Nexus interventions for small tropical islands: case study Bonaire

Remote Sensing Tools

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Smalls islands are especially vulnerable to climate change and land use changes due to the competing needs for limited resources. To support the NEXUS approach we need evidence based monitoring tools that can provide policy makers, conservation managers, entrepeneurs, scientists and the general public with information on the state, pressures and associated changes in the environment. Satellite imagery can provide synoptic information at appropriate spatial and temporal resolutions that can support evidence based monitoring. Only at very detailed levels information might be added by using airplanes or drones. Remotely sensed information can help to provide information on e.g. land cover and associated dynamics such as urban sprawl, mapping habitats such as mangroves and coral reefs, surveying terrain conditions such as soil moisture conditions and erosion hazards associated within catchments, sea level rise and changing coastlines, and on many aspects of the vegetation (natural and agriculture), such as plant traits, phenology and plant growth. Remotely sensed information can in general make field surveys and monitoring more effective, and can thoroughly support decision making.

INTRODUCTION: CURRENT STATE, TRENDS & DRIVERS OF CHANGE

Since small islands like Bonaire are especially vulnerable to climate change and land use changes due to the competing needs for limited resources, it requires a holistic "Nexus approach" that considers the inter-connections between water, food, and energy sectors in relation to ecosystems. In recent years, the Water-Food-Energy-Ecosystem (WFEE) Nexus has emerged as a powerful concept to capture these interdependencies between ecosystems and the water, food, and energy sectors, and is now a key feature of policy-making (Leck et al 2015). In all these Nexus sectors remotely sensed information can be of great help. The amount of satellites and associated camera systems have increased enormously during the last decades making them fit for much more application domains. Moreover, many satellite data has become available as open source data in easy accessible archives. Small islands require in general detailed information at finer spatial resolutions. Nowadays there are many satellite sensors that can fulfil this requirement with spatial resolutions of 10-25 meter or much finer resolutions of commercial satellites such as 0.5 m on which individual trees or cars are visible. Due to the high frequency of recordings, from monthly, weekly to almost daily, the opportunities for monitoring have increased enormously. In cases that even more detailed information is needed this can be supported by airborne images from manned or unmanned vehicles. The last are also known as drones. In principle, spaceborne data is much cheaper to use than drones, although the latter can be easily applied for small areas and hot spot monitoring.

In this factsheet we concentrate on Bonaire as an example showing the way how remote sensing tools can provide useful information. A reason to concentrate on this island is that Bonaire is part of the so called Caribbean Islands Biodiversity Hotspot (Myers et al., 2000) and although many habitats are well protected they are still under much pressure. Bonaire has only limited structural monitoring of its environment, including its natural habitats and urban environment, which means that trend data are scarce. Such monitoring requires basic maps on the spatial configuration and current state of the environment, including land cover, habitats, terrain conditions, etc. We will show that remote sensing can play an important role to generate those basic maps.

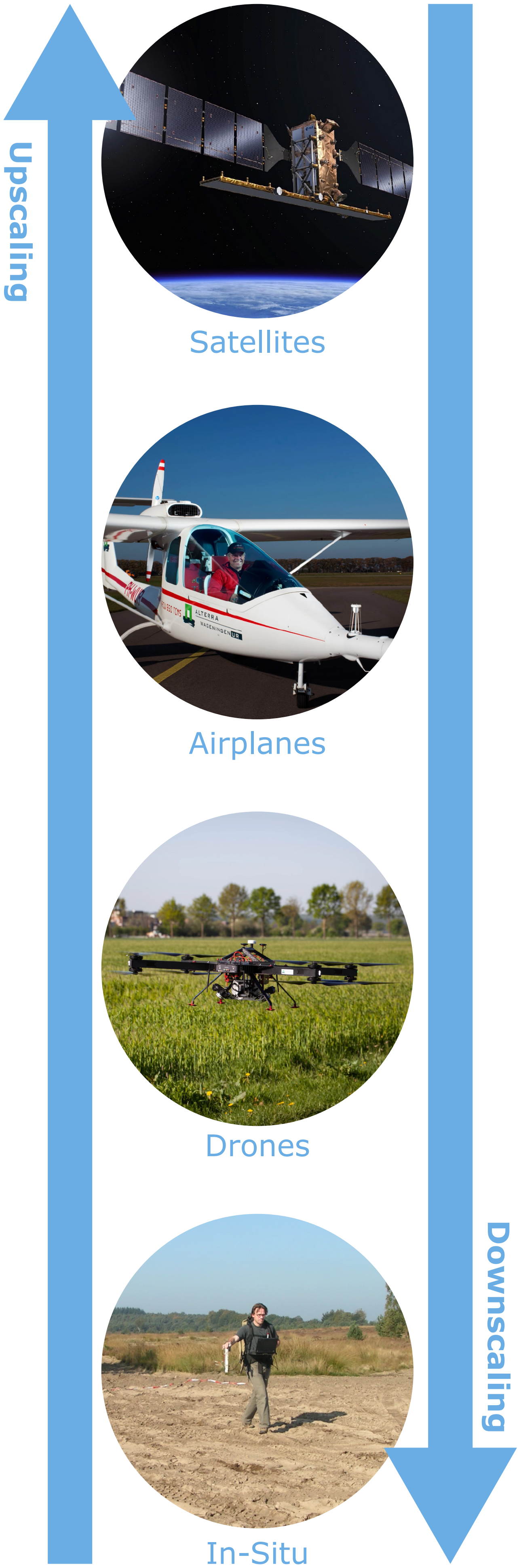


Figure 1. Multi-scale remote sensing

PRINCIPLES OF THE TECHNOLOGY

Remote sensing is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area or phenomenon under investigation (Lillesand et at al., 2008). Remote sensing involves the exploitation of electromagnetic energy sensors from airborne and spaceborne platforms that assist in inventorying, mapping and monitoring of earth resources. Visible light is only one of the many forms of electromagnetic energy. Radio waves, heat, ultraviolet rays and Xrays are other familiar forms (Lillesand et at al., 2008). Irrespective of its source, all radiation detected by remote sensors passes through some distance the atmosphere, and is influenced not only by the sun and target angle but also influenced by atmospheric effects as scattering and absorption. The figure below of hyperspectral imagery shows that very targeted material, like soil, water and vegetation have their own specific reflectance curve of the electromagnetic radiation, and these so-called fingerprints helps to identify those specific thematic objects.

