EMSN-051
Post-Matthew monitoring on rural areas in the South Region of Haiti

Technical Report

Prepared for European Commission – Joint Research Centre

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Executive summary

This technical report is delivered to the European Commission, JRC under Framework Service contract No. 259811, “Emergency Management Service – Risk and Recovery Mapping” and is in reply to the ITT “EMSN-051 - Post-Matthew monitoring on rural areas in the South Region of Haïti”. This document is from the Consortium led by Airbus Defence and Space and for this specific contract, SERTIT proposed the offer.

Cyclone Matthew struck southwest Haiti as a Category 4 storm on October 4th, the first Category 4 hurricane to strike Haiti since Hurricane Cleo in 1964. With upwards of 1,300 lives lost across the Caribbean, and more than a 1,000 lives lost in Haiti, the storm is the deadliest hurricane to strike in the Caribbean since Jeanne in 2004. The impact of Matthew will be lasting. While flooding caused significant damage and loss of life, the main impact was felt from the wind, which in some regions has destroyed more than 95% of buildings and has completely destroyed trees and agriculture. In addition, widespread environmental damage occurred. It is worth noting that the area most affected has the largest concentration of natural protected areas in Haiti.

This Emergency Management Service Risk & Recovery activation ‘’EMSN-051 : Post-Matthew monitoring on rural areas in the South Region of Haïti’’ has been requested by the Delegation of European Union in Haïti, on behalf of the Centre national d’Information Cartographique (CNIGS) of Haïti.

The scope of the request is to support and assist monitoring recovery after the passage of Matthew cyclone on the 4th of October 2016 in six selected areas to analyses of several environmental aspects including agriculture activities, over protected forest areas and mangrove areas. The aim is to build a comprehensive database to perform recovery aid organization and recovery monitoring of the critical resources destroyed. Information provided will be used by local governmental organisation and users.

This technical report is split into sections that outline the specific request and then detail in a tabular format the main elements concerning the satellite/aerial data requests, deliveries, and quality related issues. Workflow and production are outlined on a thematic basis according to the ITT offer content.

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Glossary

Acronym	Original name (French)	English translation
AU		Authorised User
CIAT	Comité Interministériel d'Aménagement du Territoire	Interministerial Committee for Territorial Planning
CNIGS	Centre National d'Information Géospatiale d'Haïti	National Center for Geospatial Information of Haïti
DAP		Data Access Portfolio
DSAS		Digital Shoreline Analysis System
DTM		Digital Terrain Model
EO		Earth Observation
ESA	Agence Spatiale Européenne	European Space Agency
FAO		Food and Agriculture Organization
KML		Keyhole Markup Language
LULC		Land use / Land cover
NDVI		Normalized Difference Vegetation Index
OGC		Open Geospatial Consortium
OSM		Open Street Map
RM		Rapid Mapping
RRM		Risk and Recovery Mapping
SI		Shadow Index
UNEP		United Nations Environment Programme
UNOSAT		UNITAR's Operational Satellite Applications Programme
USGS		United States Geological Survey
VHR		Very High Resolution

1 The specific service request

1.1 Context

Cyclone Matthew damage to Haiti

Cyclone Matthew struck southwest Haiti as a Category 4 storm on October 4th, the first Category 4 hurricane to strike Haiti since Hurricane Cleo in 1964. With upwards of 1,300 lives lost across the Caribbean, and more than a 1,000 lives lost in Haiti, the storm is the deadliest hurricane to strike in the Caribbean since Jeanne in 2004. The impact of Matthew will be lasting. While flooding caused significant damage and loss of life, the main impact was caused by the wind, which in some regions destroyed more than 95% of buildings and has completely destroyed trees and agriculture. In addition, widespread environmental damage occurred. It is worth noting that the area most affected has the largest concentration of natural, protected areas in Haiti.

On the 03 of October 2016, a Rapid Mapping activation was triggered upon request of the EC Services (DG ECHO) for Haiti since the Cyclone Matthew, a slow-moving storm, was expected to dump of torrential rainfall over Haiti in the next hours, with great danger for population and infrastructures. The damage, mostly concentrating on buildings and infrastructure, over many parts of Haiti was mapped over the following days, focussing on Grand Anse in particular.

