- to include other variables into species distribution models.

The probability maps can provide focus and cost reductions in the necessary additional field monitoring.

7 Conclusions

- The produced land cover maps give a representation of the distribution of Forest, Shrub, Pasture and Artificial surface on the islands.
- On the maps it was possible to identify the extent and location of invasive vegetation (e.g. Corallita and other species), although identification to species-level was not possible.
- The produced maps could be used to monitor different land cover development (e.g. forestation, artificial surfaces, shrub and pastures) on the long term (e.g. in years) or to gain a quick overview on the location of invasive vegetation.
- At present, these maps provide insufficient detail for biodiversity monitoring, because of the lack of connection with species.
- The available data on the distribution of key species and habitats on the islands Saba and St. Eustatius is limited.
- The production of maps through niche-modelling, to show the expected geographical distribution of species, was not possible due to the limited level of detail within the identified land cover types, and the restricted data on the habitat requirements of the species occurring on Saba and St. Eustatius.
- The amount of knowledge on habitat requirements has direct influence on the success of niche modelling. This illustrates the necessity of detailed knowledge on species biology, ecology and life history characteristics (baseline studies) even when using advanced techniques such as remote sensing.
- Field observation will remain necessary for ground truthing.

8 Recommendations

In general

- Baseline studies on the distribution of key species and habitats on the three islands Bonaire, Saba and St. Eustatius. As remote sensing analysis of the satellite images of Saba and St. Eustatius still requires fine-tuning, complementary baseline studies are still necessary to gain a better understanding of the whereabouts, abundance and (population) quality of these key species and habitats. Such baseline studies can provide ground truthing data.
- Baseline study on species biology, ecology and life history characteristics of the key species on Saba and St. Eustatius, amongst others to explicitly identify habitat requirements of these species.
- A distribution atlas of key species found on the islands of the Caribbean Netherlands, based on the above mentioned baseline studies. Such an atlas would be of value for all three islands, especially concerning the identification of conflict areas during spatial planning and socio-economic development.
- Use of a Digital Elevation Model with a high spatial accuracy of around 1 meter. Such a DEM is not yet available, but investing in such a DEM can be useful in many different studies (e.g. on geomorphology, hydrology, soil surveys, vegetation mapping etc.)

Specific recommendations for continued remote sensing analysis of satellite images of Saba and St. Eustatius.

- Use of multi-temporal satellite imagery to reveal phenology of vegetation, allowing for the identification between evergreen and deciduous vegetation types.
- Measurements with field spectrometer to reveal the absorption characteristics of the different vegetation types, allowing for the identification between different vegetation types.
- Integration of the satellite imagery with topographic or cadastral maps in the process of land cover classification.
- More time for visual and object-oriented classification methods.
- Use of a Canopy Height Model (CHM) as derived from LiDAR (laser altimetry) or stereoscopic aerial photographs to complement the spectral information to characterize vegetation types.
- Limit the period of time between the acquisition of satellite imagery and the collection of ground truthing data.

9 References

Arengo, F., G. Baldassarre, 1998. Potential food availability and flamingo use of commercial salt impoundments in the Ria Lagartos Biosphere Reserve, Mexico. Colonial Waterbirds, Vol. 21, 2; 211-221.

ASTER GDEM Validation Team - T. Tachikawa, M. Kaku, A. Iwasaki, D. Gesch, M. Oimoen, Z. Zhang, J. Danielson, T. Krieger, B. Curtis, J. Haase, M. Abrams, R. Crippen, C. Carabajal (ASTER GDEM Validation Team), 2011. ASTER Global Digital Elevation Model Version 2 – Summary of Validation Results. Compiled by Dave Meyer4 on behalf of the NASA Land Processes Distributed Active Archive Center and the Joint Japan-US ASTER Science Team.

Baldassarre, G.A., F. Arengo, 2000. A review of the ecology and conservation of Caribbean Flamingos in Yucatan, Mexico. Waterbirds: The international Journal of Waterbird Biology, Vol. 23, Special Publication 1: Conservation Biology of Flamingos (2000); 70-79.

Barnes, J.R., 2007. An intergrative approach to conservation of the crested caracara (Caracara cheriway) in Florida: linking demographic and habitat modeling for prioritization. Dissertation. Graduate college of Bowling Green.

Barnes R.S.K., R.N. Hughes, 1999. An introduction to Marine Ecology, 3rd edition. Blackwell Science Ltd.

Berkel, 2009. St. Eustatius National Parks foundation Sea turtle Conservation Program – STENAPA Annual report 2009.

BirdLife International 2012a. *Phoenicopterus ruber*. In: IUCN 2012. IUCN Red List of Threatened Species. Version 2012.2. <www.iucnredlist.org>. Downloaded on 30 January 2013.

BirdLife International 2012b. *Fulica caribaea*. In: IUCN 2012. IUCN Red List of Threatened Species. Version 2012.1. <www.iucnredlist.org>. Downloaded on 04 October 2012.

BirdLife International 2012c. Puffinus lherminieri. In: IUCN 2012. IUCN Red List of Threatened Species. Version 2012.2. <www.iucnredlist.org>. Downloaded on 30 January 2013.

BirdLife International 2012d. Sterna antillarum. In: IUCN 2012. IUCN Red List of Threatened Species. Version 2012.2. <www.iucnredlist.org>. Downloaded on 30 January 2013.

BirdLife International 2012e. *Sterna hirundo*. In: IUCN 2012. IUCN Red List of Threatened Species. Version 2012.2. <www.iucnredlist.org>. Downloaded on 29 January 2013.

BirdLife International 2012f. *Amazona barbadensis*. In: IUCN 2012. IUCN Red List of Threatened Species. Version 2012.2. <www.iucnredlist.org>. Downloaded on 13 February 2013.

Breuil, M., Day, M. & Knapp, C. 2010. Iguana delicatissima. In: IUCN 2012. IUCN Red List of Threatened Species. Version 2012.2. <www.iucnredlist.org>. Downloaded on 14 November 2012.

Brown, A., N. Collier, A. Debrot, A. Del Nevo, J. Wells, 2009. Dutch Caribbean, pp 179-188 in C. Devenish, D.F. Diaz Fernandez, R. P. Clay, I. Davidson, L. Yépez Zabala Eds. Important Bird Areas Americas – Priority sites for biodiversity conservation. Quito, Ecuador: Birdlife International (Birdlife Conservation Series no. 16).

Buchan, K., http://www.unesco.org/csi/pub/papers/buchan.htm

Büttner, G., Feranec, J., Jaffrain, G., Mari, L., Maucha, G., & Soukup, T. (2004). The CORINE land cover 2000 project. In R. Reuter (Ed.), EARSeL eProceedings, Vol.3 (pp. 331–346). Paris: EARSeL, 3.

Carreker, R.G. 1985. Habitat suitability index models: Least tern. U.S. Fish Wildl. Serv. Biol. Rep. 82(10.103). 29 pp.

CAR-SPAW-RAC, 2012. www.car-spaw-rac.org

Ceyhun, O., A. Yalcin, 2010. Remote sensing of water depths in shallow water via artificial neural networks. Estuarine, coastal and shelf science, 89. 89-96. DOI:10.1016/j.ecss.2010.05.015

CMFC – Caribbean Fishery Management Council, 1996. Fishery Management Plan, Regulatory Impact Review and Final environmental impact statement for the Queen Conch resources of Puerto Rico and the U.S. Virgin Islands. http://www.strombusgigas.com/qcpdfs/qconch%20plan.htm

CMS, 2012. Convention on Migratory Species, www.cms.int/

Collier, N., A. Brown, 2006. Waterbirds in Sint Eustatius (Statia). Waterbird Conservation for the Americas.

Collier, N., A. Brown, 2009. Waterbirds in Saba. Final Report Waterbird conservation for the Americas.

Collier and Brown, 2008. Important Bird Areas St. Eustatius. In Wege, D. C. and Anadon-Irizarry, V. (2008) Important Bird Areas in the Caribbean: Key Sites for Conservation. BirdLife International.

Costanza, R., R. d'Arge, R. De Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R.V. O'Neill, J. Pareulo, R.G. Raskin, P. Sutton, M. van den Belt, 1997. The value of the world's ecosystem services and natural capital. Nature, Vol. 387, 1997.

Dahdouh-Guebas, F., E. Coppejans, D. Van Speybroeck, 1999. Remote sensing and zonation of seagrasses and algae along the Kenyan coast. Hydrobiologia 400, 63-73, 1999.

Davaasuren, N., H.W.G. Meesters, 2012. Extent and health of mangroves in Lac Bay Bonaire using satellite data. IMARES report number C190/11.

Davis, J.E., 2003. Population assessment of Queen Conch, *Strombus gigas*, in the St. Eustatius Marine Park, Netherlands Antilles. St. Eustatius Marine Park.

Davis, M., 2005. Species profile Queen Conch, Strombus gigas. Southern Regional Aquaculture Center Publication no. 7203.

DCNA 2012. Species Management Plan: Yellow-shouldered Amazon Parrot, Amazona barbadensis, Dutch Caribbean. Sam Williams. Conservation Handbook Series No. 009. Dutch Caribbean Nature Alliance, Dutch Caribbean.

Debrot, A.O., C. Wentink, A. Wulfsen, 2012. Baseline survey of anthropogenic pressures for the Lac Bay ecosystem, Bonaire. IMARES report number C092/12.

Debrot, A.O., J. Sybesma, 2000. Seas at the Millennium: an environmental evaluation. Ch. 38. The Dutch Antilles. Pergamon, 2000.

Debrot, A.O., C. Boogerd, D. van den Broeck, 2009. The Netherlands Antilles III. Curacao and Bonaire. In: Bradley, P.E. & Norton, R.L. (eds) An inventory of breeding seabirds of the Caribbean: 207-215. University Press Florida.

De Freitas, J.A., A.C. Rojer, B.S.J. Nijhof, A.O. Debrot, 2012. A landscape ecological vegetation map of Sint Eustatius (Lesser Antilles). IMARES report number C053/12

De Freitas, J.A., B.S.J. Nijhof, A.C. Rojer, A.O. Debrot, 2005. Landscape ecological vegetation map of the island of Bonaire. CARMABI Foundation, Curacao, 2005.

De Freitas, J.A. *et al*., (in press). A landscape ecological vegetation map of Saba.

Dow, W., K. Eckert, M. Palmer, P. Kramer, 2007. Sea turtle nesting in the Wider Caribbean Region – WIDECAST Technical report no. 6

Duke, J.A., 1983. Handbook of Energy Crops. Unpublished. http://www.sms.si.edu/irlspec/Avicen_germin.htm Downloaded 22 November 2012.

Duke, N.C., J.A. Allen, 2006. Rhizophora mangle, R. samoensis, R. racemosa, R. harrisonii (Atlantic-East Pacific red mangroves), ver. 2.r. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Holualoa, Hawai'i. http://www.traditionaltree.org

Ellison, A., Farnsworth, E. & Moore, G. 2010. Laguncularia racemosa. In: IUCN 2012. IUCN Red List of Threatened Species. Version 2012.2. <www.iucnredlist.org>. Downloaded on 30 January 2013.

Engel, M.S., 2008. Results of survey Lac Bay, Bonaire Queen Conch (*Strombus gigas*) and Seagrass characterization in 2007. Prepared for Bonaire National Marien Park, STINAPA.

Feranec, J., Hazeu, G., Christensen, S., Jaffrain, G., 2007. Corine land cover change detection in Europe (case studies of The Netherlands and Slovakia). Land Use Policy 24 (1), 234-247.

Garcia-Santos, V., E. Valor, V. Casseles, 2010. Determination of temperature by remote sensing. Tethys no. 7, pp. 67-74.

Geelhoed *et al*., (in press). Important Bird Areas in the Caribbean Netherlands. IMARES report.

Giles, P.T., 2001. Remote sensing and cast shadows in mountainous terrain. Photogrammetric Engineering & Remote Sensing, Vol. 67, No. 7, pp. 833-839.

GRID-Arendal, http://www.grida.no/publications/rr/our-precious-coasts/page/1288.aspx Extraction date: 29 January 2013.

Guisan, A., Zimmermann, N. E., 2000. Predictive habitat distribution models in ecology. Ecol. Model. 135 (2-3), 147-186.

Guisan, A., Thuiller, W., 2005. Predicting species distribution: Offering more than simple habitat models. Ecol. Lett. 8 (9), 993-1009.

Hansen, A.J., deFries, R.S., Turner, W., 2004. Land Use Change and Biodiversity: A Synthesis of Rates Consequences during the Period of Satellite Imagery, in: Gutman, G., Janetos, A.C., Justice, C.O., Moran, E.F., *et al*. (Eds.), Land Change Science: Observing, Monitoring and Understanding Trajectories of Change on the Earth's Surface. Series title Remote sensing and digital image processing (vol. 6) Publisher Kluwer Academic Publishers, pp. 277-300.

Hazeu, G.W., M.J. Metzger, C.A. Mucher, M. Perez-Soba, Ch. Renetzeder, E. Andersen, 2011. European environmental stratifications and typologies: An overview. Agriculture, Ecosystems & environment, Vol. 142, Iss 1-2, 29-39.

Helmer, E.H., O. Ramos, T. del M. Lopez, M. Quinones, W. Diaz, 2002. Mapping the forest type and land cover of Puerto Rico, a component of the Caribbean Biodiversity Hotspot. Caribbean Journal of Science, Vol. 38, no 3-4, 1665-183, 2002.

Helmer, E.H., T.A. Kennaway, D.H. Pedreros, M.L. Clark, H. Marcano-vega, L.L. Tieszen, T.R. Ruzycki, S. R. Schill, C. M. S. Carrington, 2008. Land cover and forest formation distributions for St. Kitts, Nevis, St. Eustatius, Grenada and Barbados from Decision Tree Classification of Cloud-Cleared Satelilte Imagery. Caribbean Journal odf Science, Vol. 44, no. 2, 175-198, 2008.

Henderson, R.W., 2004. Lesser Antillean snake faunas: distribution, ecology, and conservation concerns. Oryx, 38, pp 311-320. Doi10.1017/S0030605304000559.

Heymann, Y., Ch. Steenmans, G. Croisille, M. Bossard, 1994. CORINE land cover. Technical guide. Office for Official Publications of the European Communities, Luxembourg, 136 p.

Hoogenboezem-Lanslots, K.M.A., Y.M. Schenau, R.J. van Leeuwen, M.F.M Briene, J.A. de Freitas, 2010. St. Eustatius Strategic Development plan. RBOI 42107.14685.00, 22nd October 2010.

Iversen, E.S., D.E. Jory, S.P. Bannerot, 1986. Predation on queen conch (S. gigas) in the Bahamas. Bulletin Marine Science 39(1), 61-75.

Jensen, J. R. (2005). Introductory Digital Image Processing: A Remote Sensing Perspective. Upper Saddle River : Pearson Prentice Hall.

Jongman, R.H.G., H.W.G. Meesters, A.O. Debrot, 2010. Biodiversiteit voor de BES-eilanden: Bonaire, St. Eustatius en Saba. Alterra-rapport 2080. IMARES-rapport C117/10.

Judd, WS, Campbell, SC, Kellogg, EA, Stevens, PF, and Donoghue, ML. 2008. Plant systematics: A phylogenetic approach. Sinauer Associates, Inc. Massachusetts, USA. http://www.sms.si.edu/irlspec/Avicen_germin.htm 22 nov 2012.

Lagerloef, S.E., C.T. Swift, D.M. Le Vine, 1995.Sea surface salinity: the next remote sensing challenge. Oceanography, Vol. 8, no. 2.

Ligon, J.C., 2006. Annotated checklist of birds of Bonaire, October 2006. http://www.bonairediveandadventure.com. Downloaded on 28 January 2012.

Lirman, D., W.P. Cropper, Jr., 2003. The influence of salinity on seagrass growth, survivorship, and distribution within Biscayne Bay, Florida: Field, Experimental and Modeling studies. Estuaries, 26(1): 131-141.

Lott, C., 1994. Research and monitoring results for the size class distribution and abundance of the Queen Conch, Strombus gigas, and seagrass characterization in lac Bay, Bonaire.

Martinuzzi, S., W.A. Gould, O. M. Ramos Gonzalez, A. Martinez Robles, P. Calle Maldonado, N. Pérez-Buitrago, J.J. Fumero Caban, 2008. Mapping tropical dry forest habitats integrating Landsat NDVI, Ikonos imagery, and topographic information in the Caribbean Island of Mona. Rev. Biol. Trop. Vol. 56 (2), 625-639, 2008.