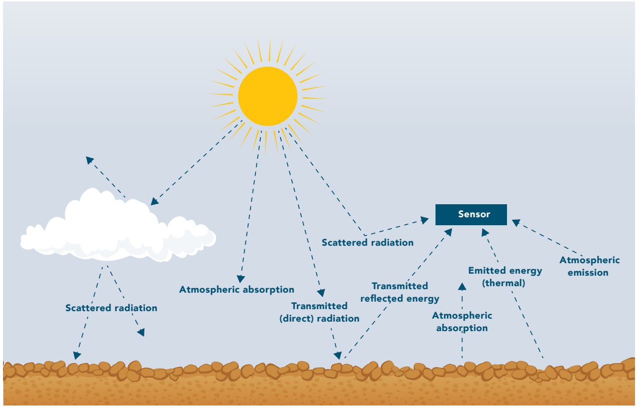
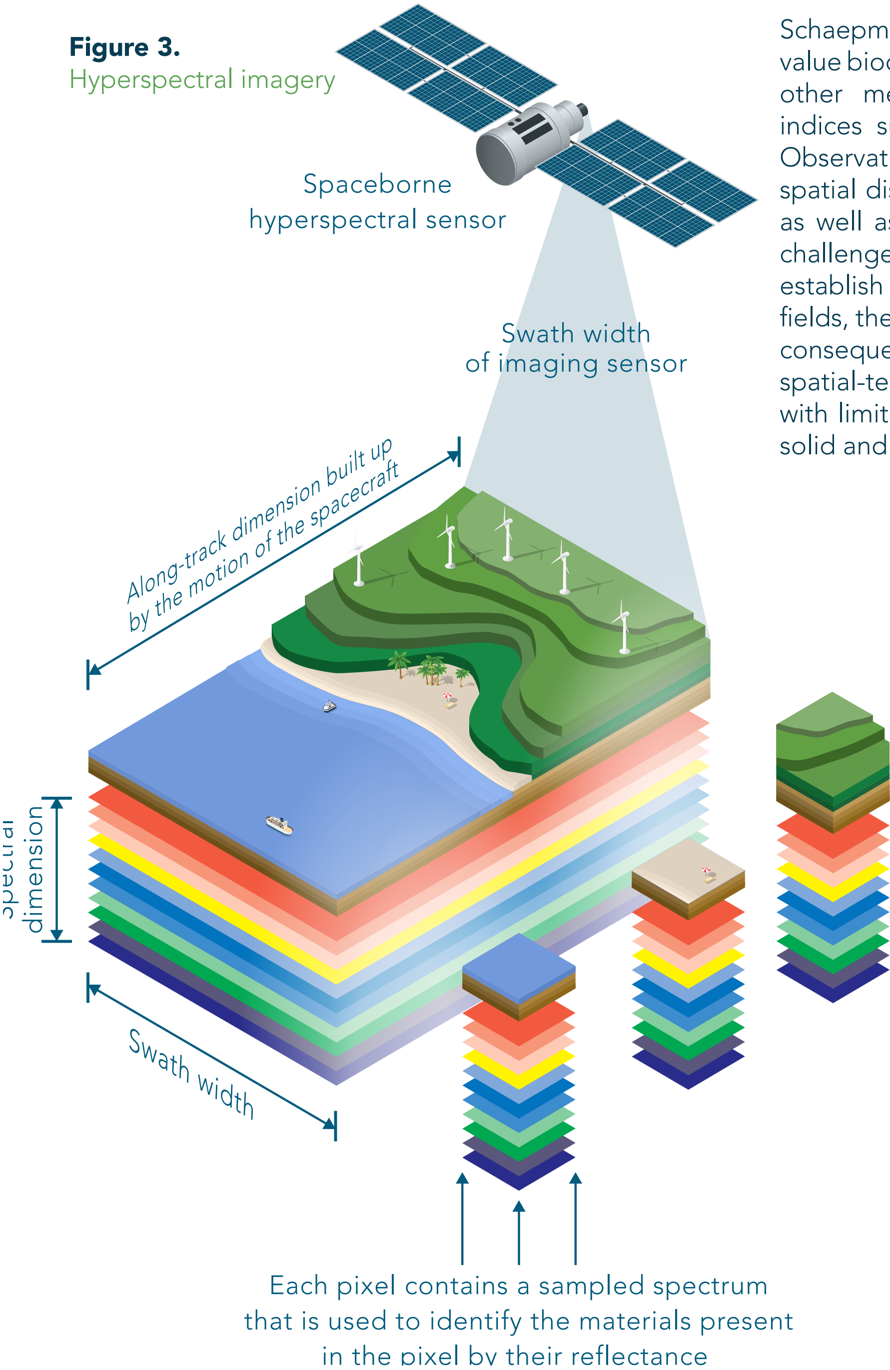
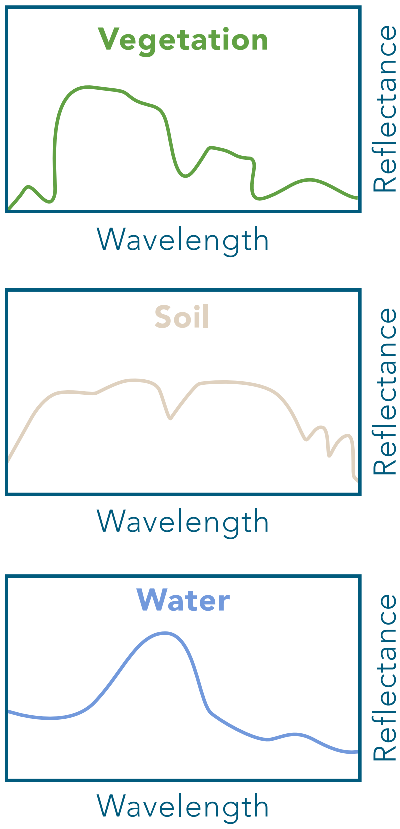


Figure 2. Energy interaction in atmosphere & surface

Schaepman et al. 2007 states that ecologists mainly value biodiversity in terms of species richness amongst other metrics as well as using various diversity indices such at the Shannon index, whereas Earth Observation based instruments usually measure the spatial distribution of radiance fields, backscattering, as well as polarization state changes. It is the main challenge of Earth Observation and Ecology to establish semantic interoperability between these two fields, then establish common sampling schemes, and consequently bridge scaling gaps finally allowing a spatial-temporal continuous sampling of biodiversity with limited discontinuities. This in combination with solid and continuous ground observations.