Service request background

This Emergency Management Service Risk & Recovery activation ‘’EMSN-051 : Post-Matthew monitoring on rural areas in the South Region of Haiti’’ has been requested by the Delegation of the European Union in Haiti, contact persons: Eloisa Astudillo Fernandez, e-mail: Eloisa.ASTUDILLO@eeas.europa.eu, on behalf of the Centre National d’Information Géospatiale of Haiti, contact person: Boby Emmanuel Piard, email: bepiard@yahoo.fr.

Scope of the request

The scope of the service request EMSN-051 is to support and assist monitoring recovery after the passage of Matthew cyclone on the 4th of October 2016 in six selected areas, to analyses of several environmental aspects including agriculture activities, forest within protected areas and mangrove areas.

The aim is to build a comprehensive database to perform recovery aid organization and recovery monitoring of the critical resources destroyed. Information provided will be used by local governmental organisations and users.

The spatial data are the main focus, hence, all the spatial and tabular data will be delivered integrated in an information system compliant with OGC and ArcGis format, together with legend description (e.g. lyr-files).

1.2 Geographic Area of Interest

The areas of interest cover several places of Haiti's southern region, ranging from Jérémie, Makaya Park, Port-Salut, Les Cayes and Pointe Abacou (Figure 1). In this area, the coastal line has also to be addressed between the cities of Jérémie and Les Cayes (nearly 250km of seashore).

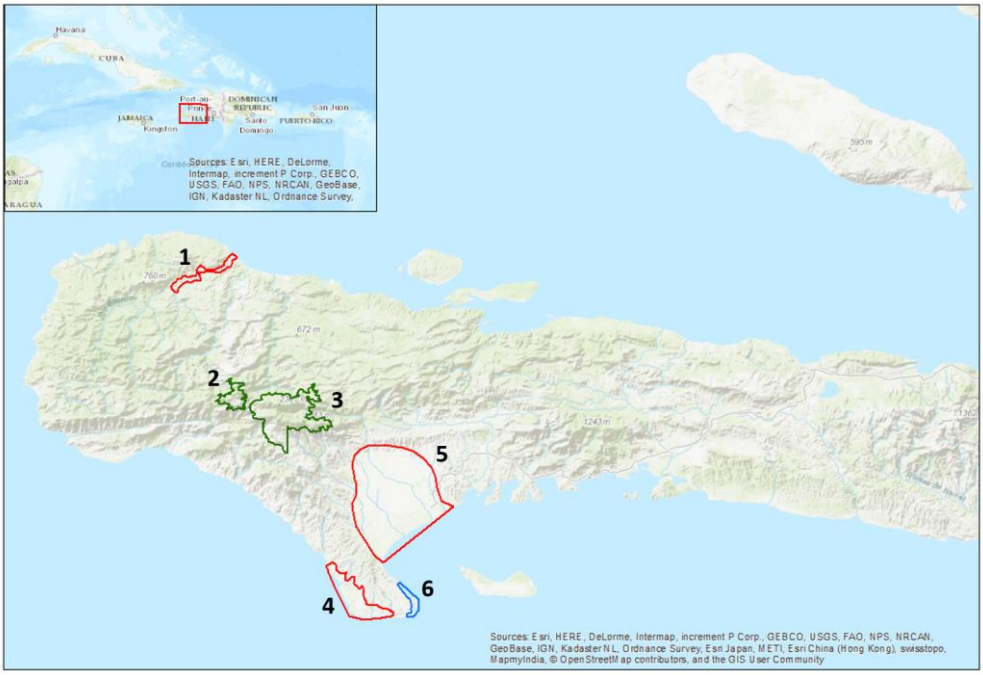


Figure 1-1: Areas of interest.

2 General cartographic content

2.1 Map deliverables

2.1.1 Map sheet layout and map scales

EMSN-051 requires a detail level for the spatial data that corresponds to a cartographic scale of 1:5000. One or more overview maps are also requested per AOI. Hence, one overview map has been produced per map-set (AOI) as detailed in Table 1.