McNair, D.B. 2006. Review of the status of American Coot (Fulica americana) and Caribbean Coot (*Fulica carbaea*) in the United States Virgin Islands. North American Birds 59: 680-686.

McRae, D.R., N. Esteban, 2007. St. Eustatius Marine Park Management Plan. Coastal zone Management (UK) and St. eustatius National Parks Foundation (STENAPA)

Moore, G.K., 1980. Satellite remote sensing of water turbidity. Hydrological Sciences – Bulletin, 25, 4, 12/1980.

Moorsel, G.W.N.M. van, A.J.M. Meijer, 1993. Baseline ecological study van het Lac op Bonaire. Bureau Waardenburg B.V.

Morrison, J.L., 1996. Crested caracara. Birds of North America 249: 1-28

Morrison, J.L., 2007. Characteristics of nest sites used by Crested caracaras in south-central Florida. Florida Field Naturalist 35(1): 1-8, 2007.

Morrison, J.L., K.V. Root, J.R. Barnes, G.J. Lipps jr., 2007. Habitat suitability and demographic population viability models for Florida's Crested Caracaras. Final report. Florida Fish and Wildlife Conservation Commission, Tallahassee, Florida, USA.

Mortimer, J.A & Donnelly, M. (IUCN SSC Marine Turtle Specialist Group) 2008. Eretmochelys imbricata. In: IUCN 2012. IUCN Red List of Threatened Species. Version 2012.2. <www.iucnredlist.org>. Downloaded on 30 January 2013.

Mücher, C.A., 2009. Geo-spatial modelling and monitoring of European landscapes and habitats using remote sensing and field surveys. PhD thesis Wageningen University, Wageningen, The Netherlands, ISBN 978-90-8585-453-1, 269 pp.

Mücher, C.A., Hennekens, S.M., Bunce, R.G.H., Schaminée, J.H.J., Schaepman, M.E., 2009. Modelling the spatial distribution of Natura 2000 habitats across Europe. Landscape Urban Plan. 92 (2), 148-159.

Mücher, C.A., Steinnocher, K., Kressler, F, Heunks, C., 2000, Land cover characterization and change detection for environmental monitoring of pan-Europe. Int. J. remote Sens. 21 (2000), 6/7: 1159-1181.

Mücher, C.A., Champeaux, J.L., Steinnocher, K.T., Griguolo, S., Wester, K., Heunks, C., *et al*., 2001. Development of a consistent methodology to derive land cover information on a European scale from Remote Sensing for environmental monitoring; The PELCOM report. Alterra Report 178, CGI report 6, 178 pp., Wageningen, the Netherlands.

Mulhall, M., 2009. Saving the rainforests of the sea: an analysis of international efforts to conserve coral reefs. Duke Environmental Law & Policy Forum Vol. 19:321.

Mumby, P.J., E.P. Green, A.J. Edwards, C.D. Clark, 1997. Coral reef habitat mapping: how much detail can remote sensing provide? Marine Biology 130, 193-202.

Nellis, D.W. (2001) Common Coastal Birds of Florida & the Caribbean. Pineapple Press, Sarasota, Florida.

Nijman, V., 2010. The importance of small wetlands for the conservation of the endemic Caribbean coot *Fulica caribaea*. Caribbean Journal of Science, Vol. 46, No.1, 112-115, 2010.

Padwick, C., M. Deskevich, F. Pacifici, S. Smallwood, 2010. Worldview-2 Pan-sharpening. ASPRS 2010, San Diego,. California.

Powell, R., 2006. Conservation of the herpetofauna on the Dutch Windward Islands: St. Eustatius, Saba, and St. Maarten. Applied herpetology 3: 293-306.

Powell, R., R.W. Henderson, 2005. Conservation status of Lesser Antillean reptiles. IGUANA, 12(2), 2005.

Prins, T.G., J.H. Reuter, A.O. Debrot, J. Wattel, V. Nijman, 2009. Checklist of the birds of Aruba, Curacao and Bonaire. South Caribbean. ARDEA 97(2), 2009.

Raffaele, H., J. Wiley, O. Garrido, A. Keith, J. Raffaele, 2003. A Guide to the Birds of the West Indies. rinceton University Press, Princeton, New Jersey. ISBN 0-691-08736-9. 511 pages.

Reef, R., I.C. Feller, C.E. Lovelock, 2010. Nutrition of mangroves. Tree Physiology 30, 1148-1160.

R.O.B., 2010. Ruimtelijk Ontwikkelingsplan Bonaire (Spatial development plan Bonaire). 8 October 2010.

Rojer, A., 1997a. Biological inventory of Sint Eustatius. KNAP project 96-10. CARMABI Foundation.

Rojer, A., 1997b. Biological inventory of Saba. KNAP project 96-10. CARMABI

Sarti Martinez, A.L. (Marine Turtle Specialist Group) 2000. Dermochelys coriacea. In: IUCN 2012. IUCN Red List of Threatened Species. Version 2012.2. <www.iucnredlist.org>. Downloaded on 30 January 2013.

Sanz, V., A. Rodriguez-Ferraro, 2006. Reproductive parameters and productivity of the Yellow-shouldered Parrot (*Amazona barbadensis*) on Margarita sland, Venezuela: a long-term study. Condor 108, 178-192.

Savit, Aaron Z.; Maley, Abigail J.; Heinz, Heather M.; Henderson, Robert W.; Powell, Robert 2005. Distribution and activity periods of *Alsophis rufiventris* (*Colubridae*) on The Quill, St. Eustatius, Netherlands Antilles. Amphibia-Reptilia 26 (3): 418-421

Sedano, F., P. Kempeneers, P. Strobl, J. Kucera, P. Vogt, L. Seebach, J. San-Miguel-Ayanz, 2011. A cloud mask methodology for high resolution remote sensing data combining information from high and medium resolution optical sensors. ISPRS Journal of Photogrammetry and Remote Sensing 66, 588-596.

Seminoff, J.A. (Southwest Fisheries Science Center, U.S.) 2004. Chelonia mydas. In: IUCN 2012. IUCN Red List of Threatened Species. Version 2012.2. <www.iucnredlist.org>. Downloaded on 30 Jan 2013.

Shroeder, Th., A.G. Dekker, C. Rathbone, 2009. Remote sensing for light attenuation mapping in the North Marine Region, Report to the Department of the Environment, Water, Heritage and the Arts, CSIRO Land and Water, 25 pp., ISBN 978-0-643-09736-0.

Short, F.T., Carruthers, T.J.R., van Tussenbroek, B. & Zieman, J. 2010 a. Syringodium filiforme. In: IUCN 2012. IUCN Red List of Threatened Species. Version 2012.2. <www.iucnredlist.org>. Downloaded on 30 Jan 2013.

Short, F.T., Carruthers, T.J.R., van Tussenbroek, B. & Zieman, J. 2010 b. Thalassia testudinum. In: IUCN 2012. IUCN Red List of Threatened Species. Version 2012.2. <www.iucnredlist.org>. Downloaded on 30 Jan 2013.

Smith, J., 2008. In-water monitoring of sea turtle aggregations in St. Eustatius National Park. St. Eustatius National Parks (STENAPA).

Smith, S.R., N. Davaasuren, A.O. Debrot, F. Simal, J.A. De Freitas, 2012. Preliminary inventory of key terrestrial nature values of Bonaire. IMARES report number C003/12.

Stanners, D., Bordeaux, P. (Eds.), 1995. Europe's Environment; The Dobříš Assessment. European Environmental Agency, Copenhagen. 676 pp. Office for Official Publications of the European Communities, Luxembourg.

STENAPA, 2012. http://www.statiapark.org/

Sternlicht, D.D., C.P. de Moustier, 2003. Remote sensing of sediment characteristics by optimized echo-envelope matching. Acoustical Society of America 114, 5, 2003.

STINAPA, 2012. http://www.stinapa.org/

Stoffers, A.L., 1956. The vegetation of the Netherlands Antilles. Volume 1 of Studies of the flora of Curacao and other Caribbean islands. Issue 15 of Uitgaven 'Natuurwetenschappelijke Studiekring voor Suriname en de Nederlandse Antillen, Utrecht.

Stoner, A.W., J.M. Waite, 1990. Distribution and behaviour of queen conch, Strombus gigas, relative to seagrass standing crop. Fishery Bulletin, U.S. 88: 573-585.

Stoner, A.W., M.D. Hanisak, N.P. Smith, R.A. Armstrong, 1994. Large-scale distribution of queen conch nursery habitats: implications for stock enhancement. Pages 169-189 in R.S. Appeldoorn and B. Rodriquez Q., eds. Queen conch biology, fisheries and mariculture. Fundaci n Cientifica Los Roques, Caracas, Venezuela.

Stoner, A.W., J. Lin, M.D. Hanisak, 1995. Relationships between seagrass bed characteristics and juvenile queen conch (*Strombus gigas Linne*) abundance in the Bahamas. Journal of Shellfish Research, 14(2), 315-323. http://digitool.fcla.edu/view/action/singleViewer.do?dvs=1359461433704~549&locale=en_GB&VIEWER_URL=/view/action/singleViewer.do?&DELIVERY_RULE_ID=7&adjacency=N&application=DIGITOOL-3&frameId=1&usePid1=true&usePid2=true

Stoner, A.W., 1997. The status of Queen Conch, *Strombus gigas*, research in the Caribbean. Marine Fisheries review, 59(3), 1997.

Sybesma, J. 1992. WIDECAST Sea Turtle Recovery Action Plan for the Netherlands Antilles (Karen L. Eckert, Editor). CEP Technical Report no.11, UNEP Caribbean Environment Programme, Kingston, Jamaica, 63p.

Travaini, A., J.A. Donázar, O. Ceballos, F. Hiraldo, 2001. Food habits of the Crested Caracara (Caracara plancus) in the Andean Patagonia: the role of breeding constraints.

Voous, K.H., H.J. Koelers, 1967. Check-list of the birds of St. Martin, Saba and St. Eustatius. Ardea 55, 1967.

Voous, K.H., 1983. Birds of the Netherlands Antilles, Walburg Press.

Wells J.V., A. Child Wells, 2006. The significance of Bonaire, Netherlands Antilles, as a breeding site for terns and plovers. Journal Caribbean Ornithology 19:21-26.

Williams, S.R., 2009. Factors affecting the life history, abundance and distribution of the yellow-shouldered Amazon parrot (*Amazona barbadensis*) on Bonaire, Netherlands Antilles. PhD thesis. University of Sheffield.

Wolf, A., 2010. Using Wolrdview-2 VIS-NIR MSI Imagery to support land mapping and feature extraction using normalized difference index ratios. Proceedings of DigitalGlobe 8-band Challenge, DigitalGlobe Inc., Dec. 2010.

World Travel Guide, 2012. Saba. http://www.worldtravelguide.net/saba/weather-climate-geography

Xie, Y., Z. Sha, M. Yu, 2008. Remote sensing imagery in vegetation mapping: a review. Journal of Plant Ecology, Vol. 1, No. 1, 9-23.

Yarrow, G., 2009. Habitat Requirements of Wildlife: Food, Water, Cover and Space. Forestry and Natural Resources, Fact Sheet 14.

10 Quality Assurance

IMARES utilises an ISO 9001:2008 certified quality management system (certificate number: 124296-2012-AQ-NLD-RvA). This certificate is valid until 15 December 2015. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical laboratory of the Fish Division has NEN-EN-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 1 April 2017 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation.

11 Justification

Report C124/13
Project Number: 430.87010.12

The scientific quality of this report has been peer reviewed by a colleague scientist and the head of the department of IMARES.

Approved: Ingrid J.M. van Beek
Tropical marine ecologist

Signature:

Date: 7th November 2013

Approved: F.C. Groenendijk, MSc.
Head of department

Signature:

Date: 7th November 2013

Appendix A. Ecoprofiles

Corals

Occurrence:
Saba: mainly coral boulders, no biogenic reef (14 ha.)
Saba bank: 40 x 60 km, with reefs mainly on the eastern and south-eastern edges.
Statia: mainly boulders, no biogenic reef (180 ha.)
Bonaire: Biogenic reef (4372 ha.)

Species description:
Marine ecosystems constructed of various calcium carbonate secreting coral species resulting in large limestone structures, e.g. drop off walls, volcanic fingers. Coral colonies consist of individual coral polyps that occur in groups and live in symbiosis with microscopic algae (zooxanthellae).

Functions:
Foraging grounds, unique habitat for numerous marine species (high biodiversity and density), provide coastal protection, uptake of CO_2 and release of O_2.

Nourishment requirements (food & water):
Currents and wave activity to supply the coral reef with low concentrations of nutrients such as phosphate, ammonium and nitrate. Coral polyps feed through digesting plankton and through zooxanthellae (symbiotic algae). Nutrient quality requirements (biologically available):
Nitrogen (< 1.0 µmol/l), Phosphorus (< 0.1 mmol/l) and Ammonium.

Other requirements:
Sea water - preferably continuous submersion under water (against heat damage).
Salinity range: 30-40 ppt
Sunlight (photosynthesis by zooxanthellae)
Temperature range: (shallow warm water) (21 – 29°C), minimum of 20°C..
High oxygen concentration.
High water clarity (for light availability)
Depth range: 0 – 100m (restricted due to light availability for symbiotic algae).
Maximum growth rates occur at depths less than 18 m.

Which habitat requirements would be possible to identify from satellite data?
Temperature.
Water clarity.

Corals are difficult to distinguish because they are very similar to algae in spectral information.

Threats (anthropogenic or climate):
Sedimentation, pollution, sewage-runoff.
Overfishing, destructive fishing, reef mining.
Climate change: increase of water temperature and ocean acidification.
Tidal emersion, storms and hurricanes.

References:

- GRID-Arendal http://www.grida.no/publications/rr/our-precious-coasts/page/1288.aspx
- Mulhall, 2009.
- Debrot, A.O., J. Sybesma, 2000.
- Barnes R.S.K., R.N. Hughes, 1999.

Lesser Antillean Green Iguana

(*Iguana delicatissima*)

Occurrence:
Saba: not present.
Statia: present, only in tiny remnant populations.
Bonaire: not present.

Species description:
The Lesser Antillean Green Iguana is an arboreal lizard and are endemic to the Lesser Antilles. It may come to the ground at night to seek shelter (in a burrow).
Functions:
Seed dispersal for a number of coastal forest plant species.

Nourishment requirements (food & water):
Leaves, flowers, and fruits of a wide range of shrubs and trees. (e.g. fruit trees, neem, calabash), maybe also birds' eggs. Juveniles occasionally eat insects and other small animals. Seasonal variation in feeding ecology: folivory during the dry season , folivory and frugivory during the wet season.

Reproduction requirements (nesting & mate attracting):
The female iguana lays her eggs (up to 18) in a burrow in soft ground . Nest sites occur in sandy but also in clayish, well-drained soils exposed to prolonged sunlight. Hatchlings and juveniles live predominantly among bushes and low trees, usually in thick vegetation offering protection, basking sites, and a wide range of food.

Shelter requirements (roosting & shelter from predators):
Burrows in the ground and in trees.
The iguana is most abundant in areas where threats (usually anthropogenic) are minimised, e.g. in the Quill and Boven national parks on St. Eustatius. Juvenile iguanas are preyed upon by American Kestrels (*Falco sparverius*), Red-tailed Hawks (*Buteo jamaicensis*) and the *Alsophis*. Rats and snakes may also eat the eggs.

Space requirements:
The species exists in xeric scrub, dry scrub woodland, littoral woodland, and mangrove, as well as lower and mid-altitude portions of transitional rainforest.
It is able to survive in extremely xeric degraded habitats (less than 1,000 mm annual rainfall) to mesic forests (3,000-4,000 mm annual rainfall) in the absence of introduced predators or competitors.

Distribution data:
The Quill , 0 - 601 m, shrub land and forest.
Little Mountain

Other requirements:
Unknown.

Which habitat requirements would be possible to identify from satellite data?

- Sandy/clayish, well-drained soils exposed to prolonged sunlight.
- Thick vegetation.
- Areas with minimised disturbance.
- Fruit and flowering trees.

Threats (anthropogenic or climate):

- Roaming goats, due to foraging for the same food source within the parks. Extensive over-browsing continues to cause a shift in plant species composition and habitat structure .
- Hunted by humans.
- Habitat loss due to coastal development .
- Road casualties.
- Healthy adults have no naturally occurring enemies, however introduced predators such as dogs, cats and rats are known to kill iguanas of all ages.