Figure 3. Hyperspectral imagery





REMOTE SENSING DATA SOURCES

More and more satellite imagery becomes freely and easily accessible. Good examples of these are the USA Landsat programme and the European Copernicus programme with the Sentinels 1-5 with their specific application domains, next to commercial satellite information at very high resolutions (around 1 meter resolution). A great advantage is also that large archives exist with historical data which makes the assessment of changes more convenient.

Since, amongst others, Sentinel-2 satellite imagery is freely available at high spatial and temporal resolution, we can collect times series for various periods of time.

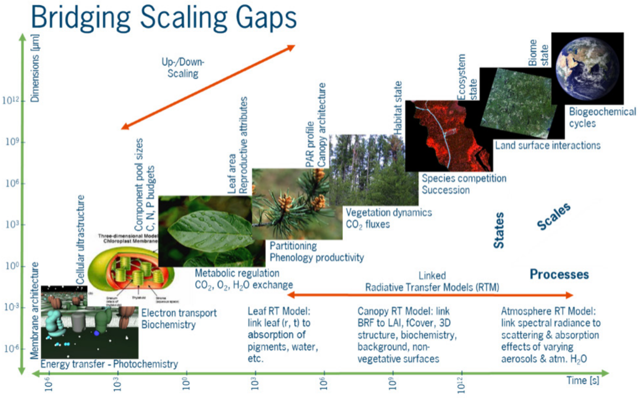


Figure 4. Scaling of states and processes from the cell scale to global scales (Schaepman et al, 2007; Modified after John Miller).

Satellite sensor	Launch	Number & Types	Spatial resolution [m]	Revisit time (days)	Examples products
Landsat-8	2013	11 (VNIR,SWIR,TIR)	15 (pan), 30m (ms), 100m (TIR)	16	Reflection, NDVI, LAI, temperature, and thematic classifications
Aster	1999	3, 6, 5 (VNIR,SWIR,TIR)	15 (VNIR), 30 (SWIR) 90 (TIR)		Reflection, NDVI, LAI, temperature, and thematic classifications
RapidEye (5 satelliet constellatie)	2008	5 (B,G,R,NIR, RedEdge)	5 (ms)	1	Reflection, NDVI, LAI, chlorofyl / N concentration and thematic classifications
SPOT-6 & 7	2012/2014	4 (B,G,R,NIR)	1.5 (pan) 8 (ms)	1	Reflection, NDVI, LAI, temperature, and thematic classifications
Sentinel-2A & B (2 satelliet constellatie)	2015/2016	13 (VNIR, NIR, SWIR)	10, 20, 60	< 5	Reflection, NDVI, LAI, chlorofyl / N concentration, and thematic classifications
Sentinel-1	2015	2 (VH, VV)	10	6	Height, soil moisture, biomass, phenology, land cover
Ikonos	1999	4 (B,G,R,NIR)	1 (pan) 4 (ms)		Reflection, NDVI, LAI, and thematic classifications
QuickBird	2001	4 (B,G,R,NIR)	0.65 (pan) 2.6 (ms)	1 - 3.5	Reflection, NDVI, LAI Classification
GeoEye-1	2008	4 (B,G,R,NIR)	0.4 (pan)	~3	Reflection, NDVI, LAI
GeoEye-2 (WorldView-4)	2016		0.3 (pan) 1.2 (ms)	<3	Reflection, NDVI, LAI, chlorofyl / N concentration Classification
SkySat-1 & 2	2013/2014	4 (B,G,R,NIR)	0.9 (pan) 2 (ms)		Reflection, NDVI, LAI, and thematic classifications
Pleiades-1A & B (2 satelliet constellatie)	2011/2012	4 (B,G,R,NIR)	0.5 (pan) 2 (ms)	1	Reflection, NDVI, LAI and thematic classifications Classification
WorldView-3	2014	8(B,G,R,coastal, yellow,NIR, RedEdge,NIR2) 8 SWIR 12 CAVIS	0.31 (pan) 1.24 (ms) 3.7 (short wave IR)	<1	Reflectiion, NDVI, LAI, chlorofyl / N concentration Classification

Box 1. Overview of common satellite sensors and their main characteristics. Note PAN means panchromatic (B&W), MS means multi-spectral, VNIR means Visible and Near Infra-Red, and SWIR means Shortwave Infrared. NDVI: Normalized Difference Vegetation Index, LAI: Leaf Area Index.

