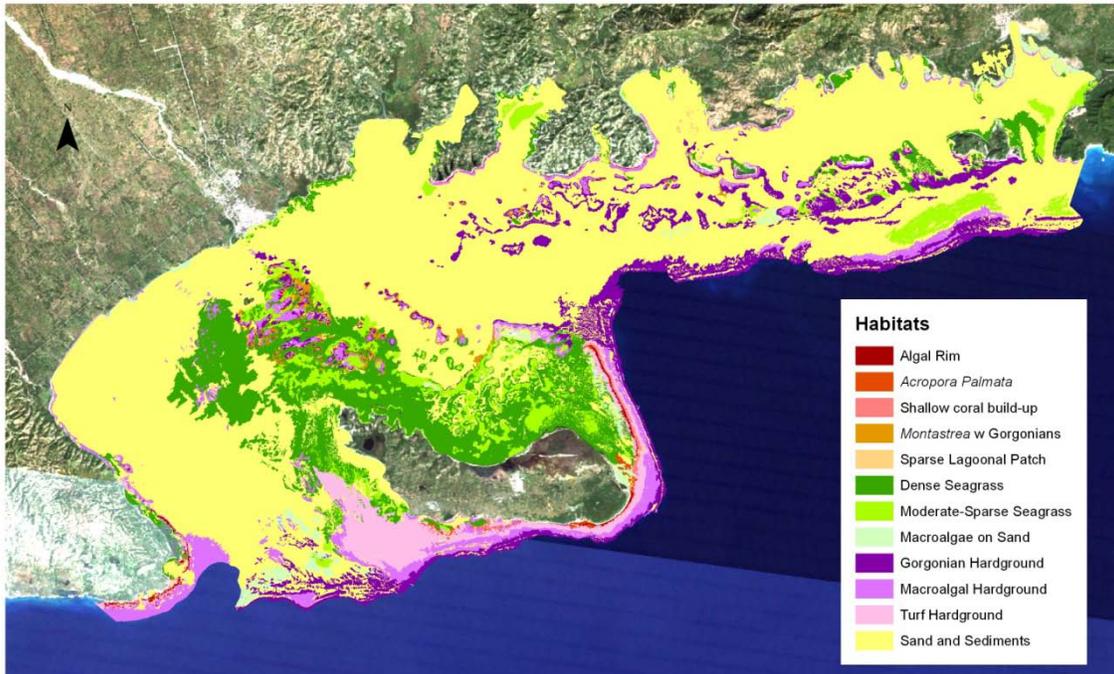


Haiti Southwest Sustainable Development Project

Integrated Coastal and Marine Management

# Île à Vache, Haiti: Benthic habitat mapping



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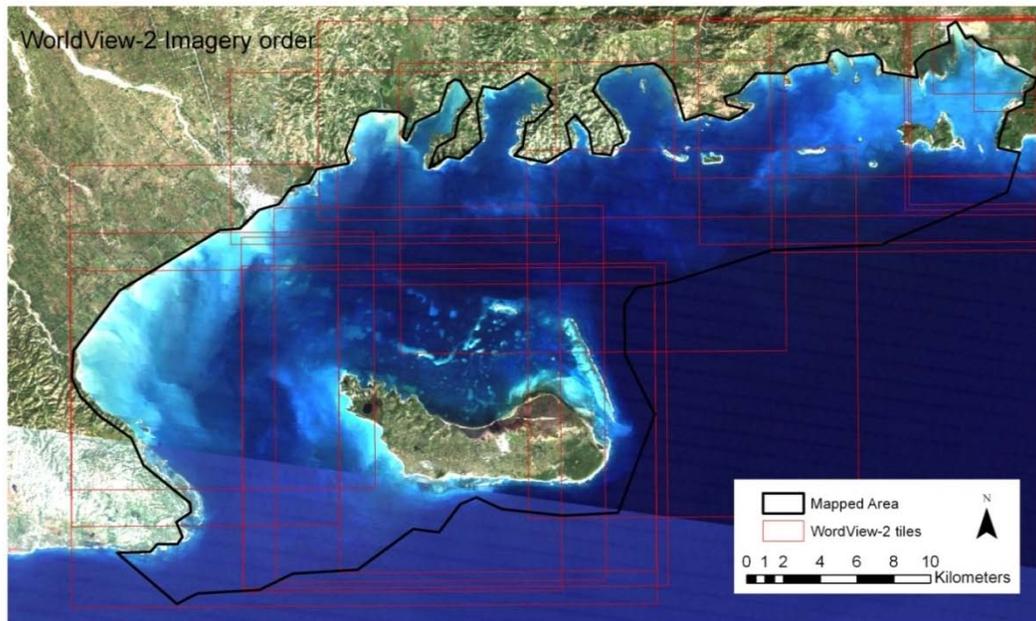
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Caribbean Science Program  
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## Optical Remote Sensing

The aim of this project was to map the benthic habitats such as coral reefs and seagrass within the 800 sq km shallow marine shelf that surrounds Île à Vache, Haiti (Figure 1). The project utilizes well established image-based remote sensing techniques (Phinn et al., 2012; Purkis, 2005; Rowlands et al., 2012; Schill et al., 2011; Scopélitis et al., 2010). Much of the field methodology was developed for similar benthic habitat mapping campaigns in St Kitts and Nevis (Schill et al., 2011). This study differs somewhat from this template in the use of a more advanced high-resolution satellite sensor (Worldview-2) and in the use of object-based mapping techniques.