References

- Personal comments Hannah Madden (STENAPA).
- Breuil, M., Day, M. & Knapp, C. 2010.
- Rojer, 1997a

Queen Conch

(*Strombus gigas*)

© D.M.E. Slijkerman

Occurrence:
Saba: present.
Statia: present.
Bonaire: present, mainly at Lac bay (STINAPA).

Species description:
The Queen conch is a large, herbivorous, marine gastropod found primarily in the Western Atlantic Caribbean region. Active at night.

Functions:
Prevents excessive covering of sea grass by algae. Empty conch shells function as (shelter)habitat for juvenile fish and hermit crabs and the hard substrate is a basis for algal growth .

Nourishment requirements (food & water):
Juveniles and adults : algae (e.g. *Batophora oerstedi*, *Dictyota cervicornis*, *Enteromorpha prolifera*, *Spyridia filamentosa* and *Spirulina)* and detritus or diatoms commonly associated with *Thalassia testudinum*, *Syringodium filiforme* and *Halodule wrightii.*

Shelter requirements (roosting & shelter from predators):
The conch finds shelter in its shell.

Reproduction requirements (nesting & mate attracting):
Juveniles: buried in the sand (up to 20 cm deep) until 1-1.5 years old or 5 cm long (e.g. in sandbars). Sub-adult: migrate to deeper water to form spawning aggregations .
The occurrence of sandbars, where larval settlement may occur, adjacent to sea grass meadows as nursery areas is potentially significant (at least in Lee Stocking island, Bahamas).
It is expected that sea grass and detritus biomass, sea grass shoot density and depth are critical features in nursery habitats . Most nurseries are located in areas with an intermediate density of sea grass (30-80 g dry wt/m2) and in depths of 2-4 m (Bahamas). Productive nurseries are located directly in the paths of strong tidal currents and are flushes with oceanic water on every tide.
Nursery grounds: < 6m, sea grass density 600-900 shoots/m2 (Thalassia). Juveniles have also been found in algal flats and on deep banks.

Space requirements:
In or around sea grass beds (*Thallassia testudinum*). But also on gravel, coral rubble, smooth hard coral, beach rock bottoms and sandy algal beds . Juveniles: shallow waters with strong reversing tidal currents.

Other requirements:
Restricted to areas where light can penetrate to a depth sufficient for plant growth.
Optimal temperature range: 17 – 32 ◦C.
Optimal salinity range: 30 – 40 ppt .
<u>Seasonal migration: inshore during the spring and offshore, deeper water in the autumn .</u>
Depth range: up to 25m, predominantly between 10-18m (adults).

Which habitat requirements would be possible to identify from satellite data?
Shallow waters .
Sea grass biomass, sparse to medium sea grass meadows (*Thalassia testudinum, Syringodium filiforme*)
Areas with dense *Dictyota sp.,* or *Acanthophora spicifera*
Water depth
Tidal circulation patterns.

Distribution data:
St. Eustatius: see distribution data (Appendix xx).
Saba: no specific areas found.
Bonaire: Lac Bay

Threats (anthropogenic or climate):
Overfishing (commercial importance and high market value).
Water quality (eutrophication, pollution).
Predation by crabs, lobsters, filefish and shrimps (as buried juvenile). In addition gastropods, crustaceans, sea stars, rays, sharks, bonefish, loggerhead sea turtle.
Storms. Low tides, low wind speed and lack of clouds can contribute to *Strombus gigas* mortality.

References
CMFC, 1996; Davis, J.E., 2003; Davis, M., 2005; Lott, C., 1994; Moorsel and Meijer, 1993; Engel, M.S., 2008; Stoner and Waite, 1990; Stoner *et al*., (1994, 1995, 1997); Iversen *et al*., 1986.

Caribbean coot

(*Fulica caribaea*)

© A.O. Debrot

Occurrence:
Saba: present.
Statia: present.
Bonaire: present.

Species description:
A waterbird endemic to the Caribbean that is globally threatened. It is found on freshwater lakes, ponds, marshes.

Functions:
Contributes to food webs.

Nourishment requirements (food & water):
Filamentous green algae, in addition to leaves, seeds and tubers of aquatic plants., and newly sprouted grass. Also grasshoppers and aquatic insects, tadpoles, snails and small fish.

Reproduction requirements (nesting & mate attracting):
Natural seasonally (low-salinity) salt ponds, marshes and freshwater lakes and ponds (usually man-made). Nesting occurs in marshy areas.

Shelter requirements (roosting & shelter from predators):
Not applicable.

Space requirements:
In the Netherlands Antilles there is no relationship between numbers of coots and wetland size. Use of large wetlands but also smaller fresh water ponds (ponds, dams, wastewater treatment plants).

Other requirements:
Unknown.

Distribution data:
Bonaire: Onima reservoir, Playa Grandi reservoir, Washikemba reservoir.
Saba and St. Eustatius: no specific areas found.

Which habitat requirements would be possible to identify from satellite data?
- Salt ponds, marshes and freshwater lakes and ponds.

Threats (anthropogenic or climate):
- Hunting pressures (including eggs for local consumption)
- Habitat degradation , due to (wetland) drainage or land reclamation.
- Introduced predators
- Pollution

References

- BirdLife International 2012. Fulica caribaea.
- McNair, D.B. 2006.
- Prins *et al*., 2009.
- Nellis, D.W., 2001.
- Nijman, 2010.
- Raffaele *et al*., 1998

Common tern
(*Sterna hirundo*)

© Hans Verdaat

Occurrence:
Saba: present.
Statia: present.
Bonaire: present.

Species description:
The Common tern is a migratory seabird. On Bonaire it is a scarce breeding visitor.

Functions:
Contribution to food webs.

Nourishment requirements (food & water):
Small fish and occasionally planktonic crustaceans and insects. The Common tern forage over fresh water and marine habitat.

Reproduction requirements
(nesting & mate attracting):
Along the coast, nesting may occur within several habitats (flat rock surfaces, open shingle and sandy beaches, dunes, spits, vegetated inter-dune areas, sandy, rocky, shell-strewn or well-vegetated islands in estuaries,
coastal lagoons, salt marshes, mainland peninsulas and grassy plateaus atop coastal cliffs).

The nest is a shallow depression on open substrate with little or no vegetation, often placed near a vertical object for shelter. On Bonaire, the Common tern is found at seacoasts, in bays, estuaries, lakes and marshes. In winter primarily coastal waters and beaches.

Shelter requirements (roosting & shelter from predators):
Nonbreeding Common terns winter on sheltered coastal waters, estuaries, coastal wetlands, including lagoons, rivers, lakes, swamps, salt works, mangroves and salt marshes. It roosts on unvegetated sandy beaches, shores of estuaries or lagoons, sandbars and rocky shores.

Space requirements:
Most Common terns are observed within 10 km of a breeding colony.

Distribution data:
On Bonaire**,** larger saltworks area surrounding the Pekelmeer harbours Common tern . Also found at Salina Slagbaai, Pekelmeer, Lake Goto and Sorobon on Bonaire. Saba and St. Eustatius no specific areas found.

Other requirements:
Unknown.

Which habitat requirements would be possible to identify from satellite data?
- Wetlands
- Coastal zone
- Rocky cliffs
- Beaches

Threats (anthropogenic or climate):
- Human disturbance at nesting colonies during breeding season (e.g. recreation, off-road vehicles, motor boats, dogs etc.)
- Hunting pressures (egg collection)
- Flooding of nest sites.
- Habitat loss due to coastal development, vegetation overgrowth and chemical pollution.

References
BirdLife International 2012e. *Sterna hirundo*; Prins *et al*. 2009; Debrot *et al*., 2009; Ligon, 2006; Wells & Child Wells , 2006

Caribbean Flamingo

(*Phoenicopterus ruber*)

© A.O. Debrot

Occurrence:
Saba: not present.
Statia: not present.
Bonaire: present.

Species description:
The Caribbean Flamingo is a highly specialized waterbird native to the three islands. On Bonaire it is an abundant breeding resident.

Functions:
Contribution to food webs.

Nourishment requirements (food & water): The Flamingo forage in shallow lakes of low and high salinity, salinas. It feeds on widgeongrass, turtlegrass; crustaceans, nematodes and molluscs located in the substrate (low salinity ponds, 4 – 87 ppt). Cyanobacteria green layer, purple sulfide bacteria on the surface of underlying mud; brine shrimp and brine flies, within the water column (high salinity ponds (127-218 ppt). Intermediate salinity (68 – 150 ppt) ponds are not used.

Other requirements:
Unknown.

Reproduction requirements (nesting & mate attracting):
The Flamingo builds nests in shallow salinas , lagoons and coastal estuaries.

Shelter requirements (roosting & shelter from predators):
Resting and preening also occurs in salinas and lagoons.

Space requirements:
Flamingos have been seen leaving their habitat when water depths exceeded 60 cm.

Distribution data:
On Bonaire, Pekelmeer harbours a breeding colony. Saba and St. Eustatius no specific areas found.

Which habitat requirements would be possible to identify from satellite data?
- Salinas and lagoons
- Salinity
- Water depth

Threats (anthropogenic or climate):
- Use of Salinas by humans for commercial salt extraction.
- Tropical storms and hurricanes (high winds and rain) may affect food abundance, availability, water depth and salinity , but also directly affect flamingo mortality.
- Predation (....in CN?)
- Potential collection of eggs by humans
- Flooding is a risk for nesting colonies

References

- Arengo & Baldassare, 1998
- BirdLife International 2012a. *Phoenicopterus ruber*.
- Baldassarre & Arengo, 2000.
- Jongman *et al*., 2010
- Prins *et al*., 2009
- Rafaelle *et al*., 2003

Northern Caracara

(*Polyborus plancus*)

(juvenile *Polyborus plancus*) © Hans Verdaat

Occurrence:
Saba: present.
Statia: present.
Bonaire: present. (scarce breeding resident).

Species description:
The Crested Caracara is a bird of prey, native to the three islands. Long-lived and monogamous, non-migratory, territorial.

Functions:
Contribution to food webs.

Nourishment requirements (food & water):
Carrion, live prey, insects, small and occasionally large vertebrates, incl. fish, reptiles, amphibians, birds, mammals, eggs . Forages while walking about on the ground, might therefore prefer short ground vegetation (open areas) Little is known about the specific habitat features that they require .

Reproduction requirements (nesting & mate attracting):
Nesting occurs in trees. Habitat consists of semi-arid open country, including palm savannahs, cut-over areas and pastures. In Florida, most nests were built in cabbage palms, and nest tress typically occurred in short-stature pasture or grassland habitats. All nest sites had cover.

Reproduction requirements (continue):
Nests were also recorded nests in a cypress, in an oak and in eastern red-cedar (*Juniperus virginiana*). Mean nest tree height was 7,5 m. Nest trees ranged from single trees to clumped trees. Nesting reported in: mesquite (*Prosopis articulata*), elm (*Ulmus sp*.), cardon (*Pachycereus pringlei*), yucca (*Yucca valida*), palo verde (*Cercidium microphyllum*), palo fierro (*Olneya tesota*), palm (*Washingtonia robusta*), McCartney rose (*Rosa bracteata*), yaupon (*Ilex vomitoria*).

Nest characteristics: nest support structure typically are isolated and are the tallest structures in the immediate area and the area around the nest support structures is generally open, e.g. prairie, pasture or grassland . Canopy of the nest support structure is thick around the nest so the nest is rarely visible from a distance .

Space requirements:
Little is known about the specific habitat features that they require, but seem to prefer open grassland. In Florida, five types of vegetation and two water types were associated with the presence of Crested Caracara. Cabbage palm-live oak hammock, grassland, improved pasture, unimproved pasture, hardwood hammocks and forest, lentic water (standing water habitats) and lotic water (flowing water).

Shelter requirements (roosting & shelter from predators):
Trees.

Other requirements:
Site location and habitat structure may be more important than tree species composition to breeding raptors .

Which habitat requirements would be possible to identify from satellite data?

- Highest clumps or single trees, with thick vegetation cover, surrounded by open land.
- Semi-arid open country, pastures.

Distribution data: Bonaire, Saba and St. Eustatius.

Threats (anthropogenic or climate):

- Habitat loss and habitat conversion to agriculture/ranching/urban.
- Small population size, geographic isolation.

References
Barnes, J.R., 2007; Morrison, J.L., (1996, 2007); Morrison *et al*., 2007; Prins *et al*., 2009; Travaini *et al*., 2001; Morrison & Humprey, 2001 & U.S. Fish & Wildlife, 1999 as mentioned in Morrison *et al*., 2007), Raffaele *et al*., 2003.

Red-bellied racer

(*Alsophis rufiventris*)

© Hans Verdaat

Occurrence:
Saba: present.
Statia: present.
Bonaire: not present.

Species description:
The Red-bellied racer is a diurnal, ground-dwelling snake that is endemic to the Lesser Antilles in the Caribbean.

Functions:
Contribution to food webs.

Nourishment requirements (food & water):
Ground-dwelling predators of frogs, lizards (specifically *Eleutherodactylus* and *Anolis* spp), and juvenile iguanas. On St. Eustatius there are no rivers, lakes or ponds on the island, therefore rainwater is essential.

Reproduction requirements (nesting & mate attracting):
Nothing is known about the reproduction behaviour of the *Alsophis* besides that it lays eggs .

Shelter requirements (roosting & shelter from predators):
Rocky environments offering plenty of refuge.
Space requirements:
On St. Eustatius the snake is quite abundant throughout the island but its main habitat is the Quill..

Other requirements:
On Saba and St. Eustatius predominantly found in xerophytic (dry and arid habitat) vegetation zone.

Distribution data.
Known to occur in a variety of natural and altered habitats (incl. urban and suburban situations).

St. Eustatius: southern forested areas (Rojer, 1997), western slope of The Quill (mesic environment, semi-evergreen seasonal forest, deciduous seasonal forest at lower levels and dry evergreen forest at elevations near the rim of The Quill), Quill Boven National Park (rocky terrain). Higher encounter rate at higher levels, due to presence of rocks and abundance of prey. Anoline (lizard) densities were found to be > 6000/ha > 300m, 3000/ha intermediate elevations with fewer rocks but some deadfall, < 1000/ha at lower elevations with litter as only cover.

Saba: no specific areas found.

Which habitat requirements would be possible to identify from satellite data?
- Rocky surfaces.
- Xerophytic vegetation zone

Threats (anthropogenic or climate):
- Killed by humans, due to the irrational fear of snakes among the general public that leads to them being pointlessly killed.
- Predation by cats, dogs and rats.
- Habitat destruction due to tourist developments.

References

- Henderson, 2004.
- Medina Diaz *et al*., (in press) as mentioned in Savit *et al*., 2005
- Powell, 2006.
- Powell & Henderson, 2005.
- Personal comments Hannah Madden (STENAPA)
- Rojer, 1997a

Yellow-shouldered Amazon parrot
(*Amazona barbadensis*)

© A.O. Debrot

Occurrence:
Saba: not present.
Statia: not present.
Bonaire: present.

Species description:
Small, overall green parrot. Long-lived species with corresponding life history traits: e.g. long-lived adults, single breeding attempts per season, few offspring, delayed maturity. Changes in adult survival are therefore the most important determinants of population fluctuations and populations are slow to recover from perturbations.

Functions:
Seed dispersal.

Nourishment requirements (food & water):
Flowers, fruit, seeds, bark and leaves of a wide variety of plant species both native (e.g. Lignum Vitae, West Indian Cherry and Mesquite) and introduced (e.g. West Indian Mahogany, Kenepa and Tan Tan).
Fruit trees. In urban areas the parrots feed on Lignum Vitae, Sea Grape, Mango and Almond and Calabash when available.

Reproduction requirements (nesting & mate attracting):
Nesting takes place in cavities in large mature trees, cacti or rocky cliffs. The majority of observed breeding occurs in rural areas .Trees were nests have been found: Lignum Vitae (*Guiacum officinale*).

Shelter requirements (roosting & shelter from predators):
Roosting occurs communally in large mature trees. YSAP abundance is positively correlated with habitat maturity (a greater density of large, trunk diameter, and tall trees, and greater coverage from trees).

Space requirements:
The Yellow-shouldered parrot inhabits xerophytic vegetation, frequenting desert shrublands dominated by cacti and low thorn-bushes or trees.

Other requirements:
Unknown.