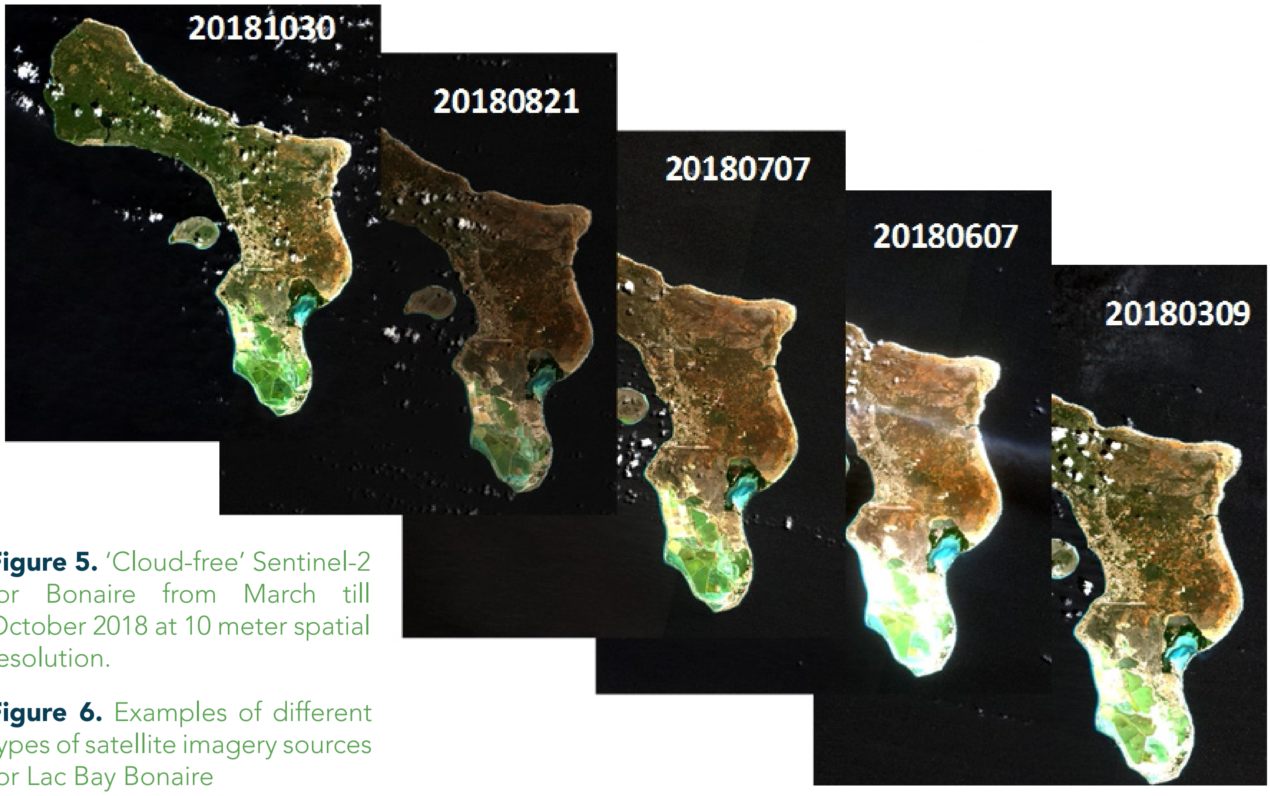


Figure 5. 'Cloud-free' Sentinel-2 for Bonaire from March till October 2018 at 10 meter spatial resolution.

Figure 6. Examples of different types of satellite imagery sources for Lac Bay Bonaire

Landsat-5 27th of December 1984. 30 m pixels

Landsat-5 24th of September 2014. 30 m pixels

Sentinel 2A 14th of April 2016. 10 m pixels

Same Sentinel 2A 14th of April 2016. 10 m pixels. But more zoomed in.

Pleiades 28th of February 2014 2m pixels.

Same Pleiades 28th of February 2014 2m pixels. But more zoomed in.

EXAMPLES OF THE USE OF REMOTE SENSING TOOLS

Sea Level Rise and coastlines

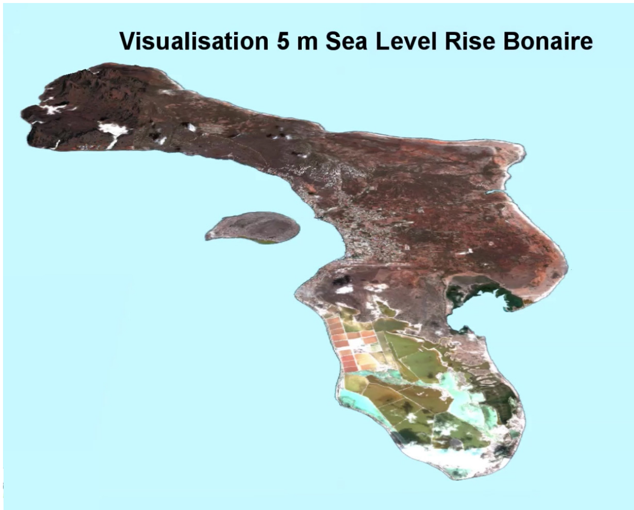
The most recent climate change predictions for the Caribbean region (2013/2014) by the Intergovernmental Panel on Climate Change (IPCC) are alarming and suggest that the islands of the Dutch Caribbean will go through profound environmental changes within the next century (DCNA, 2016). Under the intermediate low-emissions scenario, the IPCC has projected a sea level rise of 0.5 to 0.6 m for the Caribbean Region by the end of this century. What does this mean for Bonaire?

Figure 7. Simulating impact sea level rise for Bonaire using a Digital Elevation Model (DEM).

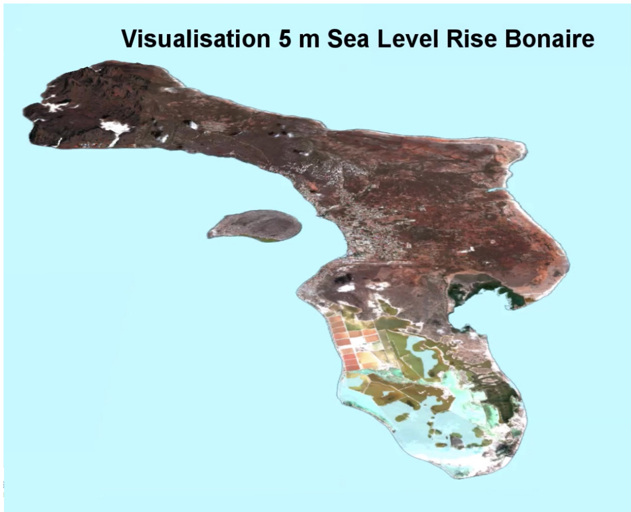
Based on Aster satellite imagery derived Digital Elevation Model, we can model the impact for Bonaire of different levels of sea rise.

It is clear that southern part of Bonaire is very sensitive for any sea level rise (SLR). The exact impact of the SLR will of course also depend on the spatial details and accuracy of the digital elevation model that is used. In the figure above it is clear that many of the beaches will disappear where turtles lay their eggs in the breeding season.