Table 2-1: Map sheets synthesis.

AOI name	Map scale	Type of map	Number of map sheets	Map orientation
01JEREMIE	1:20000	Overview	1	Landscape
02MAKAYAWEST	1:12000	Overview	1	Landscape
03MAKAYAEAST	1:25000	Overview	1	Landscape
04PORTSALUT	1:20000	Overview	1	Landscape
05LESCAYES	1:40000	Overview	1	Landscape
06POINTEABACOU	1:10000	Overview	1	Portrait
07JEREMIETOLESCAYES	1:135000	Overview	1	Landscape

Also, the coordinate reference system used for all associated products (maps and data) will be UTM/WGS1984 zone 18 North (the EPSG code is 32618). Cartographic products are produced using the supplied ArcGIS map templates for A1-size products.

The file names of the map products follow the requested file naming convention and examples. In addition, any delivered vector files follow the RRM naming conventions used in the legend items to make them self-explanatory.

2.1.2 Products overview

The Airbus DS consortium has produced a set of maps and statistics for each themes and their requested recovery products:

Agriculture

- 3 detailed map products of pre-Matthew agricultural activities (Jérémie, Port-Salut and Les Cayes);

- 3 detailed map product of post-Matthew agricultural activities (recent status for Jérémie, Port-Salut and Les Cayes);
- 3 detailed map product of agricultural land status and its change (Jérémie, Port-Salut and Les Cayes);

Coastal line

- 1 coastal line delineation map (from Jérémie to Les Cayes);
- 1 coastal line evolution map (from Jérémie to Les Cayes);

National Makaya Park

- 2 pre-Matthew vegetation classification map in Makaya Park (AOIs 2&3);
- 2 damage assessment map of forest stands in Makaya Park (AOIs 2&3);
- 2 monitoring map product of forest stands in Makaya Park (AOIs 2&3);

Mangrove

- 1 pre-Matthew situation map of the mangrove at Pointe Abacou;
- 1 post-Matthew situation and change map of the mangrove at Pointe Abacou.

A total 19 map products and associated statistics have been produced. Each set of map themes show all appropriate reference data, as well as relevant observed or estimated crisis information (Table 2, 3, 4 and 5).

Table 2-2: Map products and associated layers for agriculture.

Map layers	Reference map of agricultural activities	Post-event map of agricultural activities	Change map of agricultural activities
Agricultural activities (reference)	✓		
Agricultural activities (post-event)		✓	
Change of agricultural activities			✓
General topography (infrastructure networks, urban, buildings, hydrographic network, Industry and facilities, contours and spot heights, shaded relief)	✓	✓	✓

Table 2-3: Map products and associated layers for coastal line.

Map layers	Coastal line delineation map	Coastal line evolution map
Coastal line (archive)	✓	
Post-Matthew coastal line	✓	
Coastal line evolution		✓
General topography (infrastructure networks, urban, buildings, hydrographic network, Industry and facilities, contours and spot heights, shaded relief)	✓	✓

Table 2-4: Map products and associated layers for Makaya Park.

Map layers	Pre-Matthew vegetation classification map	Forest stands damage assessment map	Forest stands monitoring map
Vegetation classification (pre-event)	✓	✓	✓
Damage assessment of forest stands		✓	
Monitoring of forest stands			✓
General topography (infrastructure networks, urban, buildings, hydrographic network, Industry and facilities, contours and spot heights, shaded relief)	✓	✓	✓

Table 2-5: Map products and associated layers for mangrove.

Map layers	Pre-Matthew mangrove delineation map	Post-Matthew mangrove delineation and change map
Mangrove (pre-event)	✓	
Mangrove (post-event)		✓
Changes into the mangrove		✓

Map layers	Pre-Matthew mangrove delineation map	Post-Matthew mangrove delineation and change map
General topography (infrastructure networks, urban, buildings, hydrographic network, Industry and facilities, contours and spot heights, shaded relief)	✓	✓

2.2 Reference data

This activation calls for a set of Risk and Recovery Mapping (RRM) products to support activities of the administration in reconstruction work following damages caused by Matthew cyclone (October 2016) over the southern region of Haiti. These products include general reference layers, thematic layers specific to the addressed domains, and information in alphanumeric or tabular form.