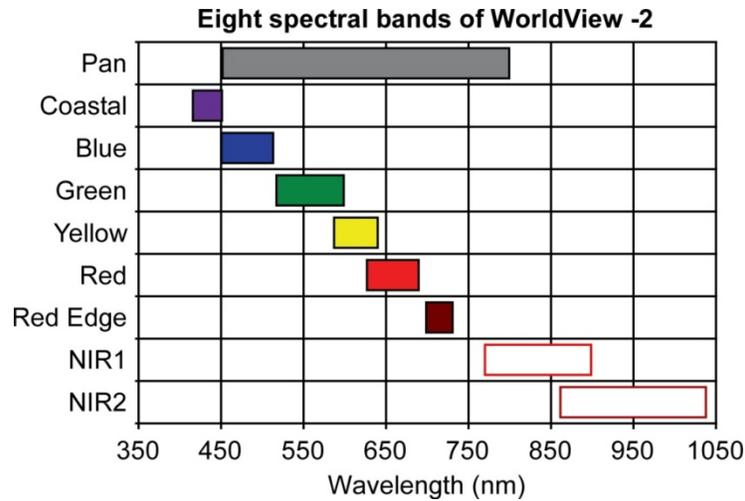


**Fig. 1** | Position of nineteen WorldView-2 image scenes acquired for Île à Vache.

## WorldView-2 sensor

The WorldView-2 sensor is a commercial satellite sensor operated by Digital Globe Inc., Colorado. This sensor has a pixel resolution of 2 m in multispectral mode, and 0.5 m in panchromatic mode. With eight multispectral bands the sensor provides spectral coverage throughout the visible light spectrum (figure 2). An archive of nineteen image scenes was acquired to cover the reefs surrounding Île à Vache and the coastal areas (Figure 2). Nine scenes were selected for mapping that exhibited the best combination of water clarity, calm ocean surface texture, and most appropriate sun angle for achieving maximum water penetration (table 1, figure 3). For some images, conditions were inconsistent across the scene. Where image quality was of good, subsets of imagery were utilized, for example in the case of image 052591285010\_01\_P003 (figure 3). When conducting benthic mapping using satellite images, it is important to select scenes where one can “see” through the water column. Figure 3 compares images from the eastern side of the study area, and to the west of Île à Vache acquired on different dates,

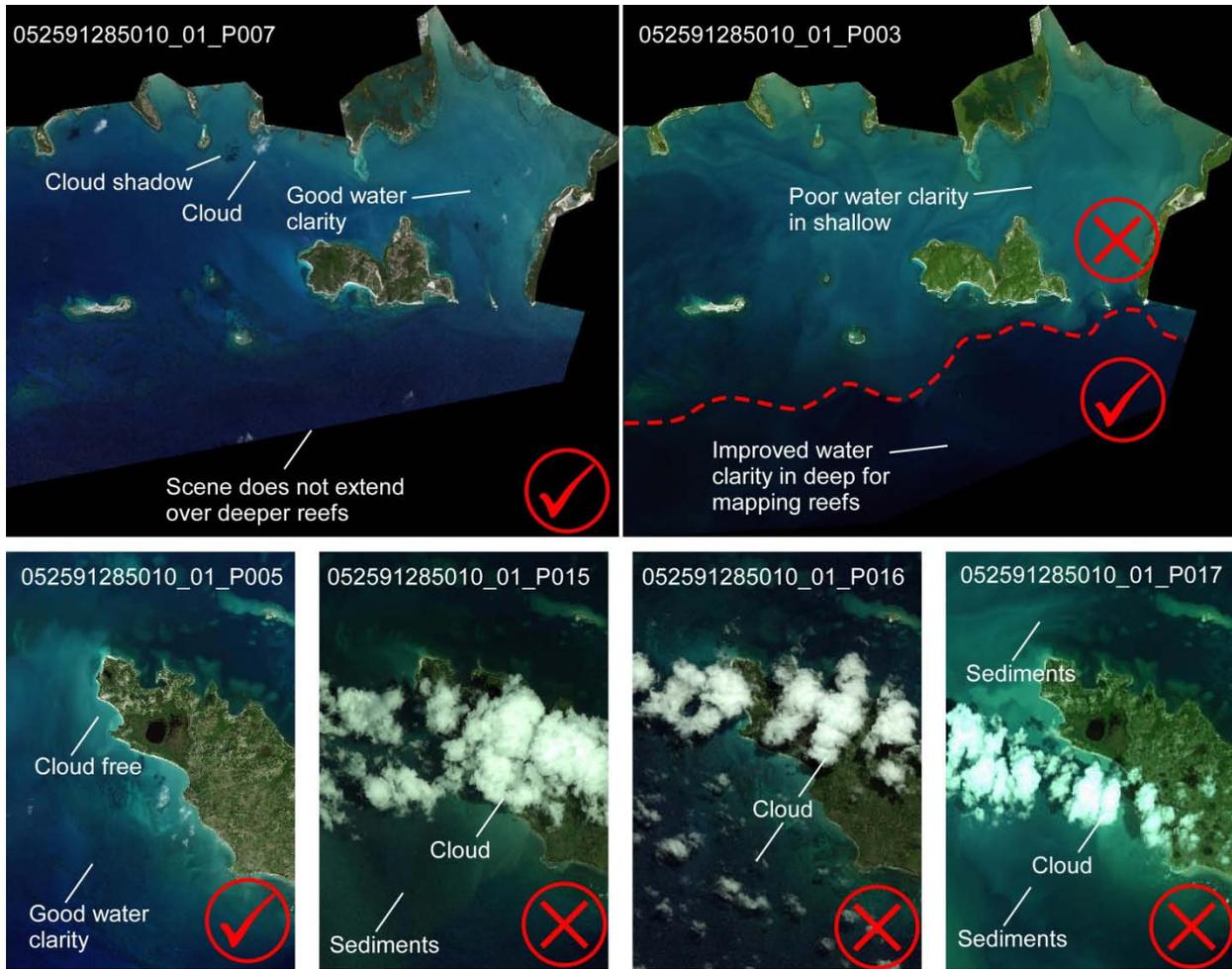
demonstrating how different the marine environment can appear depending on cloud cover, ocean surface conditions and the sun angle.