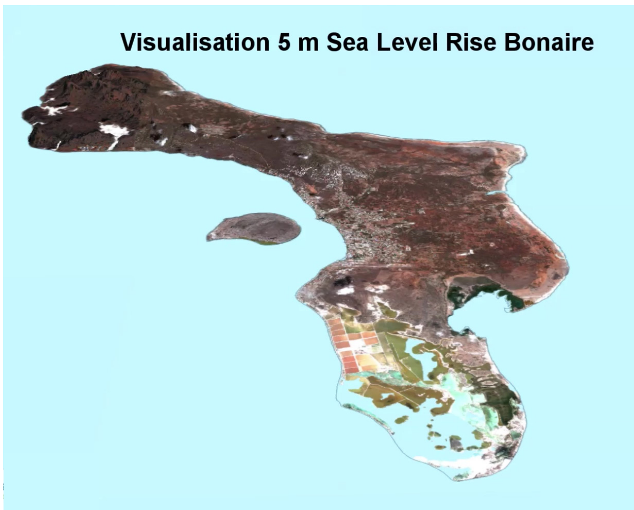
For this and other reasons, it is also important to monitor the coastal erosion. Sentinel-1 RADAR is well equipped for coastline detection and can as such be used to detect changes in coastlines. Below is an example of coastline detection based on Sentinel-1 imagery for 2015 and 2018. However, the coastline methodology should be based on much more Sentinel-1 imagery to avoid change effects due to changes in sea tides. The effect of sea tides are not completely removed in the example given below.



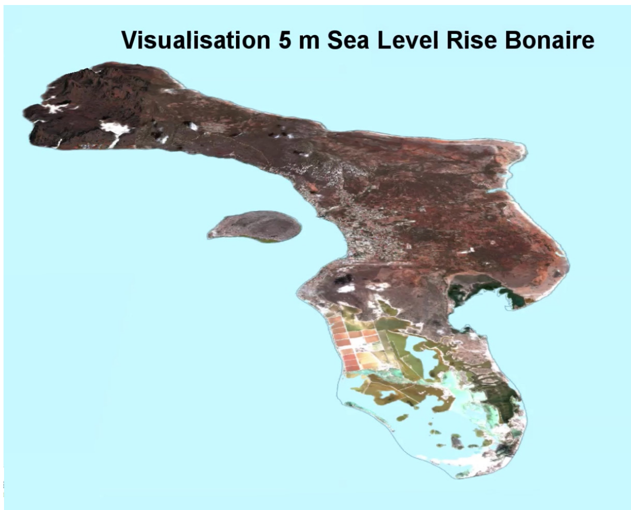
Sea Level Rise: 0 m



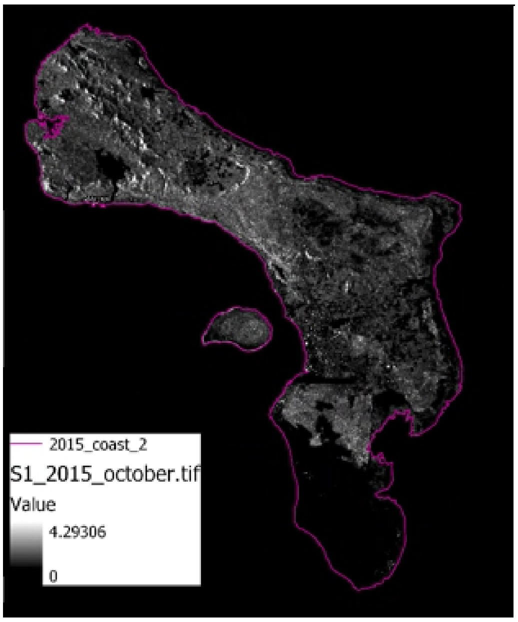
Sea Level Rise: 0.5 m



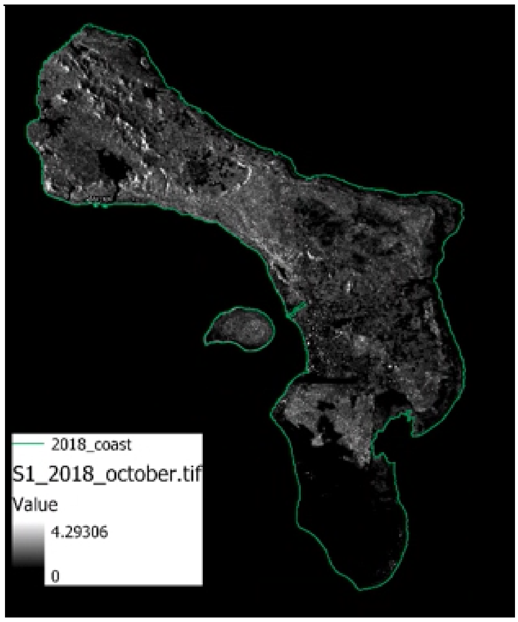
Sea Level Rise: 2 m



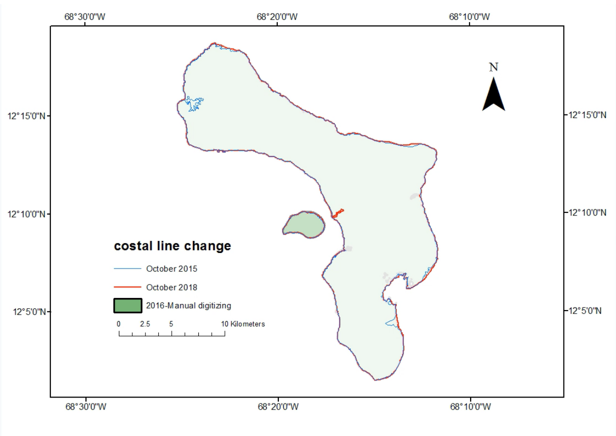
Sea Level Rise: 1 m



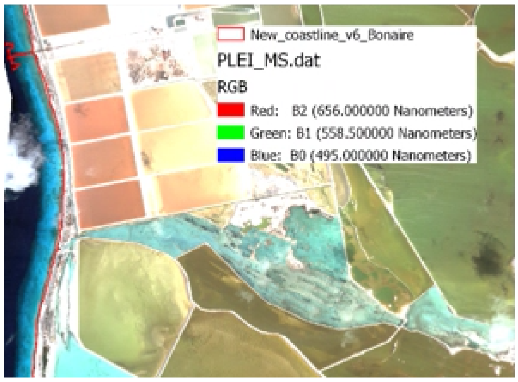
Coastline detection based on Sentinel-1 RADAR
Image of October 2015



Coastline detection based on Sentinel-1 RADAR
Image of October 2018



Changes in coastline 2015 - 2018
(Not yet corrected for differences is sea total levels)