As requested the following up-to-date general reference information appear in the RRM products as background:

- Topographic elements: toponyms and administrative boundaries, hydrology,
- Physiography, contours with 5 meters interval and spot heights,
- Populated places (based on most recent census data, or/and alternatives),
- Building footprints,
- Settlements both formal (urban, suburban, rural, etc.) and informal (slums, IDPs camps, etc.),
- Road network and all other related transport network,
- Industry and utilities: industrial facilities, power stations, water infrastructure,
- Location of hospitals, schools, government facilities, food distribution infrastructure,
- Location and type of industry or potential sites of industrial accidents.
- A land use/land cover, discrimination of land use/land cover classes must be comparable or more detailed than CORINE level 3 classes, is listed as a potential reference layer.

2.2.1 Data Sources

The Technical Annex for EMSN-051 has indicated several potential sources of geospatial data for this request (see below). Airbus DS Consortium has started the process of analysing these datasets, this offer builds upon these.

To summarize, existing data sources are:

- Haiti national reference imagery and elevation data (from CNIGS);
- Satellite imagery archives through ESA-DAP (e.g. Pléiades and SPOT imagery

acquired for the Recovery Observatory, among others);
- Ancillary data vectors and raster available at CNIGS and CIAT;
- Open reference data particularly OSM and Haitidata.org;
- Copernicus EMSR-185 database for reference data and Matthew damages.
- Copernicus EMSN-050 database for reference data.
- UNOSAT post-Matthew damage assessment
- UNEP field data gathering

Agricultural activities (pre-event)

This thematic layer was derived from scratch from pre-event satellite imagery. We have chosen to work according to the CNIGS's LULC nomenclature as far as possible.

Agricultural activities (post-event)

This thematic layer was derived from scratch from post-event satellite imagery. We have chosen to work according to the CNIGS's LULC nomenclature as far as possible.

Change of agricultural activities

This layer was derived from comparing of the two previous ones.

Coastal line (archive)

This layer was provided by CNIGS and contains the coastal line delineation for 1978, 2002 and 2010.

Coastal line (post-event)

This layer was produced by photo-interpretation of VHR satellite data acquired in 2017.

Coastal line evolution

Calculation of erosion and pro-gradation of coastal line between 2010 and post-event situation (i.e. 2017) was performed using the Digital Shoreline Analysis System (DSAS) released by USGS, through a plugin available for ArcGis software.

Pre-Matthew vegetation classification in Makaya Park

This thematic layer has been derived from scratch from pre-event satellite imagery. We have chosen to work according to the CNIGS's LULC nomenclature as far as possible.

Damage assessment of forest stands in Makaya Park (shortly after the event)

This thematic layer was derived from post-event satellite imagery in its entirety.

Monitoring of forest stands in Makaya Park (12 months after the event)

This thematic layer was derived from post-event satellite imagery in its entirety.

Pre-Matthew situation of the mangrove

This thematic layer was derived from post-event satellite imagery in its entirety.

Post-Matthew situation of the mangrove

This thematic layer was derived from post-event satellite imagery in its entirety.

Changes into the mangrove

This thematic layer was produced from the intersection of the two previous layers.

General topography

Airbus DS used general topographic information provided by CNIGS and CIAT. Missing layers will be extracted from OSM and Haitidata.org databases.
The layers include: administrative boundaries, infrastructure networks, urban information, toponyms and populated places, hydrographic network, etc., where necessary these were updated over the area of interest.

Since the map scales are equal to or larger than 1:10 000 (1:10 000 to 1:40 000), buildings footprint are not foreseen in the maps. Hence, for background map layers only urban blocks will be displayed. They are derived by a combination of:

- urban areas provided by CIAT/CNIGS, and will be updated with OSM and reference ortho-photo of 2014, or VHR satellite imagery when applicable;
- transportation network provided by CIAT/CNIGS, and are also updated with OSM, reference ortho-photo from 2014, or VHR satellite imagery when applicable.