**Fig. 2 |** Spectral characteristics of the WorldView-2 sensor.

**Table 1 |** Image characteristics of scenes used

Product ID	Category ID	Acquisition date	Sun elevation (°)	Satellite elevation (°)	Cloud cover (%)
052591285010_01_P001	103001000C29C000	30/08/2011	72.0	45.2	0.000
052591285010_01_P003	10300100037A2F00	15/01/2010	44.3	49.2	0.000
052591285010_01_P004	10300100029A4A00	10/12/2009	45.8	68.8	0.000
052591285010_01_P005	1030010002C94E00	10/12/2009	45.7	73.9	0.000
052591285010_01_P006	103001000B985C00	23/06/2011	71.5	59.7	0.000
052591285010_01_P007	103001000A9BC900	15/04/2011	75.5	52.9	0.000
052591285010_01_P008	1030010004276A00	16/03/2010	61.4	74.5	0.001
052591285010_01_P012	10300100073EB500	07/11/2010	53.6	67.3	0.007
052591285010_01_P017	10300100034BCA00	23/01/2010	46.4	60.2	0.108

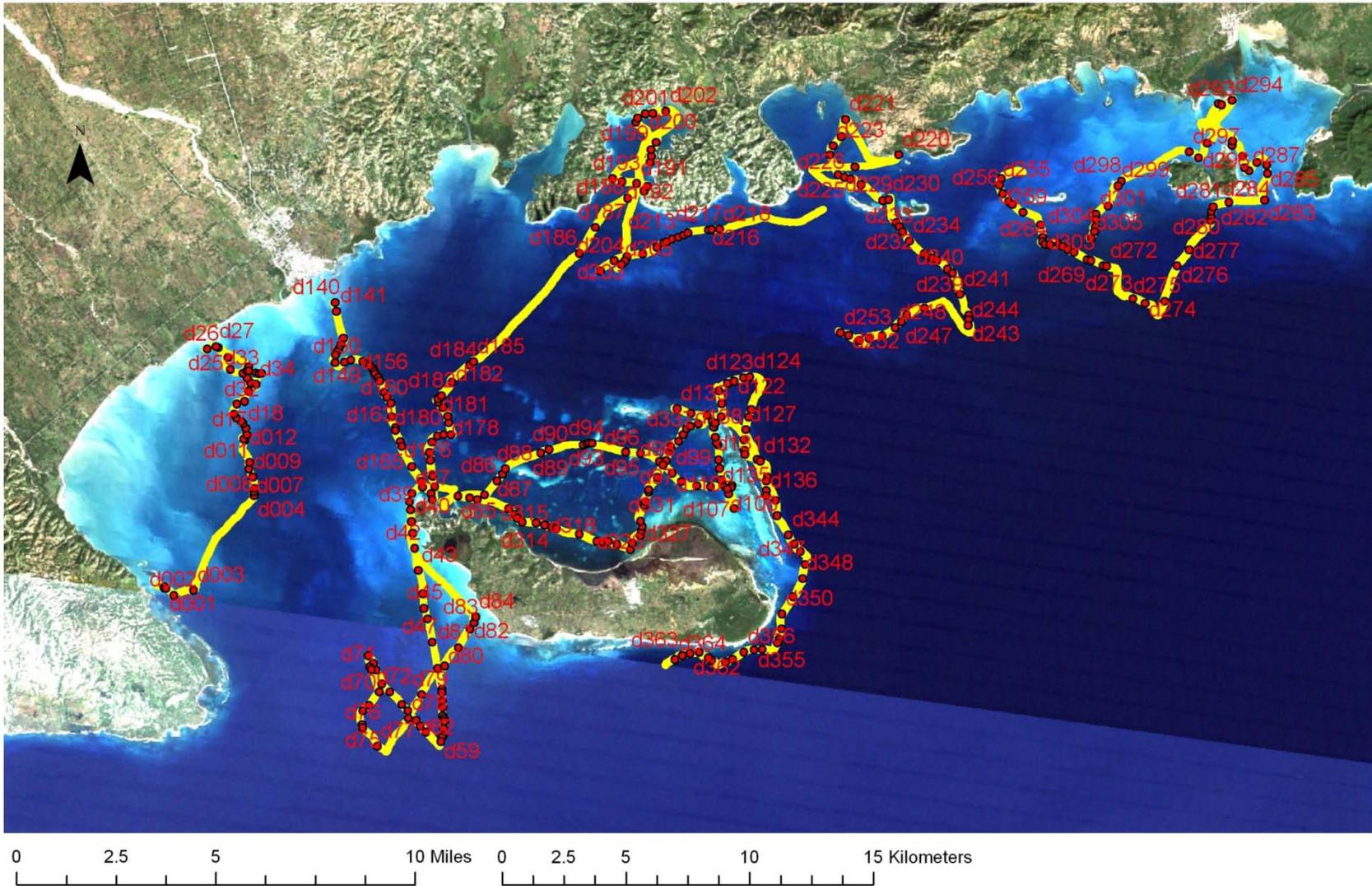


**Fig. 3** | Images are selected based on cloud cover, water clarity, and surface roughness. Multiple images are used to map the study area.

### Ground-survey

In preparation for field work, imagery were stretched and saved as separate files to maximize the appearance of benthic features in shallow (0–10 m) and deep (10– 30 m) nearshore areas. Being able to identify different benthic features at different depths was extremely valuable to the field team, permitting the identification and sampling of a wide variety of nearshore benthic habitats.

The field work and mapping of benthic habitats was done in collaboration with the National Coral Reef Institute (NCRI) at Nova Southeastern University’s Oceanographic Center, a leader in the field of rapid assessment of reef systems and quantification of benthic habitats using satellite-based mapping combined with field measurements. NCRI worked with our team to deploy an underwater video system coupled with GPS and a depth sounding device. Ground survey consisted of accurately positioned videos of the seafloor, as well as continuous survey of the water depth; this provided both the data necessary for habitat mapping, but also a historical archive. The mapping software Fugawi™ was used to interrogate satellite imagery in real time and carefully position the survey vessel over ground targets. A



**Fig.4** | Ground survey around Île à Vache. Boat track in yellow, position of camera drops in red.

SeaView Sea-Drop® underwater video camera, angled slightly downwards, with 50 m of cable was used. Positional data were gathered using a Garmin GPSmap® GPS with a positional accuracy of <3 m (95% typical). Time, speed, heading, and position were embedded in each video using a SEA-TRAK® GPS Video Overlay and then saved as compressed MPEG files. Videos were viewed on a laptop in real time to allow the user to control a smooth flight approximately 1 m above the seafloor. A point feature shapefile was created at each drop location using ESRI ArcPad