Detail of the coastline shown on Pleiades
Image of 2016

Figure 8. Coastline detection and detection of coastal erosion using RADAR and optical satellite data

Coral reef mapping using hyperspectral imagery

The importance of coral reefs is multifunctional and provides ecosystem services not only to attract tourism and therefore income, but also as a natural barrier to protect the coast, and as a habitat for many species, providing food as well. The general consensus is that the extent and biodiversity of Bonaire's coral reef is decreasing due to local and regional anthropogenic and global climate pressures. However, the last extensive study of the coral coverage of the reef ecosystem was performed in 1985 by Van Duyl who created an underwater atlas of Bonaire and Curaçao. In order to update this atlas of Bonaire's coral reefs, a hyperspectral mapping campaign was performed in October 2013 using the Wageningen UR Hyperspectral Mapping System (HYMSY) with 101 spectral channels. The HYMSY camera consists of a custom pushbroom spectrometer (range 450–950nm, FWHM 9nm, ~20 lines/s, 328 pixels/line), a consumer camera (collecting 16MPix raw image every 2 seconds), a GPS-Inertia Navigation System (GPS-INS), and synchronization and data storage units. The weight of the system at take-off is 2.0kg allowing it to be mounted on varying platforms (Mucher et al., 2017).

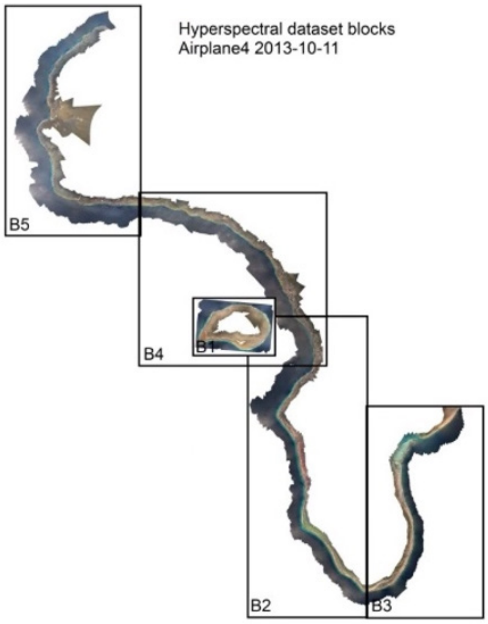


Figure 9. The hyperspectral data were recorded on 11th October 2013 by the HYMSY camera mounted on a Cessna airplane and were mosaicked and georeferenced to form a hyperspectral image of the coastline of Bonaire. Data were processed in 5 hyperspectral dataset blocks (Mücher et al., 2017).

In order to interpret the data more consistently, the hyperspectral data were corrected for the water depth into at-ground-reflectance factor units. A bathymetric (sea bottom) model was used for the calibration of the hyperspectral imagery based on a former field campaign by measuring water depth at specific locations along the western coast. The final bathymetric model that we used was based on extrapolation of the terrestrial digital elevation model through fitting with additional in-situ bathymetric measurements on sea. A better bathymetric model would of course have been preferred to calibrate the hyperspectral data with a 1 meter spatial resolution more accurately (Mucher et al., 2017).

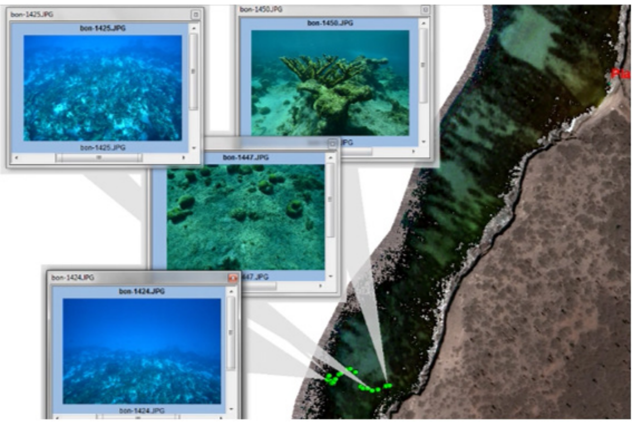


Figure 10. HYMSY hyperspectral spectral imagery (RGB: 520 nm, 480 nm, 476 nm) with green dots showing the most northern diving transect. Image (mainly the land section) behind the hyperspectral image is a Pleiades satellite image (brown to greyish colours) with 50 cm resolution (Mucher et al, 2017).

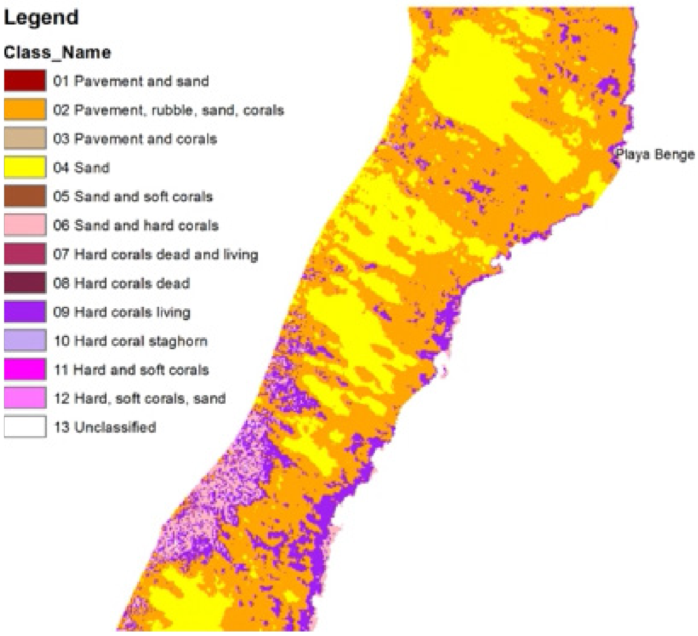


Figure 11. Detail of the Hyperspectral Coral Reef Classification (HCRC) near Playa Benge on the Northern coast of Bonaire (Mucher et al., 2017).