Distribution data:
Bonaire: northern 'natural' areas such as Fontein, Dos Pos, Wasao, Juwa and Put Bronswinkel . Washington-Slagbaai National Park, Dos Pos and Washikemba-Fontein-Onima.

Which habitat requirements would be possible to identify from satellite data?
- Habitat maturity.
- Xerophytic vegetation, desert shrublands dominated by cacti and low thorn shrubs.
- Rocky cliffs.

Threats (anthropogenic or climate):
- Impoverished food sources and lack of mature trees for nests limits population size.
- Due to habitat degradation parrots move to more urban areas, resulting in conflicts with humans (collisions with vehicles and buildings) + negative attitude as they eat from garden fruit trees.
- Poaching and nest destruction (preventing future use).
- Grazing by herbivores (goats, donkeys, pigs) causes decrease in plant diversity (several plant species are food and/or nest trees for parrots. Herbivores have halted regeneration of edible species .
- Drought periods in combination with habitat degradation may lead to mortality (Voous, 1983). Drought periods may become increasingly common with global climate change.
- Predation by cats and rats .
- Introduced (e.g. European honey-bee (*Apis mellifera*) and native (e.g. Pearly-eyed thrasher (*Margarops fuscatus*) nest competitors. Food competitors (e.g. Brown-throated Conure and Troupial)

References: Birdlife International 2012f *Amazona barbadendis*, DCNA, 2012; Sanz and Rodríguez-Ferraro ,2006; Voous, K.H., 1983; Williams, S.R., 2009.

Least tern
(*Sterna antillarum*)

© M. Walsh-McGehee, USA

Occurrence:
Saba: present.
Statia: present.
Bonaire: present.

Species description:
The Least tern is a highly migratory seabird. On Bonaire it is a common breeding visitor.

Functions:
Contribution to food webs.

Nourishment requirements (food & water):
Least tern hunt in shallow water areas (nearshore ocean, estuaries, lagoons, lakes, ponds, rivers) and feeds on small fish that swim near the surface, but also shrimp, marine worms and insects. Hunting method consists of hovering an diving from height up to 10 m. No information on least tern drinking water requirements was found in the literature.

Shelter requirements (roosting & shelter from predators):
Adult least terns require no cover during breeding season. Chicks use sparse vegetation and water deposited debris for shade and protection. Night roosting has been seen on a wide stretch of sandy beach.

Reproduction requirements (nesting & mate attracting):
Breeding habitat; generally characterized as open sand, soil or dried mud in the proximity of a lagoon, estuary or river. Areas used for mating, nesting and feeding young have been describes as bare. Least terns in marine environments nest on islands, peninsulas, beaches, sandbars, and isolated sandpits usually between the high tide line and the area of dune formation. They scrape out shallow nests on unconsolidated substrates such as sand, soil, shell or gravel. Nesting habitat is generally characterized as ephemeral (short-lasting), represented vegetatively by pioneering plant species that are low-growing, scattered or form dispersed clumps.

Space requirements:
Seacoasts, lakes, rivers. In winter also beaches, bays and estuaries.

Other requirements:
Unknown.

Distribution data:
Bonaire: The larger saltworks surrounding the Pekelmeer harbour 180 nesting pairs of Least Tern .

Which habitat requirements would be possible to identify from satellite data?
- Nearshore ocean, lagoons.
- Bare, ephemeral , low-growing scattered vegetation habitat.
- Open sand/ dry mud/ shell/gravel.
- Beaches

Threats (anthropogenic or climate):
- Loss of feeding and nesting habitat due to recreational activities and development.
- Loss of nesting due to inundation.
- Disturbance of breeding sites by human activities.
- Natural and introduced predators.

References

- BirdLife International 2012d. *Sterna antillarum*.
- Carreker, R.G. 1985.
- Prins *et al*., 2009
- Debrot *et al*., 2009
- Wells & Child Wells, 2006

Audubon's shearwater
(*Puffinus lherminieri*)

No picture available

Occurrence:
Saba: present. National bird of Saba.
Statia: present.
Bonaire: present.

Species description:
The Audubon shearwater is a tropical common seabird. On Bonaire, it is a scarce, possibly breeding, visitor.

Functions:
Contribution to food web.

Nourishment requirements (food & water):
This species feeds at sea on fish, squid and crustaceans obtained by pursuit-diving, pursuit-plunging, pattering and surface-seizing. Feeding occurs during the day. It prefers to feed at open sea as close to the shore predators occur (e.g. fregat), which steel food.

Reproduction requirements (nesting & mate attracting):
This species breeds on oceanic islands, coral atolls and rocky offshore islets, mainly on cliffs and earthly slopes. Nest are predominately made burrows on rocky areas (and crevices) and in cliffs, supplying the necessary shelter. Breeding occurs at night. The nesting habitat is quite varied. The birds nest in holes on the ground high in the hills, but also in natural hollows under cliffs, rocks and limestone, sometimes only just above sea level.

Shelter requirements (roosting & shelter from predators):
Cliffs.

Space requirements:
The Audubon shearwater is a colonial seabird, found on pelagic, offshore and inshore waters. A free flight path is preferred.

Other requirements:
Unknown.

Distribution data:
Information on the distribution and population size is scarce.

Confirmed areas on Saba are: Rainforest ravine on the north coast, the Sulphur mine canyon on the north coast and near The Bottom, east side of Great Hill and at the cliffs of Great Hill between Ladder Point and Cape Point (17.624 W, 63.26 S).

St. Eustatius: Tumble Down Dick Bay (nowadays much disturbed by Oil Terminal activities and Gallows Bay.
Saba: sheltered places in the higher parts of the island.

Which habitat requirements would be possible to identify from satellite data?
- Cliffs and earthly slopes.
- Open sea in the vicinity.
- Sparsely vegetated area.

Threats (anthropogenic or climate):
- Cats and rats prey on eggs and young.
- Climate (sea level rise): only when their habitat is in danger.
- Habitat destruction/loss.
- Human collecting of eggs and young hardly occurs anymore (on Saba).

References

- BirdLife International 2012c. *Puffinus lherminieri*.
- Collier and Brown, 2009
- Geelhoed *et al*., 2012 *(in press*)
- Jongman *et al.,* 2010
- Prins *et al*., 2009
- Personal comments Steve Geelhoed
- Rojer, 1997a

Sea turtles

© H.W.G. Meesters

Species description:
Highly migratory species.

Function:
Contribute to marine and coastal food webs (e.g. control sponge and algal growth).

Nourishment requirements (food & water):
Green turtle: marine algae and sea grasses (*Thalassia sp*.)
Leatherback: soft-bodied animals, such as jellyfish and salps (forage in coastal waters)
Hawksbill: sponges, soft-bodied invertebrates and other reef-dwelling creatures (may therefore be predominantly found on coral reefs, hard bottom habitats, sea grass, algal beds, mangrove bays, creeks, mud flats).

Reproduction requirements (nesting & mate attracting):
Nesting: sand beaches, preferably non-volcanic sand, without lights in the background from buildings or roads. Volcanic beaches are used (St. Eustatius).
Leatherback: juveniles remain in tropical waters (> 26 °C)

Shelter requirements (roosting & shelter from predators):
Their shell provides shelter.

Space requirements:
Pelagic, open ocean, coastal waters, sandy beaches.

Which habitat requirements would be possible to identify from satellite data?
- Sand beaches
- Coastal waters
- Seagrass meadows and coral reefs.

Threats (anthropogenic or climate):
- Destruction and/or modification of habitat (nesting beaches have been degraded by joy riding, pollution and sand mining as well as commercial and tourist development .
- Foraging grounds have been altered or destroyed by development, pollution, increased shipping traffic and recreational activity .
- Marine debris e.g. lost and discarded fishing gear.
- By catch in marine fisheries.
- Harvesting of eggs, juveniles and adults.
- Light sources near nesting beaches.
- Oil pollution
- Artificial light

References
- J. Smith, 2008.
- Sybesma, J. 1992.
- Seminoff, 2004.
- Dow *et al*., 2007
- Sarti Martinez, 2000.
- Mortimer, J.A & Donnelly, M. 2008.

Sea turtles species	Common name	Bonaire	Saba	St. Eustatius	Status
Chelonia mydas	Green turtle	Yes (N,F)	Yes (IN,F)	Yes (N,F)	Endangered
Dermochelys coriacea	Leatherback	I	I	Yes (N)	Critical
Eretmochelys imbricata	Hawksbill	Yes (N,F)	Yes (IN,F)	Yes (N,F)	Critical

N – nesting, F – foraging, IN – infrequent nesting, I – infrequent.

Morning glory

(*Ipomoea sphenophylla*)

No picture available

Occurrence:
Saba: not present.
Statia: present.
Bonaire: not present.

Species description:
The Morning glory is a rare endemic species of St. Eustatius of the family *Convolvulaceae*.

Nourishment requirements (food & water):
Unknown.

Reproduction requirements:
Unknown.

Shelter requirements:
Unknown.

Space requirements:
Unknown.

Other requirements:
Unknown.

Distribution area:
A small area to the south of Little Mountain / St. Eustatius Terminal ground.

Which habitat requirements would be possible to identify from satellite data?

- St. Eustatius Terminal ground.

Threats (anthropogenic or climate):
Habitat loss due to expansion of St. Eustatius Oil Terminal.

References

- Rojer, 1997a.
- Jongman *et al*., 2010.

Sea grasses

Thalassia testidinum

Species description:
A mixed group of flowering plants that grow submerged in shallow marine and estuarine environments.

Functions:
Habitat forming species. Slow water flow and trap sediment, filtering lagoon water. Holds sediment in place, prevents erosion.
Oxygen production and CO2 sequestration.
Provides shelter, foraging en nursery habitat for various species (e.g. sea turtles, Queen conch).

Nourishment requirements (food & water):
- Light (photosynthesis)
- Oligotrophic areas (nutrient low).

Reproduction requirements:
Production of seeds.

Space requirements:
Sandy, muddy bottoms in inland bays.
Protected coves and lagoons.
Deeper water where wave action is less and water is still transparent. Back reefs.

Shelter requirements:
Shelter against currents , wave action and tide (produce resuspension and transport of sediment, limiting light availability).

Other requirements:
T. testudinum depth range: lower intertidal to maximum 10 - 12 m depth and below 20m.
T. testudinum salinity range: 5 – 45 ppt with max. growth rate at 30 – 40 ppt.
S. filiforme depth range: upper sublittoral down to more than 20 m.
S. filiforme does not grow in brackish water. Salinity range: 5 – 45 ppt, with max. growth rate 25 ppt.
Clear water.

Threats (anthropogenic or climate):
- Poor water quality
- Eutrophication
- Sedimentation
- Coastal development
- Pollution (landbased sources)
- Recreation

Distribution area: Bonaire - Lac Bay.

Which habitat requirements would be possible to identify from satellite data?
- Inland bays, coves, lagoons, back reefs.
- Sea grass beds

References

- Short *et al*., 2010 a.
- Short *et al*., 2010 b.
- Debrot and Sybesma, 2000.
- Jongman *et al*., 2010
- Lirman & Cropper, 2003

Sea grass species	Common name	Bonaire	Saba	St. Eustatius
Thalassia testidinum	Turtle grass	yes	limited	absent
Syringodium filiforme	Manatee grass	yes	limited	yes

Mangroves

© A.O. Debrot

Species description:
A mixed group of flowering plants that grow submerged in shallow marine and estuarine environments.

Functions:
Habitat forming species. Slow water flow and trap sediment, filtering lagoon water. Holds sediment in place, prevents erosion. Oxygen production and CO2 sequestration. Provides shelter, foraging en nursery habitat for various species .

Nourishment requirements (food & water):
Nitrogen (N) and phosphorus (P), Potassium (K).

Reproduction requirements:
Flowering and production of propagules. Propagules need to remain in water before germination.

Shelter requirements:
Sheltered from waves: cannot occur direct in the sea, but needs to be sheltered, e.g. behind a coral reef in a lagoon (e.g. Lac) or further inland within bays (e.g. Lagun on Bonaire).

Space requirements:
Oligotrophic tropical tidal environments.
Coastal zone: only along the coast, not inland (for the delivery of nutrients by tidal inundation and flood waters.)

Distribution area:
Bonaire: Lac and Lagun.

Other requirements:
- Seawater: can predominantly occur in salt water or water to open sea.
- Sunlight: full (Red, White)
- Elevation range: 0 -6m (Red), upper margins of mangrove-upland interface (White).
- Soil acidity (pH): 6-8.5 (Red, Buttonwood), 5.3-7.8 (Black)
- Salinity – 0-90ppt. Occasionally ,White :> 90 ppt

Which habitat requirements would be possible to identify from satellite data?
- Sea water
- Coastal zone

Threats (anthropogenic or climate):
- Sedimentation (due to erosion)
- Overgrazing (due to erosion)
- Pollution
- Acidification
- Sea level rising
- Logging

References
Davaasuren & Meesters, 2011; Debrot & Sybesma, 2000; Duke, 1983; Duke & Allen, 2006; Ellison *et al.*, 2010. Jongman *et al.*, 2010; Judd *et al.*, 2008; Reef *et al.*, 2010.

Mangrove species	Common name	Bonaire	Saba	St. Eustatius	Status
Rhizophora mangle	Red mangrove	Yes	Absent	Absent	Least concern
Laguncularia racemosa	White mangrove	Yes	Absent	Absent	Least concern
Avicennia germinans	Black mangrove	Yes	Absent	Absent	Least concern
Conocarpus erectus	Buttonwood	Yes	Absent	Absent	-

Appendix B. Distribution data on selected species and habitats.

Distribution data	Bonaire	Source	Saba	Source	St. Eustatius	Source
Sea turtles						
Green turtle	Beaches (nesting, quiet, unlighted, undisturbed are preferred), seawater e.g. Lac Bay (foraging)	Debrot *et al*., 2012	insignificant nesting, foraging occurs	Dow *et al*., 2007	Zeelandia beach, Turtle beach, Lynch Bay, Oranje Bay, Kay Bay/Crooks castle (nesting). Foraging occurs.	Dow *et al*., 2007; Berkel, 2009
Hawk's bill	Beaches (nesting), seawater (foraging)	Smith *et al*., 2012	insignificant nesting, foraging occurs	Dow *et al*., 2007	Zeelandia beach, Turtle beach, Lynch Bay, Oranje Bay, Kay Bay/Crooks castle (nesting). Foraging occurs.	Dow *et al*., 2007; Berkel, 2009
Leatherback	Beaches (nesting), seawater (foraging)	Smith *et al*., 2012	infrequent	Dow *et al*., 2007	Zeelandia beach, Turtle beach, Lynch Bay, Oranje Bay, Kay Bay/Crooks castle (nesting).	Dow *et al*., 2007; Berkel, 2009
Reptiles						
Red-bellied racer	N.A.	N.A.	Predominantly higher altitudes. Mary's point.	Rojer, 1997b	Western slope of The Quill (mesic environment, Semi-evergreen seasonal forest, deciduous seasonal forst at lower levels and dry evergreen forest at elevations near the rim of The Quill), Quill Boven National Park (rocky terrain). Higher encounter rate at higher levels, due to presence of rocks and abundance of prey (Medina Diaz *et al*., (in press): anoline (lizard) densities > 6000/ha > 300m, 3000/ha intermediate elevations with fewer rocks but some deadfall, < 1000/ha at lower elevations with litter as only cover.)	Savit *et al*., 2005, Powell and Henderson, 2005
Lesser Antillean green iguana	N.A.	N.A.	N.A.	N.A.	The Quill (Important Bird Area) 0 - 601 m, shrubland and forest.	Collier and Brown, 2008
Mollusc						
Queen Conch	Lac Bay	Debrot *et al*., 2012	Present, but no specific areas known.		Outer Statia Harbour (17 28.46'N 62 59.81'W, 80-90 ft depth, coral rubble); West of Barracuda reef (17 27.34'N, 62 29.55'W, 80-90 ft depth, Coral rubble/sand), Zeelandia (17 30.99'N 62 58.69'W, 70-80 ft depth, sand/algal cover), Drop off (17 27.67'N, 62 58.42'W, 60-70 ft depth, sand/algal cover)	Davis, 2003
Bird species						
Caribbean coot	Freshwater ponds, manmade ponds, dams, Onima reservoir, Playa Grandi reservoir, Washikemba reservoir.	Smith *et al*., 2012	? (-)	Voous and Koelers, 1967	? (-)	Voous and Koelers , 1967
American Flamingo	Inner waters of Bonaire, small ponds, Lake Goto, Salina such as Slagbaai, Onima reservoir Pekelmeer.	Smith *et al*., 2012	N.A.	N.A.	N.A.	N.A.
Northern Caracara	?		N.A.	N.A.	N.A.	N.A.
Yellow shouldered parrot	Lower terraces (with exception of TL5), Middle terraces, Higher terraces and plateau, Escarpments, Undulating landscape, Water and areas of anthropogenic use North of Lac Bay, except Lower terraces	Smith *et al*., 2012, pers. ob. Sam Williams	N.A.	N.A.	N.A.	N.A.
Least tern	Lower Terraces N and NE Bonaire, Salina Klein Bonaire, South coast of Klein Bonaire, Island Goto Lake, Island Salina Slagbaai, Cargill saltworks (nesting)	Debrot *et al*., 2009	? (-)	Voous and Koelers , 1967	? (-)	Voous and Koelers , 1967
Common tern	Goto Lake, Salina Slagbaai, Cargill saltworks (nesting)	Debrot *et al*., 2009	(Passage migrant and winter visitor in very small numbers)	Voous and Koelers , 1967	? (-)	Voous and Koelers , 1967
Audubon's shearwater	N.A.	N.A.	Hellsgate (definite breeding). Important Bird Area: Saba coastline (2000 ha)	Voous and Koelers , 1967. Brown *et al*., 2009	Tumble Down Dick Bay (suspected breeding). Breeding ground or as migratory stopover.	Voous, 1967. MacRae & Esteban, 2007.
Plant species						
Morning glory	N.A.	N.A.	N.A.	N.A.	The Quill (Important Bird Area) 0 - 601 m, shrubland and forest.	Collier and Brown, 2008
Habitat types						
Coral reefs	Fringing reefs around Bonaire and Klein Bonaire		Hard corals on the east side of the island only. Soft corals all around.	Buchan	Found around the island. See habitat map McRae & Esteban, 2007	MacRae & Esteban, 2007
Mangroves	Lac Bay, Lagun	Debrot *et al*., 2012,	N.A.	N.A.	N.A.	N.A.
Sea grass beds	Lac Bay, Lagun	Debrot *et al*., 2012	Small patches of Syringodium on the leeward western coast of the island	Buchan	Found all around the island, from approximately 10 m and deeper until about 35m. See habitat map McRae & Esteban, 2007	MacRae & Esteban, 2007