software to facilitate subsequent video analysis. Water depth data were measured using a Garmin GPSmap® transducer. Depth readings from the transducer were collected as a continuous string from the Garmin and combined with GPS positional data in FugawiTM. These data were processed further using a script written in Matlab to determine the depth of each ground control video based on the nearest sounding at time of capture. The entire survey system was wired to allow data to be collected, overlaid, and stored on a single laptop powered from the boat battery.

Over the course of 7 days, the field team collected 364 underwater ~30 second video samples, representing each of the major benthic habitats identified (Figure 4, Appendix A). The GPS location and bathymetric data collected at each sample point allowed the matching of the underwater video samples and bathymetry to the same location on the satellite image. Light reflection and depth patterns found in the satellite imagery were analyzed and modeled for each of the twelve benthic habitat classes. Since each depth and habitat type reflected light differently across each scene, these patterns could be used to map the entire nearshore in depths less than ~25 m.

## Habitat mapping

### Image Processing

One of the main challenges to resolving seafloor character using optical remote sensing lies in accounting for the attenuation of both the incident and reflected light as it passes through the atmosphere and water column, prior to detection. A number of processing steps are therefore carried out which improve the quality of imagery and increase the accuracy of the resultant habitat map, streamlined within a series of Matlab scripts. Measures of the quality and quantity of light reflected from Earth's surface are stored at the WorldView-2 sensor as a digital number on a per-pixel basis. This light is partitioned into one of several spectral bands (Figure 1). Processing is carried on each image band in turn. Digital number values are first converted to 'real-world' units of radiance. This parameter describes a flux of electromagnetic energy. From units of radiance mathematical models that account for absorption and scattering of photons in the atmosphere are used to convert pixel values into units of remote sensing reflectance. Though care was taken to select the best images, some were still compromised by mild sea-surface-glitter. Glitter consists of small bright portions on the image where light reflecting off of the water surface, overwhelming and obscuring the signal emanating from the seabed. Glittered pixels in an image were corrected using models based on their comparative brightness in the near-infrared (NIR) portion of the visible spectrum (Hedley et al., 2005). Further details on methods used can be found in Schill et al. (2011) and Rowlands et al. (2012).