Catchments and erosion hazards

Past deforestation, overgrazing and urbanization have led to an increase in surface runoff and erosion in amongst others the Playa catchment, Bonaire. Together with the lack of sufficient spatial planning, this has led to increased flooding and larger sediment flows into the ocean causing harm to the island's famous coral reefs (Koster, 2013). The study of Koster (2013) concentrated only on a selected part of the island. Remote sensing and associated sciences with respect to soil erosion can provide relevant information for the entire island, to inform decision makers in a better way. The simplest way to calculate soil loss is to use the Universal Soil Loss (USL) Equation used to estimate average annual soil loss caused by sheet and rill erosion. The equation is limited for making predictions for long-term annual soil loss only compared to making predictions on single rainfall event. The USLE Equation is: A = R * K * LS * C * P, where, A = predicted soil loss (tons per acre per year), R = rainfall and runoff factor, K = soil erodibility factor, LS = slope factor (length and steepness); C = crop and cover management factor; P = conservation practice factor interesting is to find out where surface runoff and erosion reaches the coast and threats the coral reefs.

But first of all, a catchment classification has to be made of the entire island, to enable such a study. For mapping these catchments, remote sensing is very useful. In addition, a Digital Elevation Model (DEM) with a very high resolution and accurate height measurements are a prerequisite. Since the required remotely sensed DEM data were at this stage not freely available, we used in this preliminary study the ASTER DEM to demonstrate the potential value of this remote sensing application for policy making and environmental management.

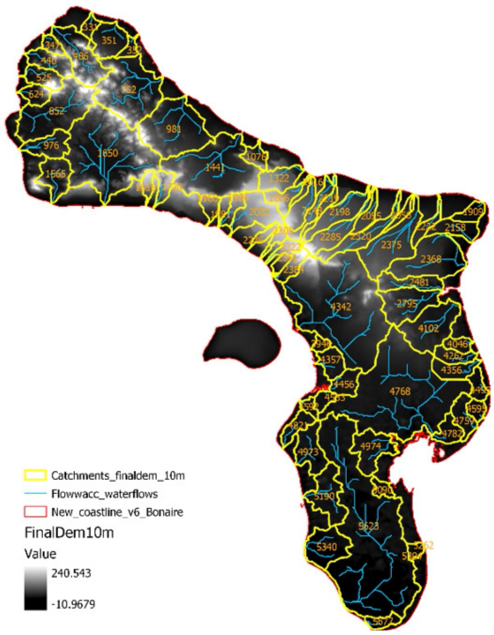


Figure 12. Catchment classification with potential water flows made with ARCGIS hydrology tools using the ASTER DEM as an input.

A preliminary erosion hazard map for Bonaire was made based on calculating the vegetation fraction (at moments with maximum vegetation cover) based on Sentinel-2 imagery and derivation of slope and length based on ASTER DEM. The example below shows the erosion hazard for those catchment that are completely or partly covered with agriculture-Konuku.

It shows that most of the catchments with agriculture-Konuku have potentials of serious erosion hazards with the risk that sediments will reach the coastal waters. Specific measures should be taken to avoid such an impact.

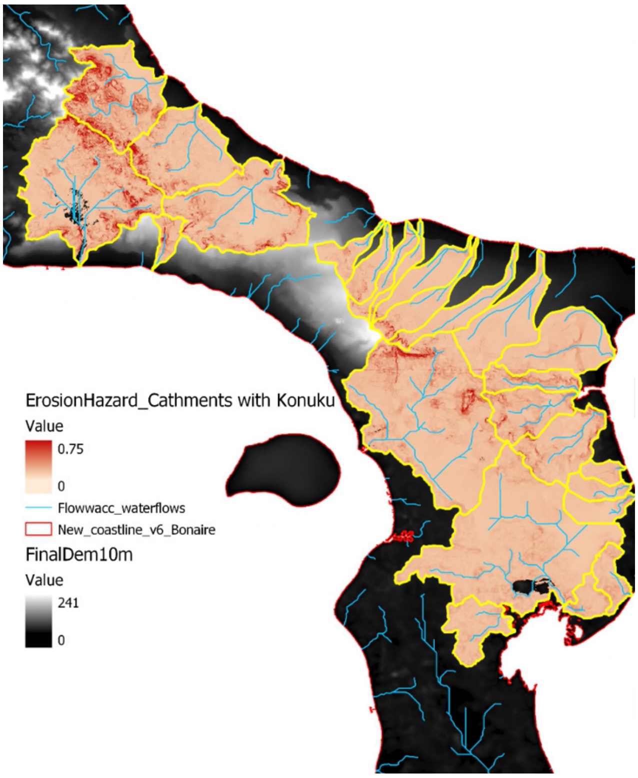


Figure 13. A preliminary erosion hazard map for Bonaire for those catchment that are completely or partly covered with agriculture-Konuku.

Soil moisture

Information on surface soil moisture is especially important in relation to agriculture. Soil moisture maps can be derived from RADAR satellite data, and the example below is showing so for SENTINEL-1 Synthetic Aperture Radar (SAR) instrument of which the acquired data is freely available. The figure below shows the workflow to produce such soil moisture map by SAR (Sentinel-1) data.

The moisture content is scaled between 0 (0% moisture) and 1 (100% moist). Next to the value of such soil moisture maps, we should also notice that very specific flat surfaces such as asphalt or salty soils also appear as very moist pixels, and should be corrected for.