Appendix C. Worldview-2 satellite imagery

With the launch of WorldView-2 on October 8, 2009, a new very high resolution satellite has become available, with a spatial resolution of 0.5 meter for the panchromatic band and 2.0 meter for the 8 multispectral bands. WorldView-2 satellite is owned by DigitalGlobe (Longmont, CO, USA). The 0.5 m panchromatic band can improve the resolution of the multi-spectral bands of lower resolution and capture more details. The satellite orbits the earth in a sun synchronous orbit, at an altitude of 770 km and it has an orbit period of approximately 100 minutes, and a revisit frequency of 1.1 days. The imaging sensor on board captures 8 multispectral bands as well as a panchromatic band, with a swath size of 16.4 km. More precisely it has a spatial resolution for panchromatic bands of 0.46 m at nadir (0.56 m at 20° off-nadir), while multispectral imagery is captured with a resolution of 1.8 meters at nadir (2.4 meters off-nadir) (Padwick *et al.*, 2010; Wolf, 2010). The multispectral bands that are captured are shown in Table 1, each spectral band has certain characteristics that make it useful for certain application, 4 spectral bands increases its capabilities; Coastal band, Yellow band, Red-Edge band and NIR 2 band.

Table 1. Characteristics of the 8 spectral bands of WorldView-2 (derived from Davaasuren & Meesters, 2012).

Coastal band (400 – 450 nm) • Absorbed by chlorophyll in healthy plants and aids in conducting vegetative analysis • Least absorbed by water, and will be useful in bathymetric studies • Substantially influenced by atmospheric scattering and has the potential to improve atmospheric correct techniques.
Blue band (450 – 510 nm) • Readily absorbed by chlorophyll in plants • Provides good penetration of water • Less affected by atmospheric scattering and absorption compared to the Coastal band
Green band (510 – 580 nm) • Able to focus more precisely on the peak reflectance of healthy vegetation • Ideal for calculating plant vigor • Very helpful in discriminating between types of plant material when used in conjunction with the Yelllow band
Yellow band (585 – 625 nm) • Very important for feature classification • Detects the “yellowness” of particular vegetation, both on land and in the water.
Red band (630 – 690 nm) • Better focused on the absorption of red light by chlorophyll in healthy plant materials • One of the most important bands for vegetation discrimination • Very useful in classifying bare soils, roads and geological features
Red Edge band (705 – 745 nm) • Centred strategically at the onset of the high reflectivity portion of vegetation response • Very valuable in measuring plant health and aiding in the classification of vegetation
NIR 1 band (770 – 745 nm) • Very effective for the estimation of moisture content and plant biomass • Effectively separates water bodies from vegetation, identifies types of vegetation and also discriminates between soil types.
NIR 2 band (860 – 1040 nm) • Overlaps the NIR 1 band but is less affected by atmospheric influence • Enables broader vegetation analysis and biomass studies

The high spatial resolution of WorldView-2 enables the discrimination of fine details, like vehicles, shallow reefs and individual trees in an orchard, and the high spectral resolution provides detailed information on diverse areas such as the quality of road surfaces, the depth of the ocean, and the health of plants (Davaasuren & Meesters, 2012). The two red and two infra-red channels are useful for detecting biomass and chlorophyll content in vegetation. The difference between the near-infrared NIR 1 and NIR 2 band is that the NIR 2 band is less affected by atmospheric influence, while enabling broader vegetation analysis compared to the NIR 1 band, according to the official specifications of the WorldView-2 sensor (DigitalGlobe, 2009).

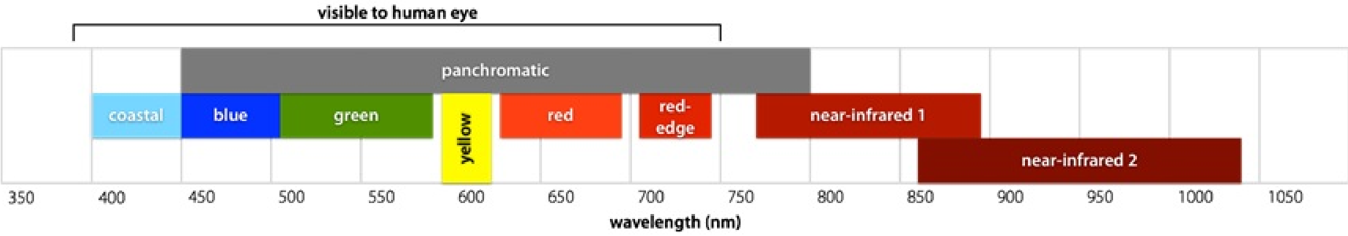


Figure 1. A graphical representation of the bands captured by the Worldview-2 sensor.

Appendix D. Pre-processing.

Atmospheric corrections

Image pixel data are unique to the sensor that captures them and should not be directly compared to imagery from other sensors in a radiometric/spectral sense. Instead, image pixels should be converted to Top-Of-Atmosphere (TOA) spectral reflectance. And for many multispectral analysis techniques such as band ratios, Normalized Difference Vegetation Index (NDVI), matrix transformations, etc., it is common practice to convert multispectral data into TOA reflectance before performing the analysis. For more information on the conversion to Top Of Atmosphere spectral reflectance data, see the technical note in Appendix E.

The atmospheric correction allows to get rid of the atmospheric effect on the measured values and to obtain the at-surface reflectance values. Figure 1. compares the satellite images with and without atmospheric correction.

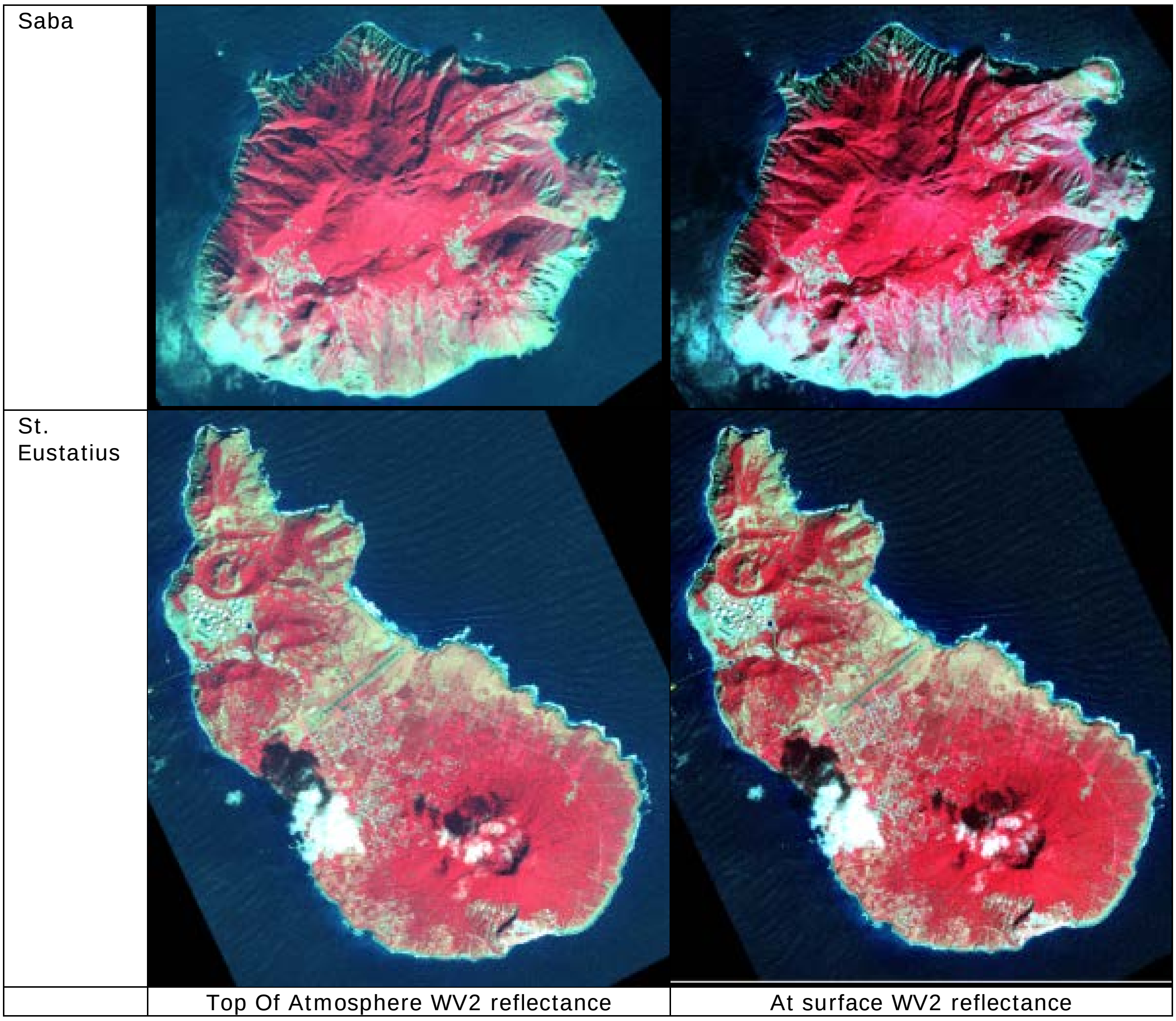


Figure 1. Atmospheric correction of the satellite images of Saba and St. Eustatius.

Geometric accuracy and Pan-sharpening

By overlaying the satellite image with ancillary data (vegetation maps), geometric accuracy can be determined.

Figure 2. WV-2 image overlaid with topographic information from the vegetation map for St. Eustatius. The topographic data can be seen as roads and the airstrip (red lines) and buildings (black lined squares) on top of the satellite image.

When the geometric accuracy is acceptable for both multi-spectral and panchromatic bands, transformation such as pan-sharpening can be performed for better visual interpretations. Pan-sharpening is a technique that merges high-resolution panchromatic data with medium-resolution multispectral data to create a multispectral image with higher-resolution features. Hyper spherical Color Space Pan Sharpening was designed specifically for WorldView-2 and is a new feature in IMAGINE 2011. However, HCS works with any multispectral data containing 3 bands or more (Padwick *et al.*, 2010).

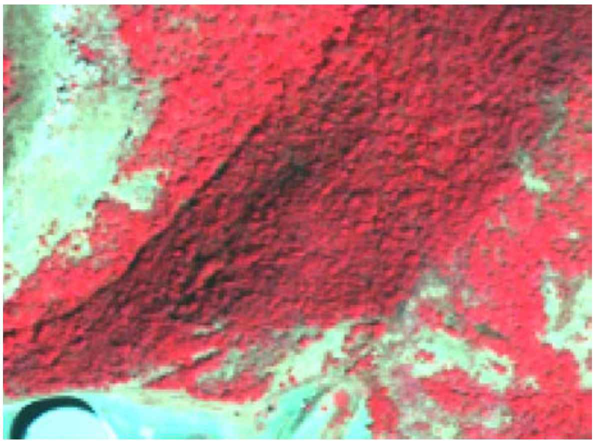


Figure 3a WorldView-2 MS 2m (original)

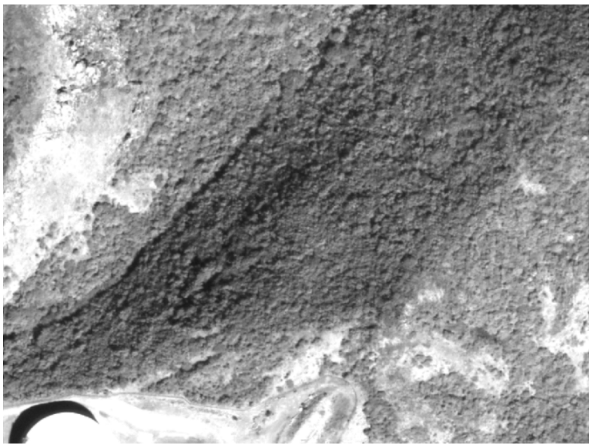


Figure 3b WorldView-2 PAN 0.5m (original)

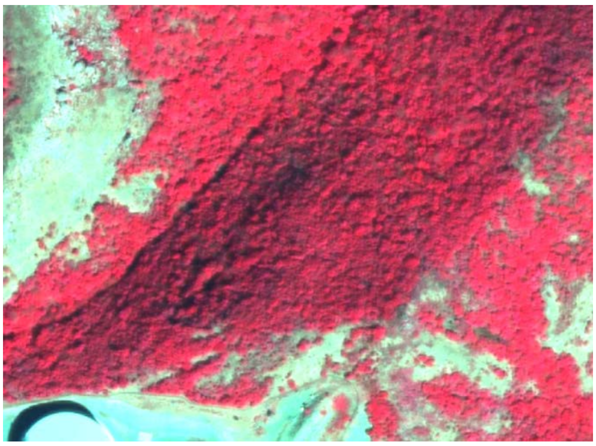


Figure 3a, b, and c, show the original satellite image, the original panchromatic image and the satellite image after pan-sharpening, respectively.

Figure 3c WorldView-2 HCS pan sharpened

Topographic corrections

A Digital Elevation Model (DEM) is a digital representation of the terrain elevations within a certain area. The model is created from terrain elevation data (predominantly obtained through remote sensing) and contains only the specific elevation values at specific locations (it does not show elevation contours or roads etc.,). With a DEM, and thus knowledge on the elevation of the terrain, it is possible to get a better understanding of the terrain, for example, it is possible to distinguish which areas lie downstream from other areas, which locations are visible from a specific point, where the steep slopes are etc. Shadow reduction can be obtained by terrain correction based on a DEM and using atmospheric correction software for satellite imagery such as ATCOR.

During the present study two DEMs were considered;

i. The ASTER GDEM (Global Digital Elevation Model) with a spatial resolution of 30 meters. An extensive description of the ASTER GDEM is given at the end of this Appendix.
ii. A High Resolution DEM with a 1 meter spatial resolution (both horizontal and vertical), from DOTKA Data.

Figure 4a. and 4b. respectively show the ASTER DEM and the High Resolution DEM for Saba. It is apparent that the High Resolution DEM provides more elevation detail. This difference is a result of the available spatial resolution.