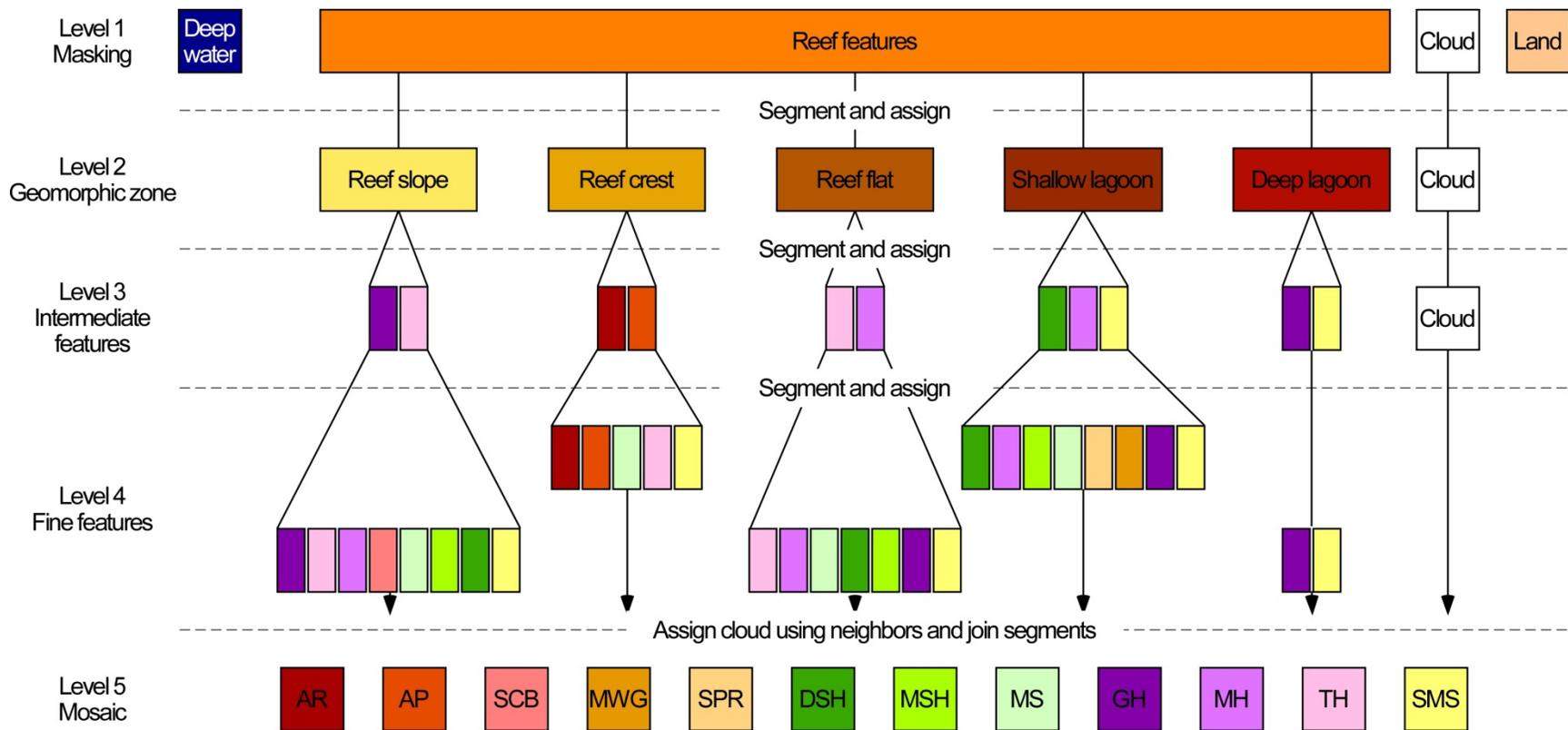
## Object-based image analysis

A recent advance in remote sensing has been the development and application of object-based image analysis (OBIA, sometimes referred to as GEOBIA for geospatial object based image analysis). Previous image classification of benthic habitats has relied on either visual analysis and interpretation or pixel-based classification based on spectral qualities (Andréfouët, 2008; Andréfouët et al., 2003). Visual analysis allows contextual information from the landscape to be incorporated by an expert classifier, or as a secondary process into spectral pixel-based classification which is easier to automate (Mumby et al., 1998). OBIA is recognized as having many of the benefits of each approach and better poised to deliver products useful to a variety of user needs (Phinn et al., 2012). OBIA provides a hierarchical or multi-scale segmentation of an image. The classification process operates on objects or polygons in an image (Blaschke, 2010). For mapping Île à Vache, the software eCognition® (Trimble, Germany) was used. The segmentation approach was similar to Phinn et al., (2011), and is outlined in Figure 5.

## Segmentation and assignment

OBIA mapping involves two steps, firstly the image is segmented into objects, and secondly these objects are assigned to classes (Blaschke, 2010). In this case an image may consist of one or more spectral bands. The image is segmented based on the color, texture and shape of pixel groups, and the level of spatial detail required using three tunable factors size, color, and compactness. A finer scale of segmentation is required to delineate intricate habitat configurations. Segmentation factors were adjusted iteratively to match reef features evident in the images and identified in ground survey.