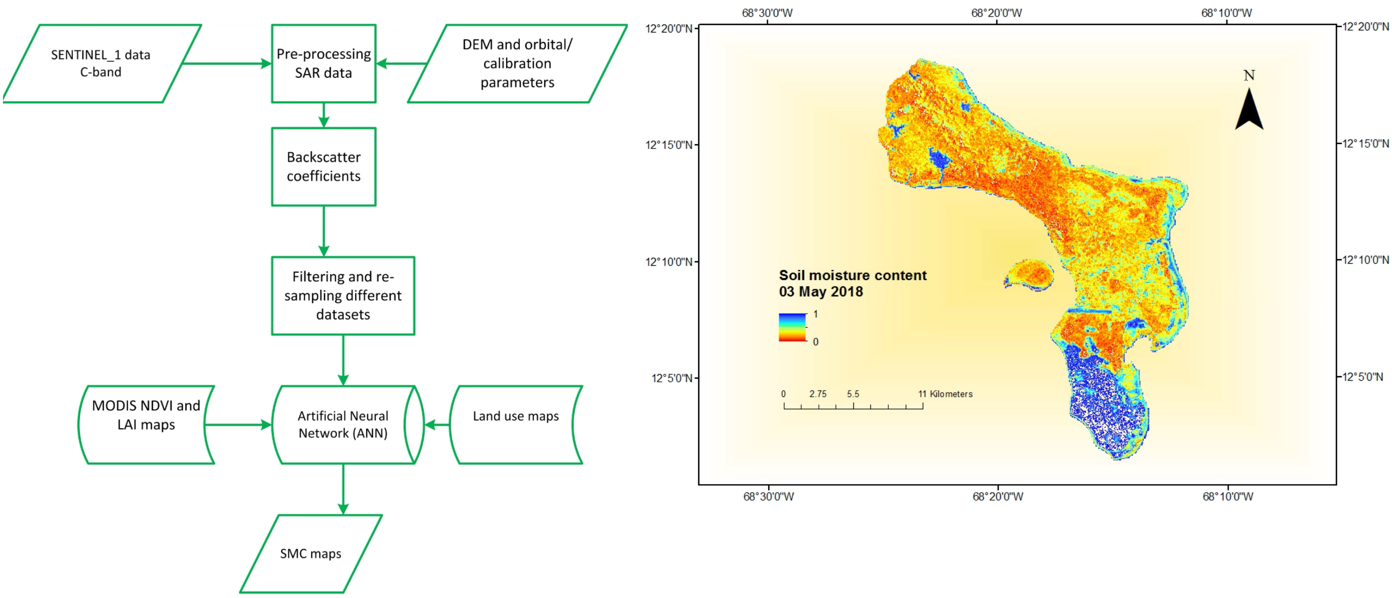


Figure 14. The workflow of producing soil moisture map by SAR (Sentinel-1) data and the resulting soil moisture map for one specific day, namely 3rd of May 2018.

Land cover mapping and monitoring

Land cover mapping and monitoring is one of the longest existing application domains in remote sensing that exists for more than a century (accounting for use of aerial imagery as well). The land cover information is often used as an input for running other models, but also as an input for spatial planning, environmental monitoring and decision making (Mücher et al, 2000; Clevers et al., 2007; Gerard et al., 2010; Feranec et al., 2010; Smith et al., 2013; Mücher et al., 2015; Hazeu 2014). The satellite sources used for land cover mapping concern mostly multi-spectral imagery acquired at specific seasons of the year. A multi-temporal approach is for example needed to distinguish bare ground from agriculture, or to distinguish wheat field from a grassland patch. Historical satellite archives make it possible to produce time series and look at specific land cover changes. Nowadays many land cover maps have a spatial resolution between 25-10 meter resolution and are regular being updated. The example below shows a preliminary land cover classification based on a Pleiades image of March 2016 for the area around Rincon. The second example shows that time series of satellite imagery can indicate when a certain land use or land cover change has taken place.

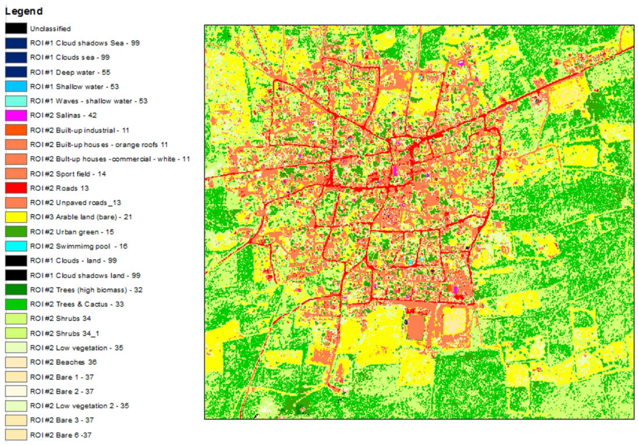


Figure 15. A example of a preliminary land cover classification based on a Pleiades image of March 2016 for the area around Rincon.

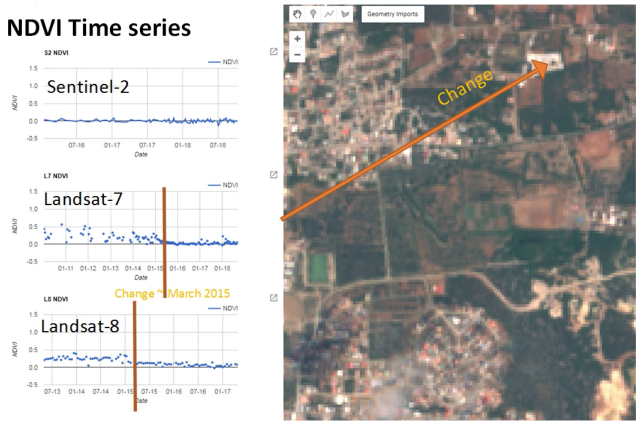


Figure 16. Time series of satellite imagery makes it possible to indicate the timing of the change. This example shows that new construction in suburb (pointed by orange arrow) Kralendijk started in March 2015 based on Landsat 7 and Landsat 8. Sentinel-2 is only available since July 2015 and shows no change in biomass at all (so showing that the construction is there).

WAY FORWARD & FUTURE WORK

The examples above are just a few examples of the way that remote sensing can provide basic surveying information and can support environmental monitoring for decision making. Also on specific events such as the amount of Sargassum that washed in March 2018 on the beaches of Bonaire could be surveyed in coastal regions and on sea using airborne or spaceborne imagery. Satellite imagery can provide synoptic information at appropriate spatial and temporal resolutions that can support evidence based monitoring that can provide policy makers, conservation managers, entrepeneurs, scientists and the general public with information on the state, pressures and associated changes in the environment. At the same time much work has to be done to bring such information in the proper format to those people on the islands that need such information and can translate it towards decision making. Only in such a way shared fact finding will work. Moreover, the more local information is added to the interpretation of the satellite imagery the better the results are.

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Colophon

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The KB program "Nexus Strategic policy case", included a Bonaire NEXUS case study. The case study was funded under KB-33-005-013, and administered under project number 4318300087. A letter report (number 1900369.ds) summarises the activities. In the study a set of 8 factsheets was drafted (and attached to the letter report). The set of factsheets can be found on : www.wur.eu/sustainablewatermanagement