Given the request is focussed on rural agriculture and forested areas (or mangroves) the urban areas, and given the fact that in EMSN-050 the urban infrastructure (buildings and networks) is the focus, it has been proposed here to either insert the EMSR-050 building footprints, if available, or OSM building footprints into the EMSN-051 database.

Given the focus on tree covered areas, trees are deemed to supersede urban areas and, hence, take precedence over the urban blocks in the maps.

Points of interest were obtained from the toponyms and other place names layers from national database (CNIGS and CIAT) and OSM.

3D requirements

The DTM Lidar (1.5m resolution) provided by CNIGS was used as elevation layer. Spot heights and contours (interval 5m) in vector format have been extracted from this later.

Industry and utilities

The industrial facilities, power stations, and other features such as water infrastructure are obtained from official and non-official sources, which include CNIGS, CIAT, and online mapping sources. It has to be noticed that no such element has been found in the AOIs.

Land use/land cover (LULC)

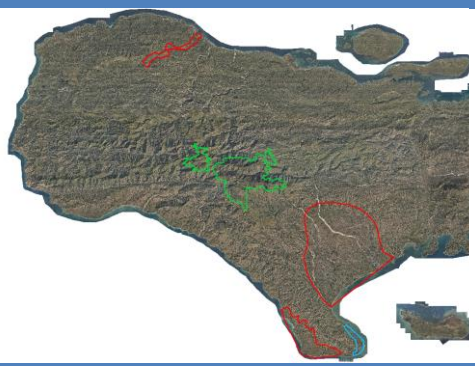
Only a land cover map produced in 1998 exists. The nomenclature is quite simple and is out-of-date. A LULC map produced by FAO also exists, but source data layer is not available at this time.

Hence, LULC is not derived as a separate product but will in fact be derived at a 1:5 000 compatible working scale by the combination of the hydrological, urban block, agricultural and tree classes that are described later in the methodological section. By definition this combined classification has a much higher resolution than Corine CLC using VHR1 and VHR2 satellite data or ortho-photos (CNIGS 2014) as sources.

Reference Ortho-photos

Ortho-photo images are made freely available by the CNIGS through the JRC. These images are airborne acquisitions from 2014 (Table 6). They will be used as the basis to validate and/or modify reference layers, and will be updated using more recent VHR archive satellite imagery (see data provision after).

Table 2-6: CNIGS reference imagery metadata.

Sensor	Date	Spatial resolution (m)	Quicklook	Comment
Ortho-photo	2014	0.25		Released by CNIGS

2.2.2 List of EO data

Archive satellite imagery

VHR1 and VHR2 optical data are necessary to produce the requested products. The result of a review of the archives available in the catalogue of the space imagery operators has been carried out, and is listed below for all AOIs. Images acquired before the passage of Hurricane Matthew and the ones taken after the event are clearly distinguished in the Tables.

Also, this work contains SPOT-6/7 and Pléiades data from the Recovery Observatory project (CEOS/CNES), and was supported by public funds received in the framework of GEOSUD, a project (ANR-10-EQPX-20) of the program "Investissements d'Avenir" managed by the French National

Research Agency.

The framework in which the satellite data were provided are listed in the Tables below:

- CDS SSO SDR means ordered through the Copernicus Users' Single Sign On Login Standard Data Request procedure
- CNES-GEOSUD means the data were sourced through the French Space Agency's Kalidéos programme for whom GEOSUD manages the data distribution procedures

- **Agriculture**

Concerning the agricultural activities, related to AOIs (1, 4 and 5), the preferred images, which have been selected according to crop calendars, pre and post Cyclone Matthew and the chronological pertinence, are highlighted in green (before event), red (close to the event) and orange (after event). By chronological pertinence, it is meant, the focus on 2017 post-Matthew imagery (recent status).