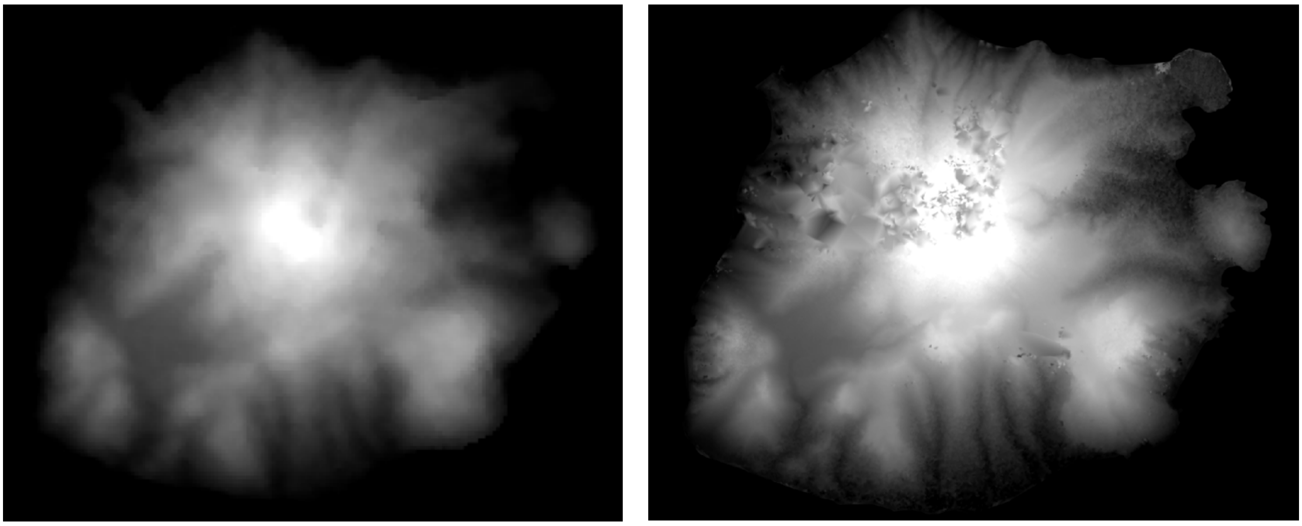


Figure 4. a) Example of the 30m spatial resolution ASTER DEM for Saba (the brightest tone represents the highest elevation values, the darkest tone the lowest),
b) High Resolution DEM for Saba produced by Dotka Data (the brightest tone represents the highest elevation values, the darkest tone the lowest).

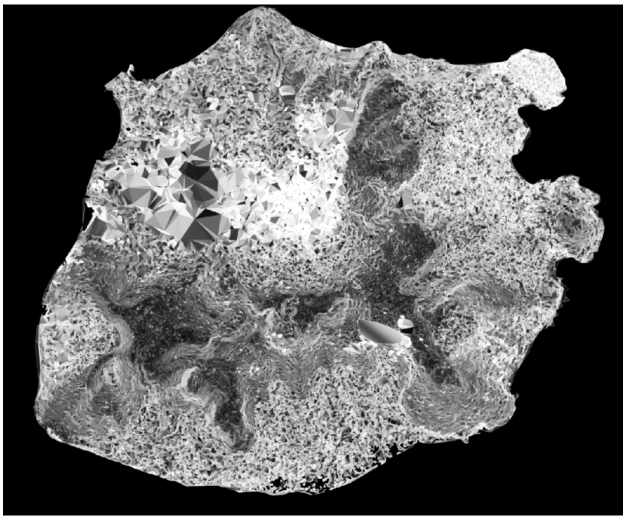


Figure 5. Slope derived from HR DEM for Saba.

Based on the High Resolution DEM, slope estimations were calculated (Figure 5). Figure 5 shows the elevation representation of Saba using triangular facets. Triangles with points that are widely spaced, represent regions with little variation in surface height. In contrast, point density increases in areas with large variations in height.

Figure 6a. and 6b. respectively show a small area of the satellite image (zoomed in) of a part of the east coast of Saba and the slope estimations for the same area based on the HR DEM.

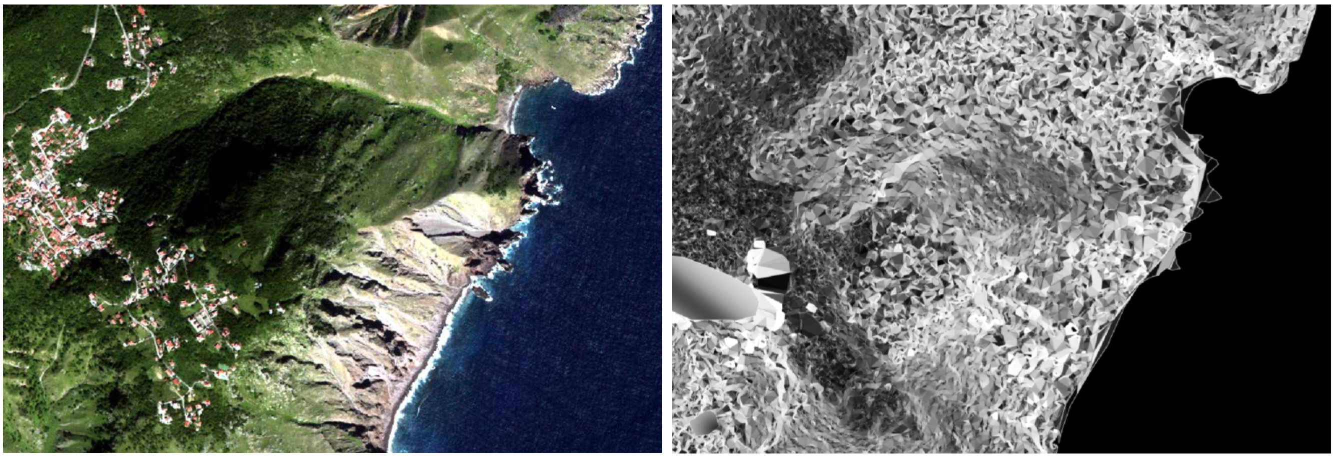
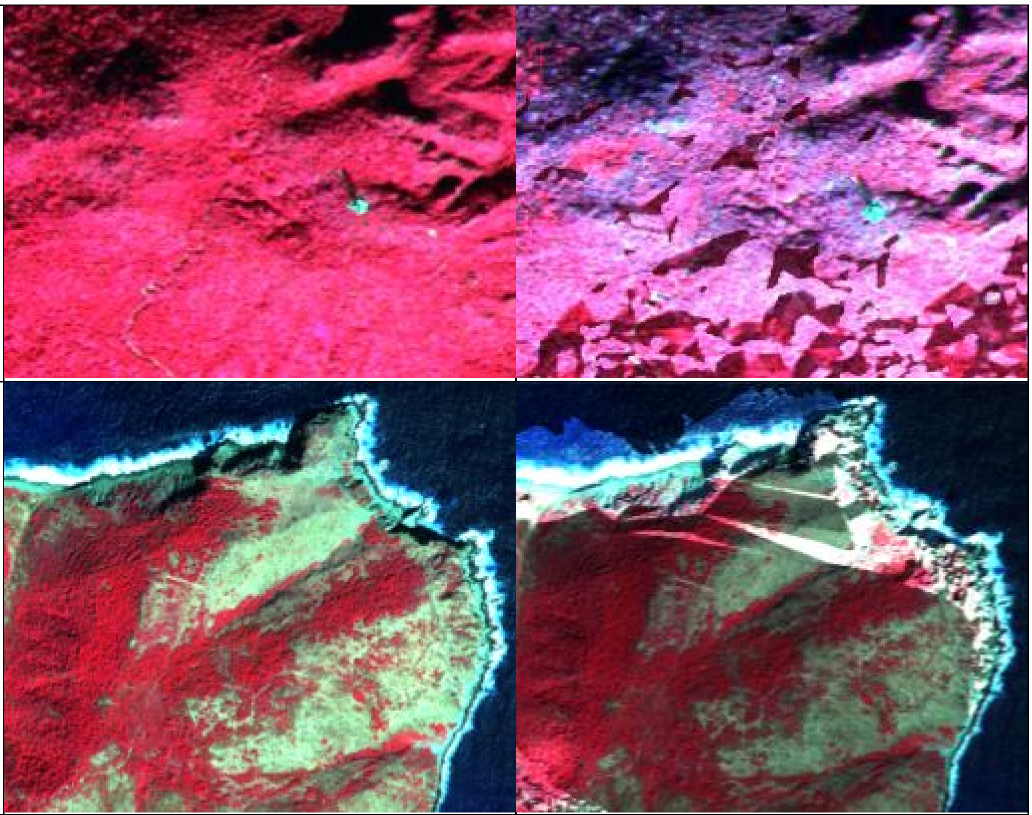


Figure 6. a) Detail of the WV-2 image of the east coast of Saba (near Windward side), b) Detail DEM slope (%) on the east coast SABA (notice artefact in below left corner).

Notice especially the artefacts in the below left corner of the latter image. Artefacts are objects that are not naturally present but may occur as a result of pre-processing. It became apparent that the HR DEM still contained too many artefacts and the vertical resolution was too low to make a good terrain correction with ATCOR-3 and the WV-2 imagery and HR DEM as an input.



Saba		
St. Eustatius		
	No topographic correction	Artefacts brought by DEM

Figure 7. Comparing images of Saba and St. Eustatius without use of DEM (left) and with use of DEM (right).

To show the effects such a DEM can have on the pre-processing, topographic corrections were performed on the satellite images of Saba and St. Eustatius, using the HR DEM from DOTKA DATA (figure 7). The artefacts visible on the right are brought on by the use of the DEM. It is clear that the use of this DEM impedes effectiveness. The current HR DEM has too many artefacts to perform a good terrain correction. For this reason, it was decided not to make any topographic correction. As a result, shadow effects on the satellite images could not be lifted, and therefore it was not possible to classify these areas.

Although the HR DEMs were not good enough to perform a topographic correction in this stage the HR DEMS are good enough for 3-D visualisation as figures 8 and 9 from ARCSCENE show.

Figure 8. Example of a 3D scene as derived from the WV-2 image and the HR DEM for Saba (using ArcScene10).

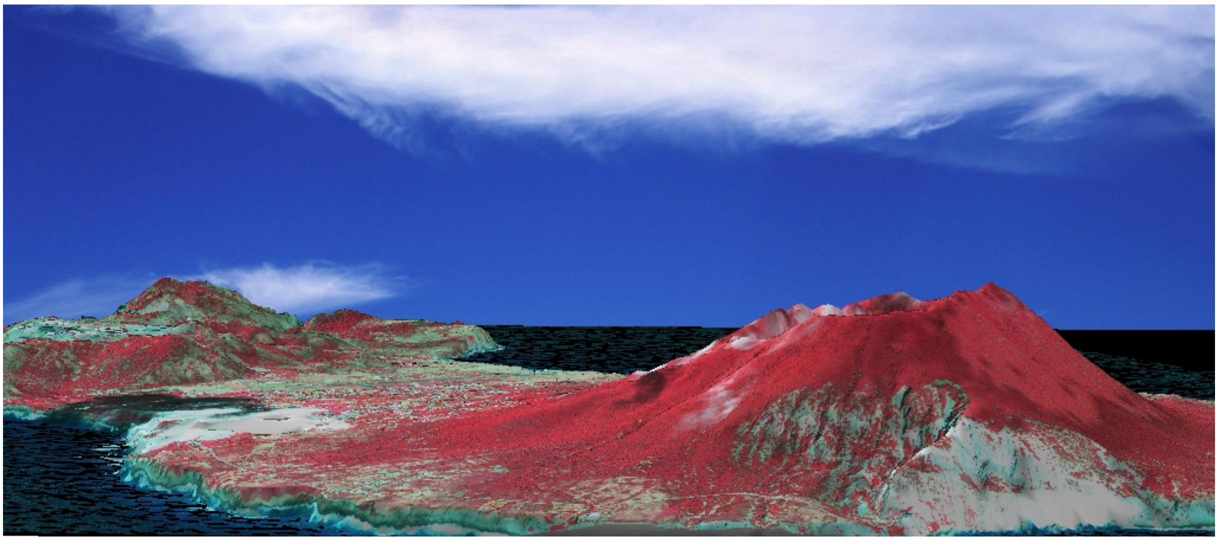


Figure 9. Example of a 3D scene as derived from the WV-2 image and the HR DEM for St. Eustatius (using ArcScene10).

ASTER GDEM

The ASTER GDEM (Global Digital Elevation Model) is described, by ASTER, as follows (Source: http://asterweb.jpl.nasa.gov/gdem.asp):

'*The first version of the ASTER GDEM (Global Digital Elevation Model), released in June 2009, was generated using stereo-pair images collected by the ASTER instrument on-board Terra (a multi-national NASA scientific research satellite). ASTER GDEM coverage spans from 83 degrees north latitude to 83 degrees south, encompassing 99% of Earth's landmass. The improved GDEM V2 adds 260,000 additional stereo-pairs, improving coverage and reducing the occurrence of artefacts (peaks or dips not existing in nature). The refined production algorithm provides improved spatial resolution, increased horizontal and vertical accuracy, and superior water body coverage and detection. The ASTER GDEM V2 maintains the GeoTIFF format and the same gridding and tile structure as V1, with 30-meter postings and 1 x 1 degree tiles. Version 2 shows significant improvements over the previous release. The ASTER GDEM V2, however, contains anomalies and artefacts that will impede effectiveness for use in certain applications. As a contribution from METI and NASA to the Global Earth Observation System of Systems (GEOSS), ASTER GDEM V2 data are available free of charge to users worldwide from the Land Processes Distributed Active Archive Center (LP DAAC) and J-spacesystems.'*

The ASTER GDEM Validation Team (2011) summarized the following findings:

' The absolute vertical accuracy study found the GDEM2 to be within -0.20 meters on average when compared against 18,000 geodetic control points over the CONUS, with an accuracy of 17 meters at the 95% confidence level. The Japan study noted the GDEM2 differed from the 10-meter national elevation grid by -0.7 meters over bare areas, and by 7.4 meters over forested areas. Similarly, the CONUS study noted the GDEM2 to be about 8 meters above the 1 arc-second NED over most forested areas, and more than a meter below NED over bare areas. The global altimeter study found the GDEM2 to be on average within 3 meters of altimeter-derived control, and also documented sensitivity to tree canopy height. The Japan study noted that the horizontal displacement in GDEM1 of 0.95 pixels was reduced to 0.23 pixels in GDEM2. Both teams noted improvements in horizontal resolution, between 71 and 82 meters, comparable to the SRTM 1 arc second elevation model, but at the cost of some increased noise. The number of voids and artefacts noted in GDEM1 were substantially reduced in GDEM2, and in some areas virtually eliminated.'

Appendix E. Technical note on conversion to TOA spectral reflectance

This technical note discusses the procedure to convert radio metrically corrected WorldView-2 products delivered as raw digital numbers (DNs) to Top Of Atmosphere (TOA) spectral reflectance data. This conversion is done in two steps, first the digital numbers are converted in TOA spectral radiance and second those spectral radiance values are converted into TOA spectral reflectance.

First step: Digital numbers to Top-of-Atmosphere Spectral Radiance
WorldView-2 products are delivered as radio metrically corrected image pixels. TOA spectral radiance is defined as the spectral radiance entering the telescope aperture at the WorldView-2 altitude of 770 km. The conversion from radio metrically corrected image pixels to TOA spectral radiance is a simple two steps process that involves multiplying radio metrically corrected image pixels by the appropriate absolute radiometric calibration factor to get band-integrated radiance [W.m-2.sr-1], and then dividing the result by the appropriate effective bandwidth to get spectral radiance [W.m-2.sr-1.µm-1]. The absolute radiometric calibration factor and effective bandwidth values for each band are delivered with every WorldView-2 product and are located in the image metadata files (extension .IMD).

1st step: Band-Integrated Radiance [$W.m^{-2}.sr^{-1}$]
Conversion of WorldView-2 products from radio metrically corrected image pixel values to band integrated radiance:

$$L_{pixel,band} = absCalFact_{Band} * q_{pixel,band}$$

where :
$L_{Pixel,Band}$ = TOA band-integrated radiance image pixels [$W.m^{-2}.sr^{-1}$],
$absCalFactor_{Band}$ = absolute radiometric calibration factor [$W.m^{-2}.sr^{-1}.count^{-1}$] for a given band as provided in the .IMD files,
$q_{Pixel,Band}$ = radiometrically corrected image pixels [counts].