The first level of segmentation distinguished land, cloud, and water objects. A scale factor of 50 was used. The normalized difference vegetation index (NDVI) was used to extract cloud and features on land. This metric draws on the physical principal that infrared light is fully absorbed within the first few centimeters of the water surface. Land and cloud pixels were separated from water-covered pixels using the significantly higher reflection in this region of the electromagnetic spectrum. A ratio of the blue and green bands was then used to separate deep water. By examining object-values across a sand dominated sloping seabed, it is possible to set a threshold at which there ceases to be any increase in band-ratio with increasing depth. This value was taken to represent the onset of optically deep water. Beyond this point, spectral based classification is no longer feasible and classification must proceed based on contextual rules. To maximize the efficiency of image analysis, land, cloud and deep water were masked from the image before subsequent segmentation steps.



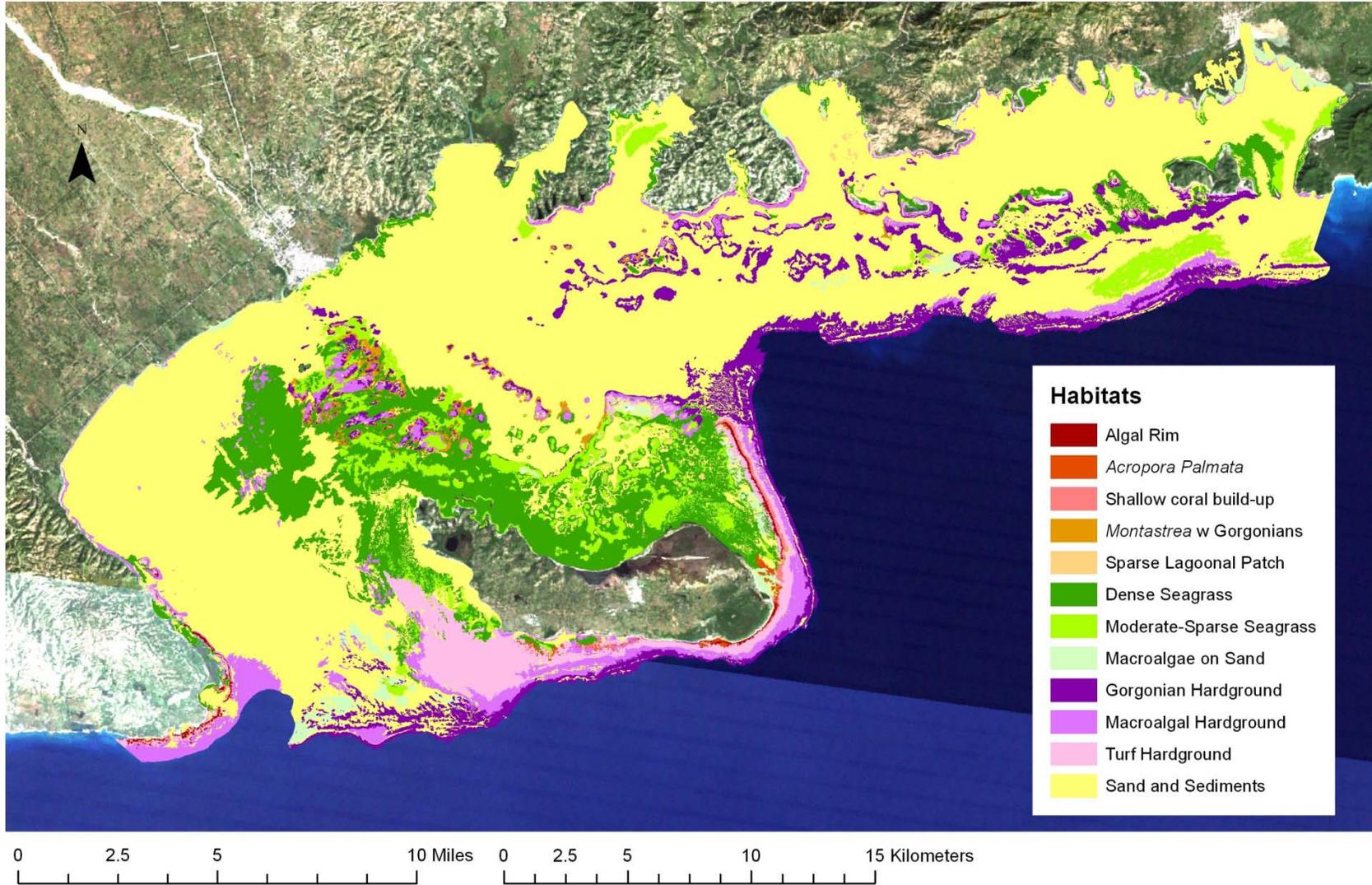
**Fig. 5 |** Multi-level segmentation of imagery to produce a thematic habitat map. AR = Algal rim; AP = *Acropora palmata*; SCB = Shallow coral build-up; MWG = Nontastrea reef with gorgonians; SPR = sparse patch reef; DSH = Dense seagrass and *Halimeda*; MSH = Moderate – sparse seagrass and *Halimeda*; MS = Moderate/ dense macroalgae on sand; GH = Gorgonian hardground; MH = Macroalgal dominated hardground; TH = Turf hardground; SMS = Sand and muddy sediment.