AOI01 – Jérémie

Due to the complexity of agricultural activities in AOI 1 – variety of crops (beans, yams, arboriculture, others), heterogeneous planting and harvesting periods – satellite images acquired at different seasons (wet/dry seasons, planting/harvesting periods) were selected in order to optimize the chance to characterize the agricultural lands (croplands, grass, shrubs, baresoils) and their changes. Two images were not used:

- the 14/06/2015 WorldView-2, as on download a thin veil of haze was seen to cover the whole image. This was not detectable in the QL,
- the 18/10/2017 Pléiades image as another image was available on the same date.

Each time a main image was selected to derive the forest layers and a number of other images were used to help focus the classification using neo-channels. This will be explained later.

Table 2-7: List of VHR1/2 imagery available over AOI1 Jérémie.

Sensor Date	Spatial resolution (m)	Comment	Use	Image provision
SPOT 6/7 **17/11/2014**	1.5	**Low vegetation coverage** (beans, yams harvested)	This image was extensively used	CDS SSO SDR
WorldView-2 **14/06/2015**	0.5	Does not cover the whole AOI. Beginning of spring crop harvesting period **High/mixed vegetation coverage**	Not used due to thin veil of haze over most of the image.	CDS SSO SDR

Sensor Date	Spatial resolution (m)	Comment	Use	Image provision
WorldView-2 28/10/2015	0.5	**Low vegetation coverage** (beans, yams harvested)	This image was extensively used	CDS SSO SDR
SPOT 6/7 26/01/2016	1.5	Beginning of autumn crop harvesting period **High/mixed vegetation coverage**	This image was extensively used	CNES-GEOSUD
GeoEye-1 07/06/2016	0.5	Does not cover the whole AOI. Beginning of spring crop harvesting period **High/mixed vegetation coverage**	This image was extensively used	CDS SSO SDR
SPOT 6/7 14/02/2017	1.5	End of harvesting period **Low vegetation coverage**	This image was extensively used	CNES-GEOSUD
SPOT 6/7 30/09/2017	1.5	**Mixed vegetation coverage**	This image was extensively used	CDS SSO SDR
SPOT 6/7 18/10/2017	1.5	**Mixed vegetation coverage**	This image was extensively used	CNES-GEOSUD
Pleiades 15/12/2017	0.5	**Low vegetation coverage** (beans, yams harvested)	This image was extensively used	CDS SSO SDR
GeoEye-1 15/12/2017	0.5	Does not cover the whole AOI. **Low vegetation coverage** (beans, yams harvested)	This image was not ordered as it was taken on the same day as the 15/12/2017 Pléiades which cover the whole AOI	-

Table 2-8: List of VHR1/2 imagery used over AOI1 Jérémie with technical details and orthorectifcation RMS.

Sensor	Date	Time	GSD (m)	% clouds	Incidence (°)	RMS (m)
SPOT 6/7	17/11/2014	15:12	1.5	1.37	12.76	1.35

Sensor	Date	Time	GSD (m)	% clouds	Incidence (°)	RMS (m)
WorldView-2	28/10/2015	15:32	0.5	3	23.4	1.25
SPOT 6/7	26/01/2016	15:13	1.5	2.92	18.37	1.157
GeoEye-1	07/06/2016	15:28	0.5	3	19	1.32
SPOT 6/7	14/02/2017	15:03	1.5	0.26	15.5	Already ortho
SPOT 6/7	30/09/2017	15:00	1.5	6.35	28.11	0.94
SPOT 6/7	18/10/2017	15:10	1.5	8.64	6.77	Already ortho
Pleiades	15/12/2017	15:41	0.5	0	14	1.36

AOI04 – Port Salut

Due to the complexity of agricultural activities in AOI 4 – variety of crops with two crop seasons satellite images acquired at different seasons (wet/dry seasons, planting/harvesting periods) were selected in order to optimize the chance to characterize the agricultural lands (croplands, grass, shrubs, baresoils) and their changes. Two images were not used:

- the 03/07/2015 WorldView-2 was not extensively used as the same data as the SPOT6/7 image. The focus was on using data with the same resolution,
- the 14/02/2017 and 18/10/2017 SPOT-6/7's were not extensively used because the images have a different resolution to the main image dataset (WorldViews),
- the 29/09/2017 Pleiades image was not really used as it is in fact comprised of a multi-date mosaic. This was not fully understood during proposal writing

Each time a main image was selected to derive the forest layers and a number of other images were used to help focus the classification using neo-channels. This will be explained later.