2nd step: Band-Averaged Spectral Radiance [$W.m^{-2}.sr^{-1}.\mu m^{-1}$]
To obtain the TOA spectral radiance, the previous result is divided by an effective bandwidth as follows:

$$L_{\lambda_{pixel,band}} = \frac{L_{pixel,band}}{\Delta\lambda_{Band}}$$

Where :
$L_{\lambda_{pixel,band}}$ = TOA band-averaged spectral radiance image pixels [$W.m^{-2}.sr^{-1}.\mu m^{-1}$],
$L_{Pixel,Band}$ = TOA band-integrated radiance image pixels [W-m-2-sr-1],
$\Delta\lambda_{Band}$ = effective bandwidth [µm] for a given band as provided in the .IMD files.

This conversion from DN to TOA Spectral Radiance can be performed directly using the preprocessing tool available in ENVI 4.8. It is essential to remember to scale the outputs as float.

Second step: TOA spectral radiance to TOA spectral reflectance
The following equation is used in order to go from TOA radiance ($L_{\lambda_{pixel,band}}$) to TOA reflectance ($\rho_{\lambda_{pixel,band}}$):

$$\rho_{\lambda_{pixel,band}} = \frac{L_{\lambda_{pixel,band}} * {d_{ES}}^2 * \pi}{Esun_{\lambda_{band}} * \cos\theta_s}$$

Where :
d_{ES} = Earth-Sun distance in Astronomical Unit [AU],
$Esun_{\lambda_{band}}$ = band averaged solar spectral irradiance [$W.m^{-2}.\mu m^{-1}$]
θs = solar zenith angle [rad]

Earth-Sun Distance

In order to calculate the Earth-Sun distance for a given product, the image acquisition time is used to calculate the corresponding Julian Day (JD). The acquisition time for a product is contained in the image metadata file (.IMD file extension) and allow to retrieve the year, month, day and Universal Time (UT). Once the Julian Day has been calculated, the Earth-Sun distance (dES) can be determined using the following equations (U.S. Naval Observatory):

$$D = JD - 2451545.0$$
$$g = 357.529 + 0.98560028 * D$$
$$d_{ES} = 1.00014 - 0.01671 * \cos(g) - 0.00014 * \cos(2g)$$

The Earth-Sun distance is expressed in Astronomical Units (AU) and should have a value between 0.983 and 1.017. At least six decimal places should be carried in the Earth-Sun distance for use in radiometric balancing or TOA reflectance calculations.

Solar Zenith Angle

The solar zenith angle does not need to be calculated for every pixel in an image because the sun angle change is very small over the 16.4 km image swath and the along-track image acquisition time. The average solar zenith angle for the image is sufficient for every pixel in the image. The average sun elevation angle [degrees] for a given product is calculated for the centre of the scene and can be found in the .IMD files (meanSunEl). The solar zenith angle is simply:

$$\theta = 90.0 - meanSunEl$$

Solar Spectral Irradiance

Specific to WorldView-2, the band-averaged solar spectral irradiance values for an Earth-Sun distance of 1 AU, normal to the surface being illuminated, are listed in the following table:

Spectral band	**Spectral Irradiance [$W.m^{-2}.\mu m^{-1}$]**
Panchromatic	1580.8140
Coastal	1758.2229
Blue	1974.2416
Green	1856.4104
Yellow	1738.4791
Red	1559.4555
Red Edge	1342.0695
NIR1	1069.7302
NIR2	861.2866

The TOA spectral reflectance obtained with this method does not account for topographic, atmospheric, or BRDF differences.

Appendix F. Thematic classes for Saba and St. Eustatius

Cluster for Saba and associated thematic classes

Cluster nr.	Reflective	
7	Highly reflective. No vegetation. Rooftops/buildings, bare ground, roads. No clouds.	**Highly reflective non vegetation. (Roads, Buildings)**
17	no vegetation, highly reflective, barren land, *part of clouds*, parts of buildings, white lines on airstrip	
24	no vegetation. Highly reflective, *thin clouds, (thicker than class 10 (and 13*), rocks. Less reflective than 9 and 7. Nearly same reflectance as 17.	
9	Supplementary to 8, More reflective than 8. less than 7. *Clouds,* Tarmac/beton? roads, barren slopes.	
8	Reflective. Less reflective than 7 and 9. *Clouds*, Buildings, Bare ground with no vegetation. Non-water.	
13	Land: *thinner clouds (not as thin as class 10)*, hardly to no vegetation, less vegetation than 10 reflective, houses, bare soil. Non-water.	
27	*Thin clouds, thinner than 26,* parts of buildings, predominately along the coast, cliffs/rocks. Less reflective than 24 and 8.	**Light reflective non vegetation. (**cliff/rocks, buildings.**.)**
30	*Thin clouds, thinner than 27.* Cliff/rocks. Less reflective than 27.	
31	Water: ***edges of clouds****, thinner than 27 and 30.* Cliff/rocks.	
Clouds/Barren		
26	Land: reflective, *thin clouds*, non-vegetation, rocks and cliffs, cars and parts of buildings, barren land, less reflective than 24 and 8. no water	**Rocks and cliffs**
22	Land: little vegetation (more than 13, less than 15, similar to 10), barren land, rocks/cliffs, l*ow reflective parts of clouds* and buildings. No water.	
29	Land: clouds, shadowy little vegetation/barren, cliffs, rocks, shadow of buildings? Transition to shadow. No water.	

Vegetation		
10	Land: *Edges of clouds (thinner clouds)*, little vegetation, less than 15, transition from vegetation to barren land, also buildings. No water	**Very low vegetation**
15	vegetation: little and low, shrub and grass. Low vegetation on slopes and around buildings. Less vegetation than 5. no water	**Low vegetation (shrubs and grass)**
21	vegetation: low shrub, on slopes, on road, *edge of cloud shadow,* transition to grass? A lot like 15. no water	
5	Lower vegetation than 4. Grass. Seen also around airstrip. Predominately in de south and east of the island. No water.	**Medium vegetation trees, shrubs and grass (lower vegetation).**
12	low vegetation: low shrubs, found also on slopes, appears lower vegetation compared to 6. no water	
6	Low shrubs. More vegetation than 5 it seems. Lower/less vegetation than 4. no water.	
4	Lower vegetation compared to 1, along roads, appears to be grass. Grass and low shrubs and low trees. Not as much in the centre of the island as 1 to 3. Predominately in de south and east of the island. No water.	
1	vegetation, shrub, following runoff streams, transition of higher vegetation to grass, predominantly found in the centre of the island en between buildings. No water	**Tops of trees and shrubs.**
2	supplementary to 1, relative higher vegetation compared to 1 (this class shows more structure), shrub & trees, transition of higher vegetation to grassland. Centre of the island and between buildings. No water	
3	supplementary to 1 and 2, relative higher vegetation compared to 1 (more structure), shrub & trees. Centre of the island and between buildings. No water	
11	vegetation: transition from vegetation to shadow, trees, light shadow side of trees. Found on entire island, high distribution. No water	**Sides of trees.**
14	vegetation: trees, not the highest, side of trees (darker purple) shadow/side is darker than class 11 but not the darkest shadow/side. High distribution. Lighter than 16. No water	
16	vegetation: side of trees(deeper purple), not yet shadow. High distribution, less to the south of the island. Darker than 11. No water	
18	vegetation: side of trees, high distribution, not yet shadow(dark purple), darker than 16. No water	

Shadow		
19	light shadow in vegetation (trees and shrubs) (darker than 18	**Light shadow in vegetation (trees and shrubs)**
20	light shadow in vegetation (trees and shrubs), darker than class 19	
23	shadow in vegetation, (trees and shrubs) darker than class 20, but not the darkest shadow	**Medium shadow in vegetation (trees and shrubs)**
25	shadow in vegetation, (trees and shrubs) darker than class 23, not the darkest shadow	
28	shadow in vegetation (trees and shrubs), darker shadow than 25 but not the darkest	
45	dark shadow in vegetation (trees and shrubs), little lighter than 43.	**Dark shadows in vegetation (trees and shrubs)**
43	dark shadows in vegetation (trees and shrubs), darker than 28	
41	dark shadows of cliffs (and shadows in vegetation(trees and shrubs)). A lot like 42.	**Dark shadows of cliffs (a little in vegetation (trees and shrubs)**
42	dark shadows of cliffs (and shadows in vegetation (trees and shrubs)).	
35	*shadow of clouds* and shadows of cliffs	**Shadow of clouds and shadows of cliffs**
47	shadows edges on coastal rocky cliffs + shadow of buildings	**Shadows edges on coastal rocky cliffs + shadow of buildings**
Seawater		
32	**Rocks**	**Rocks and cliffs (northern and west side of the island)**
33	also **rocks (north side of island).**	
38	Edges of clouds. Similar to 32 and 33. **very little cliff**	
39	**very little cliff**	
49	sometimes found in **shadow of cliffs and boats.**	
34	**also parts of cliffs/rocks (northern part of the island**).	
36	**very little cliff shadow**	
44	also **cliff (northern part of the island)**.	

Cluster for St. Eustatius and associated thematic classes

Cluster nr.	**Description**	
	Reflective	
50	Very high reflective, clouds, **white roofs of buildings**, (more reflective than 28)	**Very high reflective non water (bare land, buildings, roads)**
46	Super high reflective, white wall, roofs of buildings (more reflective than 28, less than 50), **land?**	
47	Super high reflective, very bare soil, land, **no water** (less reflective than 46)	
28	V**ery white** (roofs of tanks)	

Cluster nr.	Description	
29	High reflective barren, a few roads (less reflective than 28 and 46, more than 47)	**High reflective non water (bare land, roads)**
33	High reflective bare soil, **land,** (clouds), less reflective than 29	
35	Bare soil and very little edge of the cloud, transition to vegetation? (less reflective than 33) ships, **no water**	
	Clouds/Barren	
24	Rock on a slope and some shade in cloud	**No vegetation (bare land, tarmac, buildings)**
25	Bare rock and bitumen and cloud edges (lighter than 24),	
26	Bare rock and bare pieces of buildings, (darker than 25)	
31	Bare soil (also some cloud edge), lighter than 25	
	Vegetation	
27	Shade of slope vegetation (darker than 32)	**Lighter shadow in vegetation (trees and shrubs)**
32	Lighter vegetation shadows	
36	Light vegetation shadows (lighter/a lot like 32)	
34	Transition vegetation (predominantly from dense to bare)	**Very low vegetation (grass/moss?)**
44	Cloud edges, and grass fields, and transition to bare soil (*towards vegetation*)	
42	Almost bare, but with still some vegetation, very open vegetation (more bare than 34)	
45	Low vegetation (probably grass like, moss?) (more than 42)	
37	Lower, less dense vegetation, low bushes (higher than 45; a lot like 40)	**Low vegetation (bushes)**
38	Relatively low vegetation, but with good reflectance	
40	Low vegetation, grass like, mostly at lower altitudes, homogeneous texture (more vegetation than 45)	
41	Like 40, but a little bit higher, bushes	
39	(Medium high) higher vegetation, but not the highest	**Medium high vegetation (shrubs and trees)**
43	(Medium high) treelike vegetation (lighter than 39)	
48	Higher trees, with much reflectance (lighter than 43)	**Higher trees**
49	High reflective vegetation incl. corallita, (high probability) (lighter than 48)	**Higher trees/ (incl.) corallita**

Cluster nr.	**Description**	
	Shadow	
13	Dark shadows (darker than but a lot like 11), **no water**	**Dark shadows cliff / rock, dark shadow clouds**
11	Clouds, shadows and other shadows, **no water**	
15	Dark shadows (a lot like 13)	
20	Dark shadows on **land**	
23	Shadows (of cloud, crater and vegetation) **no water** darker than 30 but a lot like 30	**Dark shadows vegetation, crater and clouds**
30	Vegetation shadows (also in build-up area), and some cloud shadow, a lot like/lighter than 23, **no water**	
	Water	
12	**Water** glint? (oil drum shadow) ..maybe **shadow**?	**?**

Appendix G. Ground truthing data St. Eustatius and Saba

Ground truth data St. Eustatius

Nr.	Longitude	Latitude	Description
1	-62.981365	17.48436151	White zinc roofing
2	-62.983057	17.48831448	White roofing
3	-62.953824	17.48466117	Bare ground
4	-62.95403	17.48433982	Bare ground
5	-62.987405	17.49784632	Gravel, industry
6	-62.953859	17.48369064	Bare ground close to forest edge
7	-62.9635	17.46866254	Bare, dirt road
8	-62.948873	17.48539336	Road
9	-62.981491	17.49357375	Tarmac
10	-62.985476	17.49320371	Quarry
11	-62.976194	17.50073265	Road on landfill
12	-62.993178	17.48745598	Tamarind tree 10 m
13	-62.97616	17.49131694	Corallita
14	-62.99209	17.48852094	Corallita
15	-62.963142	17.48944628	Corallita
16	-62.99293	17.48951	Big field corallita
17	-62.980265	17.48242579	Corallita
18	-62.954137	17.48602234	*Caesalpinia buondoc*
19	-62.95864	17.48874	*Caesalpinia buondoc*
20	-62.95473	17.4863	*Caesalpinia buondoc*
21	-62.992591	17.48813587	*Leucaena leucocephala* up to 5 m
22	-62.992227	17.48756778	*Leucaena* thicket 5 m high
23	-62.992036	17.4875604	*Lantana* shrub
24	-62.99017	17.51071	*Leucaena* forest 4 m high
25	-62.98989	17.51295	*Leucaena* thicket, tip of it
26	-62.982177	17.49785302	Grass, no more vegetables
27	-62.982079	17.49753301	Grass, no more vegetables
28	-62.981956	17.49756871	Grass, no more vegetables
29	-62.984551	17.49634124	Short grass/Football field / Grazed by cattle and sheep
30	-62.984696	17.49642409	Grass field with dirt road
31	-62.9827	17.49733409	Short grass with bushes/ pasture
32	-62.984187	17.49643177	Short grass / Football field / Grazed by cattle and sheep
33	-62.989692	17.51503022	Grass plus *Jatropha* max 50 cm
34	-62.987342	17.49846449	Bare slope
35	-62.99025	17.51167	Acacia thicket
36	-62.988494	17.49868726	Barren hill slope
37	-62.984617	17.49811239	Melochia/Acacia 6 foot (1.88 m)

Nr.	Longitude	Latitude	Description
38	-62.964951	17.46628272	Grass with bushes
39	-62.986595	17.49779334	Rocks
40	-62.9837	17.50660817	Acacia/Croton scrub 2 m high
41	-62.982195	17.5039765	Acacia thorn scrub plus grass max 2 m
42	-62.983135	17.50463684	Thick bushes 2 m high
43	-62.991315	17.4897622	Lantana shrub
44	-62.963507	17.4894779	*Acacia lantana* high bushes
45	-62.990715	17.51007185	Dense forest, 3-4 m high
46	-62.989039	17.50809205	High scrub, 4 m
47	-62.990958	17.50969539	Dense forest, 6 m high

Nr.	Longitude	Latitude	Description
48	-62.974146	17.48572828	Forest
49	-62.9963	17.49298	*Coccoloba uvifera* 6 m high
50	-62.989012	17.51579499	*Coccoloba uvifera* 0.5-2 m, mapped wrong
51	-62.981927	17.50784824	Building surrounded by *Coccoloba uvifera* forest
52	-62.9877	17.49854783	Forest slope
53	-62.986649	17.50795231	Slope with 2 m high scrub
54	-62.989975	17.51013093	High forest, 6 m high, with patch of *leucaena*
55	-62.99302	17.4937	Dry forest
56	-62.983914	17.4984465	Shrubs 6 foot (1.88 m)
57	-62.953281	17.47554431	Forest on Quill slope
58	-62.99527	17.49605	Forest, 4 m high
59	-62.99285	17.49505	Gumbo limbo forest
60	-62.99335	17.49138	High forest in gully, 8 m high
61	-62.988506	17.51539031	Freshwater pond
62	-62.957429	17.46779462	Beach Boekaniers bay
63	-62.989439	17.51572453	Beach sand
64	-62.980806	17.50629999	Beach
65	-62.9943	17.4874	Bolder beach
66	-62.988008	17.5158786	Shore and surf zone
67	-62.99567	17.49403	Rocks
68	-62.99567	17.49572	Rocks
69	-62.988008	17.5155717	*Ipomoea* and *Coccoloba* thicket 1.5 m high
70	-62.987173	17.51579024	Coastal scrub 0.5-1 m high
71	-62.988626	17.5148409	Slope with rocks and low bushes, *Jaquinia*

Ground truth data Saba.