Using a scale factor of 100, images were partitioned into a second level consisting of broad geomorphic zones, reef slope, reef crest, reef flat, shallow lagoon, deep lagoon. Within these geomorphic classes finer scale objects were segmented. Within each geomorphic zone, habitats were segmented at a scale factor of 50 (level 3). This allowed separation of the largest most homogeneous reef and sediment features. This scale factor was not capable of capturing the detail of more heterogeneous features such as spur and groove, or accounting for rapid transitions such as occur across reef flats, or for identifying small patch reefs in relatively homogenous sediment or seagrass habitats. A final segmentation using a scale factor up to 10 was used in this case.

Objects are maintained through levels, with coarser 'super-objects' segmented into finer objects. Thus it is possible to carry assigned classes through segmentation levels. The user need assign only the finer features not identified at coarser segmentation levels. In deeper geomorphic zones the initial segmentation was based on the blue and green bands. In shallower zones such as reef flat and lagoon, the yellow band was also used. In both cases color thresholds were used to assign objects. Ground truth videos are used to develop thresholds and assign objects. Objects were assessed against underlying imagery and manually corrected where habitat boundaries were clearly misplaced. Objects classed as clouds were assigned to a habitat class based on the dominant class of neighboring objects. Differences in image radiometry made it necessary process each of the nine WorldView-2 images used through OBIA separately. In each case the final, level 5 classification was extracted as a raster image. These images were then joined into a single classification image.

### **Thematic habitat map applications**

Habitat classifications were converted to GIS-ready vector-based map products using remote sensing and ESRI ArcMAP GIS software (Figure 6). Pixel-based products, termed 'rasters', were converted into vector-based data termed 'shape files'. Under this system of storage, clumps of adjacent pixels that comprise a single patch of habitat are grouped as a single vector shape or polygon. Because only information relating to the boundary coordinates of the polygon is stored, such data is less intensive and easier to use for a number of applications. Shape files may be integrated with web-based geographic media for wider distribution. Attributes may be appended to a habitat polygon from subsequent analyses or field survey. Aside from a description of the relevant habitat class, such attributes might include geometric measures, for example area or perimeter of the habitat patch; measures of environmental context, such as distance from shore, or distance from an urban center; measures of human use, for instance fishing pressure across the habitat patch or recreational SCUBA; localized environmental data including meteorological measurements, water depth across the polygon, water temperature, or results from fine-resolution seafloor survey. In short, anything that can be measured and appended with a spatial coordinate can be brought into a GIS. As a GIS-ready product, the marine habitat data provided can form the basis of more in-depth exploration.



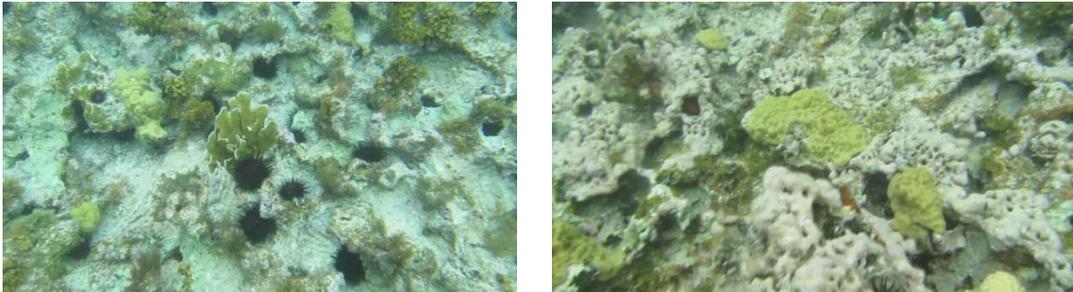
**Fig. 6 |** Thematic habitat classification of Île à Vache.

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## Appendix A: Haiti benthic habitat assemblages

### 1. Algal Rim



Algal rims are found in shallow water break zones. Benthic cover consists of turf algae and calcareous algae. Large fleshy macro-algae are largely absent and only small coral colonies are seen. .

[See snorkel photos/video]

### 2. *Acropora palmata*



Reef formed by skeletons of *Acropora palmata*, *millepora*, massive and encrusting coral species. This class is typically found just to the lee of the reef crest above ~5 m water depth.

[See snorkel photos/video]

### 3. Shallow coral build-up



Areas of coral framework located shallower than ~10 m and in close proximity to exposed reef crests. Live coral cover (*Acropora palmata*, *Montastria*, *Agaricia tenifolia*, *Millepora*) is less than 15 %. Macroalgae dominates the substrate.

[See snorkel photos/video and video d130]

### 4. *Montastrea* reef with gorgonians



Areas of framework formed of massive coral species such as *Montastria* or *Dendrogyra*. Coral structure may or maynot have a living coral veneer. The reef maintains the coral form. Live coral cover is patchy (< 15 % overall). Gorgonians dominate the substrate between corals.