Table 2-9: List of VHR1/2 imagery available over AOI4 Port-Salut.

Sensor Date	Spatial resolution (m)	Comment	Use	Image provision
SPOT 6/7 02/10/2014	1.5	Very beginning of autumn crop planting period **Low vegetation coverage**	This image was extensively used	CDS SSO SDR
WorldView-2 03/07/2015	0.5	Spring crop harvesting period **Low vegetation coverage**	Not extensively used as the same data as the SPOT6/7 image. Used imagery with the same resolution	CDS SSO SDR
SPOT 6/7 03/07/2015	1.5	Spring crop harvesting period **Low vegetation coverage**	This image was used but delicate as the vegetation response was very low due to drought conditions	CDS SSO SDR
SPOT 6/7 08/01/2016	1.5	Beginning of autumn crop harvesting period **High/mixed vegetation coverage**	This image was the main pre Matthew image for agricultural/forestry analysis	CNES-GEOSUD
SPOT 6/7 14/02/2017	1.5	Autumn crop harvesting period **Low vegetation coverage**	Not extensively used because the image has a different resolution to the main image dataset	CNES-GEOSUD
WorldView-3 07/03/2017	0.50	After autumn crop harvesting Before spring crop planting **Very low vegetation coverage**	This image was the main post Matthew image for agricultural/forestry analysis, cloud-free	CDS SSO SDR
WorldView-2 11/04/2017	0.50	Spring crop planting period **Mixed vegetation coverage**	This image was extensively used except in cloudy/shaded areas	CDS SSO SDR
WorldView-2 11/05/2017	0.50	Spring crop planting period **Mixed vegetation coverage**	This image was extensively used except in cloudy/shaded areas	CDS SSO SDR
Pleiades 29/09/2017	0.5	Very beginning of autumn crop planting period **Low vegetation coverage**	This image was not really used as it is in fact comprised of a multi-date mosaic, not fully understood during proposal writing	CNES-GEOSUD
SPOT 6/7 18/10/2017	1.5	Autumn crop planting period **Mixed vegetation coverage**	Not extensively used because the image has a different resolution to the main image dataset	CNES-GEOSUD

Table 2-10: List of VHR1/2 imagery used over AOI4 Port-Salut with technical details and orthorectifcation RMS.

Sensor	Date	Time	GSD (m)	% clouds	Incidence (°)	RMS (m)
SPOT 6/7	02/10/2014	15:14	1.5	0	21.7	1.34
SPOT 6/7	03/07/2015	15:05	1.5	2.2	1.6	1.33
SPOT 6/7	08/01/2016	15:04	1.5	11.2	17	1.98
WorldView-3	07/03/2017	15:55	0.5	0	15.4	1.63
WorldView-2	11/04/2017	15:41	0.5	10.2	14.6	1.28
WorldView-2	11/05/2017	15:34	0.5	13.3	28.1	1.48

AOI05 – Les Cayes

Due to the complexity of agricultural activities in AOI 5 – variety of crops with 2 crop seasons satellite images acquired at different seasons (wet/dry seasons, planting/harvesting periods) were selected in order to optimize the chance to characterize the agricultural lands (croplands, grass, shrubs, baresoils) and their changes.
All images were used except the 03/07/2015 WorldView-3 as this image has very similar information on the agricultural cycle as the SPOT 6/7 from the 14/02/2017. The idea being to reduce the number of images being processed.

Each time a main image was selected to derive the forest layers and a number of other images were used to help focus the classification using neo-channels. This will be explained later.

Table 2-11: List of VHR1/2 imagery available over AOI5 Les Cayes.