Nr.	Longitude	Latitude	Description
1	-63.22211904	17.64605941	Tarmac
2	-63.22245611	17.64469531	Concrete
3	-63.22197072	17.64436477	Shrub
4	-63.22288138	17.64561724	Short grazed grass Kelki hel
5	-63.22310247	17.64477815	Short grass grazed Kelki hel, crot
6	-63.22181115	17.64474562	Grass
7	-63.22464809	17.64501021	Mat of hay for sheep, "stal"
8	-63.22442129	17.64504496	Short grazed grass magdalena
9	-63.22521488	17.6434711	Concrete
10	-63.2255763	17.64359991	Croton lantana shrub 1m high
11	-63.22620952	17.64280878	Croton shrub (low), plus grass
12	-63.22660468	17.6436791	Croton lantana 1.5 m
13	-63.2285051	17.64379882	Forest
14	-63.23148301	17.62814858	Road concrete
15	-63.23174257	17.62821792	Roof red
16	-63.23183671	17.63496821	Forest
17	-63.22818628	17.62470781	Lantana camara bushes
18	-63.228	17.624	Ginea grass
19	-63.22776134	17.62399688	Hoobush
20	-63.22898026	17.62494576	Pasture, foot high grass, sheep
21	-63.22851193	17.62377847	Corallita and grass
22	-63.23522914	17.62580332	Forest
23	-63.23085209	17.63802956	Roof
24	-63.23095901	17.63789099	Ceramic tiles
25	-63.22193216	17.62331742	Rubble beach
26	-63.24869392	17.61604761	Quarry
27	-63.25058581	17.63610332	Mahogany woodland
28	-63.22785616	17.64248734	Croton shrub hoog
29	-63.22734464	17.64259293	Croton shrub
30	-63.23567645	17.62484537	Shrub magdalena (low)
31	-63.25198932	17.63767379	Mahogany woodland
32	-63.25268563	17.63682204	Mahogany woodland
33	-63.226	17.626	Elephant grass
34	-63.2381315	17.62311361	Shrubs low
35	-63.24162761	17.62516499	Concrete
36	-63.24387772	17.62179155	Concrete roof
37	-63.23793062	17.62279886	Grass, shrubs (low)
38	-63.23136807	17.63606891	Forest
39	-63.23094717	17.63179843	Concrete

Nr.	Longitude	Latitude	Description
40	-63.24798424	17.61538142	Surf
41	-63.24106	17.62857	*Taesine* grass planted
42	-63.24065	17.62845	Guinea grass planted
43	-63.25076	17.62505	Corallita
44	-63.243	17.622	Corallita
45	-63.254	17.628	*Philodredron giganteum*
46	-63.248	17.622	*Cryptostagia grandiflora*
47	-63.25	17.62	*Cryptostagia grandiflora*

Appendix H. Land cover and forest formations

Comparing surface area of the land cover classes of St. Eustatius between Helmer *et al*., 2008 and the present study.

Land cover or forest formation.					
Helmer *et al*., 2008	**Ha.**	**%**	**Present study (Level 3)**	**Ha.**	**%**
Urban or built-up land			Discontinuous urban fabric	27.8	
High-medium density urban or built-up land	100				
			Industrial and commercial units	9.4	
Low Density Built-up land (rural or residential)	42		Road and rail networks and associated land	67.0	
			Airport	3.5	
Total	142	7		107.7	5.1
Pasture and Drought Deciduous Woodland			Pastures	140.2	
			Herbaceous rangeland	58.2	
Pasture, Hay or other Grassy Areas	773		Thorn scrub	646.5	
			Arable land	3.6	
Total	773	38.1		848.5	40.2
Pasture and Drought Deciduous Woodland			Invasive (Corallita?)	14.9	
Drought Deciduous Woodland	328		Invasive (*Caesalpinia buondoc?*)	27.2	
Drought Deciduous and semi-deciduous Forest, Forest/Shrub or shrubland (dry, dry-moist), lowland or submontane			Invasive (Tamarinde?)	6.9	
Deciduous, evergreen coastal and mixed forest or shrubland with or without succulents, on either limestone or other substrates	328		Forest (seasonal broadleaved evergreen?)	69.3	
Drought deciduous forest/shrub	89		Forest (dry broadleaved evergreen?)	52.3	
Semi-deciduous forest (incl. semi-evergreen forest)	159		Forest (deciduous seasonal?)	0.4	
Seasonal Evergreen and Evergreen Forest or Forest/Shrub (Moist, Moist-Wet, Wet, rain), Lowland or Submontane			Forest (broadleaved semi-evergreen?)	610.8	
Seasonal Evergreen Forest	11				
Total	915	45.1		781.8	37.1
No vegetation			Unconsolidated materials (e.g. sand)	12.7	
Coastal sand, rock and bare soil	86				
			Rocks	120.2	
Bare soil (incl. bulldozed land)	112		Rocky slopes sparsely vegetated	19.1	
Total	198	9.76		152	7.2
Cloud cover	0		Water bodies	0.7	0.0
			Cloud cover	218.7	10.4
Total	2029	100	**Total**	2109.4	100

Appendix I. Glossary of technical terms.

(Source: Davaasuren & Meesters, 2012)

- **Ancillary data-** data from sources other than remote sensing, for example vector (see Vector) data from GIS (Geographic Information system) used to assist in analysis and image classification.
- **Bands (of image)**- bands are the recorded range of the Electromagnetic spectrum by satellite sensor of reflectances of the features. The range of the bands are expressed in nanometers (see Nanometers) and they are limited by satellite sensor mounted on satellite.
- **CORINE Land Cover-** *Coordination of information on the environment,* a European programme that gathers information on the environment, including the land cover classes.
- **Digital Elevation Model (DEM)**- it is a three dimensional representation of a terrain's surface and it is usually expressed as a series of points with X,Y, and Z values (heights), stored in image values. It enables to have a better understanding of the terrain. For example, to distinguish which areas lie downstream from other areas.
- **Ecoprofiles** describe the different abiotic and biotic needs of a species. It describes the required and preferred food, shelter, habitat etc.
- **Electromagnetic spectrum**- it is a physical definition of wavelengths, expressed in nanometers (see Nanometers). The spectrum used in Remote sensing starts from infrared region (near, middle and far infrared), visible region (Red, Green, Blue) and thermal.
- **Features**- features can be objects of nature- forest, land, water, etc. and artificial, man-made- e.g., urban structures, artificial mountains, structures in the sea, ships, platforms, etc. Objects of nature and man-made objects can be detected from the space and recorded on satellite images, based on reflectance or spectral signature (see Reflectance).
- **Filters (image processing) –** the filters in image processing of satellite images are processes in computer system to remove the noise (see Noise) from a digital image, for the purpose to improve the visibility of the features on the image. The filters can smooth the image, sharpen the image and highlight the features.
- **Georeferencing-** Georeferencing refers to the process of assigning map coordinates- X and Y to image values (pixels).
- **Grid**- square in the image, representing the smallest element of the image. In remote sensing, the grid is called Pixel (see Pixel).
- **Ground Control Points** – The points of X and Y location of a particular feature measured by GPS. The Ground Control Points (GPC) are used in image Georeferencing (see Georeferencing) and in improving the horizontal and vertical accuracies. The GPC is also used in image classification (see Image classification) and in verification of the classified image (see Image classification).
- **Image**- image is the representation of captured signal or sun light. The features are shown in colours if image is in colours or in black and white (see Panchromatic image). The image can be analogue- printed, or digital- stored in the computer. In Remote sensing, image has a two dimensional function- X and Y coordinates, and size of the image consists from Row and Columns (Height and Width). Such image is called a raster image (see Raster). Each pair of coordinates has reflectance values of the objects, expressed in number (value) (see Image, 8 bits, 11 bit, 16 bit, 32 bit).
- **Image classification-** The process of image processing (see Image processing), in detecting and separating the features from each other. The image classification uses radiometric (see Radiometric resolution) properties of the satellite sensor. The main principle of the image classification is that different objects (features) have different spectral signatures (see Reflectance) and it is based on probability, that each pixel belongs to a particular class. The image classification can be a supervised classification (see Supervised classification) and unsupervised (see Unsupervised classification).
- **Image Processing-** The process which extracts information about features based on their reflectance, transmission and absorption property (see Reflectance, Electromagnetic spectrum) of the sun light.
- **Infrared** region of wavelengths- starts from 0,7 to 5,0 nanometers.

- **ISODATA clustering-** A special case of Minimum distance to mean (see Minimum distance to mean). The difference with Minimum distance to mean is that the user (person operating computer and doing image processing) enters the desirable number of classes of the features (see Features). The desirable number of classes depends from the user's knowledge.
- **Majority filter** replaces cells in a raster based on the majority of their adjacent neighbours.
- **Maximum Likelihood** (image processing)- Statistical process on grouping the pixels into classes, to which pixel of most likely to belong, e.g. the highest probability of the membership. The process is automated and done by image processing software.
- **Minimum distance to mean**- Statistical process to find the mean of each pixel (see Pixel). The process is automated and done by image processing software. All pixels in the image are classified according to the class mean to which they are closest.
- **Multispectral image**- Image containing several bands (see Bands) which can present features in colours, depending what bands combination were used. There are two types of the colour system which is used to display the multispectral image. One colour system is called true colours composite and the other pseudo colours composite.
- **Nanometers**- a nanometer is 0.000000001 meters, equal to 10^{-13} meters.
- **Niche-modelling-** Process of using computer algorithms to predict the geographical distribution of species in a particular area.
- **Noise (image)-** Variation of hue, intensity or saturation in brightness or colour in the image. On a satellite image noise is recorded by a satellite sensor from originated haze (moisture), blocking the visibility of the features, or it can be produced by the satellite sensor itself.
- **Panchromatic image**- Black and white image and image values (see Image) are represented in range from black (zero value) to white (see 8 bit, 11 bit, 16 bit, 32 bit). The image values in between from black to white are represented in shades of grey, in different saturation, hue and intensity (see Saturation, Hue and Intensity).
- **Pansharpening-** Technique that merges high-resolution panchromatic data with medium-resolution multispectral data to create a multispectral image with higher-resolution features.
- **Parallelepiped**- Statistical process of analyzing pixels on the image. The process is automated and done by image processing software. The process makes few assumptions about character of the classes, based on texture (see Texture), surface type (see Surface type), reflectance (see Reflectance) classifying the image using the "Parallelepiped" shaped box.
- **PCA-** Principal Component Analysis. It is used to compress information from multi-spectral bands to fewer bands. The first 3 principal components contains most of the information and normally, the PCA is computed for the first 3 bands. In image processing (see Image processing), the PCA will compress information from 8 bands into 3 bands.
- **Pixel**- Area on the ground which represents a single point on a raster image, or the smallest addressable screen element on a display device; it is the smallest unit of picture that can be represented or controlled. In satellite image the pixel is related with resolution (see Resolution of the satellite image) and satellite sensor (see Satellite sensor).
- **Polygon-** mathematical definition- closed plane figure bounded by three or more straight sides that meet in pairs in the same number of vertices, and do not intersect other than at these vertices. The sum of the interior angles is $(n-2) \times 180°$ for n sides; the sum of the exterior angles is 360°. A regular polygon has all its sides and angles equal. Specific polygons are named according to the number of sides, such as triangle, pentagon, etc. In GIS and Remote sensing each polygon is consists from starting and ending points and lines connecting the points in between. Each point has X and Y coordinates.
- **Radiometric resolution**- the number of possible data file values in each band (see the Image, 8 bit, 11 bit, 16 bit, 32 bit, Bands). For example the original WorldView-2 data has radiometric resolution of 11 bits, which can be changed (resampled) to other resolution, in our case it was resampled to 8 bits.
- **Raster (image)** – raster (image) consists from the squares (grid). Each cell of the grid (see Grid) is represented by a pixel (see Pixel), also known as a grid cell.
- **Reflectance (spectral signature)**- when sun light hits any surface on earth, the sun light can be absorbed (for example by water), transmitted back (dry soil), reflected in full extent (house roof, ice and snow cover) or partially- forest, land, etc. The strength of the transmition, absorption and

reflection depends on the texture and type of the surface (see Texture; Surface types). The satellite sensors record the transmitted and reflected signals. Reflectance value (Spectral signature) is a number, presented in bits and stored as numerical values in the image (see 8 bit, 16 bit, 32 bit).

- **Remote sensing**- Remote sensing can be defined as the collection of data about an object from a distance. These sensors are positioned away from the object of interest, features (see Features) by using helicopters, planes, and satellites. Most sensing devices record information about an object by measuring an object's transmission of electromagnetic energy from reflecting and radiating surfaces (Pidwirny, 2006).
- **Resolution of the satellite image**- is a broad term commonly used to describe the number of pixels you can display on computer, or area on the ground (in meters, centimeters, etc.), often called a pixel (see Pixel) that a pixel represents in an image. The resolution is fixed for each satellite. For instance the resolution of the Landsat satellite is 30 meters; the WordView-2 is 2 meters and RapidEye is 5 meters. Resolution can be spectral, spatial, radiometric and temporal.
- **Salt and pepper effect** (speckles) highly speckled image where the different pixels are associated with different classes.
- **Satellite sensor**- is a camera mounted on satellite, which records the reflected and transmitted reflectance's of features in selected wavelengths. The each satellite has range of electromagnetic spectrum which can record.
- **Spatial resolution**- the area on the ground represented by each pixel (in meters, see the Resolution) and it is fixed for each satellite.
- **Spectral resolution**- the specific wavelength intervals that a sensor can record and it is fixed for each satellite. For example for the WordView-2 satellite, the spectral resolution is starts from Blue wavelength and includes another blue wavelength, green, yellow, 2 red and 2 infrared wavelengths of the spectrum (see Electromagnetic spectrum) . Often these wavelengths are called bands of the image (see Bands).
- **Supervised classification**- it is process of detecting features on the image, selecting the features and setting up classes. The process is "supervised", and based on knowledge of the computer analyst in detection of the features and assigning them categories and names. For detection of the feature classes the Ground Control Points can be used (see Ground Control Points). Common Classifiers includes- Parallelepiped, Minimum distance to mean and Maximum likelihood (see Parallelepiped, Minimum distance to mean, Maximum likelihood).
- **Surface types (of the features)**- can be smooth, rough, geometrically shaped, irregular. In remote sensing the surface types of the features is used in image classification (see Image classification) and visual interpretation.
- **Temporal resolution**- it is refers to how often a sensor obtains imagery of a particular area. For example, the Landsat satellite can view the same area of the globe once every 16 days. The WorldView-2 satellite every 1,1 day.
- **Texture (of the feature)**- the real objects often do not exhibit regions of uniform intensities. For example, the image of a wooden surface is not uniform but contains variations of intensities which form certain repeated patterns called visual texture. The patterns can be the result of the physical surface properties such as roughness or oriented strands which often have a tactile quality, or they could be the result of reflectance differences such as the colour on a surface. In remote sensing the texture of the surface is used in image classification (see Image classification).
- **True colours composite-** the composite present the main features of land, water and vegetation in "true" colours, like the original subject would, and it is dark brown colour for land (depending from soil moisture and vegetation cover), all vegetation in green and water in dark or light blue. The combination of bands to display image in such true colour composite is called RGB (Red, Green, Blue).
- **Typology-** distinguishing different types.
- **Unsupervised classification –** Process in which every individual pixel is compared to each other and automatically groeped into classes. Such automated process is based on reflectance (spectral) property of each feature. The features are simply clusters of pixels with similar spectral characteristics (see Reflectance). The automated process can be so-called Maximum Likelihood (see Maximum Likelihood) or ISODATA clustering (see ISODATA). The process takes maximum "advantage" of spectral variability (see Reflectance) in an image. The unsupervised classification is

separate process and it should be not mistaken with PCA (see PCA) or other pixel grouping processes.

- **Visible region** (Red, Green and Blue). The Blue region starts from 0,4 to 0,5; Green region from 0,5 to 0,6 and Red from 0,6 to 0,7 nanometers.
- **8 bit image**- the values of the image start from 0 to 255. Zero (0) is for black and 255 is for white color.
- **11 bit image**- the values of the image start from 0 to 2047. Zero (0) is for black and 2047 is for white color.
- **16 bit image**- the values of the image start from 0 to 65,536. Zero (0) is for black and 65,536 is for white color.
- **32 bit image**- the values of the image start from 0 to 4,294,967,295. Zero (0) is for black and 4,294,967,295 is for white color.