[Video d150 and d157]

## 5. Sparse patch reef



Sparse patch reef found within shallow lagoon environments. Corals occur as isolated colonies, or meter scale patches of framework. These patches are typically located on topographic highs and are separated by sand or seagrass. The assemblage consists of scleractinians, hydrocorals, gorgonians, and sponges. Lagoonal patch reefs typically occur in depths shallower than ~10 m, and rise to a depth of ~1 m. Live coral cover is less than 10 %.

[Video d110 and d333]

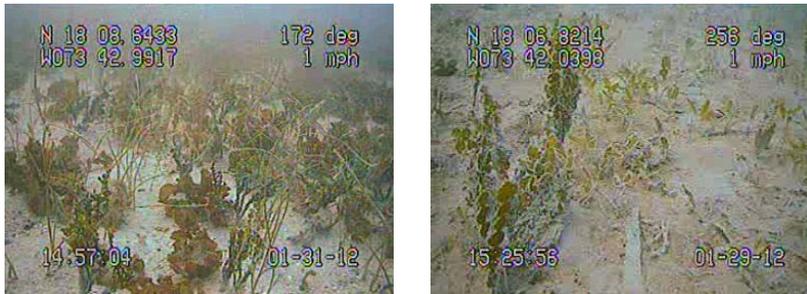
## 6. Dense seagrass and halimeda



Dense meadows of seagrass (> 60 % cover) dominated by *Thalassia testudinum*. Other seagrasses (e.g. *Syringodium filiforme*) and macroalgae (e.g. *Halimeda* sp.) are also present, but at lower density. Dense seagrass is found within lagoons at depths shallower than ~15 m.

[Video d112 and d169]

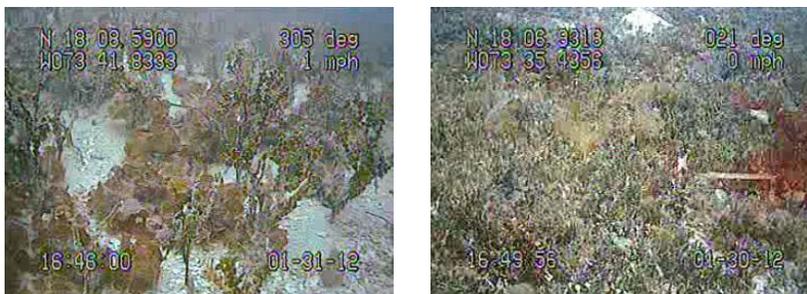
## 7. Moderate – sparse seagrass and *Halimeda*



Sand with less than 40 % seagrass/*Halimeda* cover. Community is dominated by *Thalassia testudinum* but other seagrasses (principally *Syringodium filiforme*) and macroalgae (*Halimeda* sp.) contribute significantly to cover. Moderate – sparse seagrass is typically found within lagoons at depths shallower than ~15 m.

[Video d35 and d163]

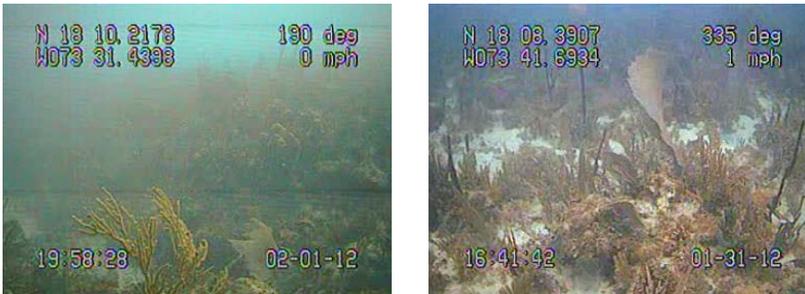
## 8. Moderate/ dense macroalgae on sand



Areas of unconsolidated sand with < 5 % seagrass cover, but relatively high macroalgae cover (> 60 %). Typically this class is located leeward of reef crests in depths above 5 m. Macroalgae include calcareous algae such as *Halimeda* as well as fleshy macroalgae such as *Padina*. Cyanobacteria often form dense mats between macroalgal stalks covering underlying sand substrate.

[Video d109 and d179]

## 9. Gorgonian hardground



Reef framework with a dominant cover of gorgonians (> 60 %). Scleractian coral cover is typically low (< 5 %). Sponges and macroalgae occupy most of the remaining substrate.

[Video d178 and d248]

## 10. Macroalgal dominated hardground



Reef framework, with a dominant cover (> 60 %) of macroalgae, principally sargassum sp.. Scleractinian coral cover is typically low (< 5 %). Sponges and macroalgae occupy most of the remaining substrate.

[Video d50 and d274]

## 11. Turf hardground



Bare flat hardground typically covered with a veneer of turf algae, and a sparse (< 5 %) cover of scleractinian coral, hydrocoral, gorgonians, sponges and macroalgae. Typically found on exposed margins seaward of the reef crest, above ~10 m where large waves may scour the seafloor.

[Video d45 and d211]

## 12. Sand and muddy sediment



Unconsolidated sediment sheets with little to invertebrate, seagrass or macroalgal cover. This class occurs at all depths and in all geomorphological zones. Within embayments and deep lagoons sediments are muddier. Towards the offshore sediments become more skeletal. In close proximity to reefs small coral and rock fragments are also seen.

[Video d37 and d61]