Sensor Date	Spatial resolution (m)	Comment	Use	Image provision
SPOT 6/7 02/10/2014	1.5	Does not cover the whole AOI. Very beginning of autumn crop planting period **Low vegetation coverage**	This image was extensively used	CDS SSO SDR
SPOT 6/7 17/11/2014	1.5	Does not cover the whole AOI. Planting period **High/mixed vegetation coverage**	This image was extensively used	CDS SSO SDR
SPOT 6/7 03/07/2015	1.5	Spring crop harvesting period **Low vegetation coverage**	This image was extensively used	CDS SSO SDR
Pleiades 25/12/2015	0.5	Does not cover the whole AOI. Very beginning of autumn crop harvesting period **High vegetation coverage**	This image was the main pre Matthew image for forestry analysis, cloud-free	CNES-GEOSUD
SPOT 6/7 08/01/2016	1.5	Beginning of autumn crop harvesting period **High vegetation coverage**	This image was extensively used	CNES-GEOSUD
SPOT 6/7 14/02/2017	1.5	Autumn crops harvesting period **Low vegetation coverage**	This image was the main post Matthew image for forestry analysis, cloud-free	CNES-GEOSUD
WorldView-3 07/03/2017	0.5	After autumn crops harvesting Before spring crops planting **Very low vegetation coverage**	This image was extensively used	CDS SSO SDR
SPOT 6/7 04/09/2017	1.5	After spring crops harvesting Before autumn crops planting **Low vegetation coverage**	This image was extensively used	CNES-GEOSUD
Pleiades 12/10/2017	0.5	Beginning of planting period **Low vegetation coverage**	This image was extensively used	CDS SSO SDR

Sensor Date	Spatial resolution (m)	Comment	Use	Image provision
SPOT 6/7 **18/10/2017**	1.5	Autumn crops planting period **Mixed vegetation coverage**	This image was extensively used	CNES-GEOSUD

Table 2-12: List of VHR1/2 imagery used over AOI5 Les Cayes with technical details and orthorectifcation RMS.

Sensor	Date	Time	GSD (m)	% clouds	Incidence (°)	RMS (m)
SPOT 6/7	02/10/2014	15:14	1.5	0	22.1	0.65
SPOT 6/7	17/11/2014	15:11	1.5	0.5	10.96	0.53
SPOT 6/7	03/07/2015	15:05	1.5	2.6	3.35	0.69
Pleiades	25/12/2015	15:37	0.5	0	1.8	0.42
SPOT 6/7	08/01/2016	15:04	1.5	0	16.27	0.43
SPOT 6/7	14/02/2017	15:02	1.5	0.37	12.9	0.35
SPOT 6/7	04/09/2017	15:00	1.5	18.15	15.4	0.27
Pleiades	12/10/2017	15:10	0.5	8.49	12.95	0.46
SPOT 6/7	18/10/2017	15:10	1.5	8.59	16.46	0.19

- **Coastal line**

The VHR2 SPOT-6/7 imagery coverage was reasonably retained, since the VHR1 required data are too important, and the range of acquisition date is too large. Also, differences between view angles, sea level and geometrical positioning would add complexity in thematic analysis.

Table 2-13: List of VHR1/2 imagery available over AOI7.

Sensor Date	Spatial resolution (m)	Comment	Use	Image provision
Spot 6/7 **14/02/2017**	1.5	Full coverage with two images acquired the same day and by the same sensor. Cloud free other the entire AOI.	These images were extensively used	CNES-GEOSUD
Pléiades **05/02/2017** **05/02/2017** **05/02/2017** **18/10/2017** **19/10/2017** **30/10/2017** **08/12/2017** **15/12/2017**	0.5	Partial coverage despite 8 images	Not used	CDS SSO SDR
Worldview-2 **Worldview-3** **Worldview-4** **GeoEye-1** **07/03/2017** **30/04/2017** **11/05/2017** **04/06/2017** **30/11/2017** **06/12/2017** **12/12/2017** **15/12/2017** **14/01/2018**	0.5	Full coverage with 9 images. The coast in the sector of Tiburon is under haze	Not used	CDS SSO SDR

Table 2-14: List of AOI7 VHR1/2 imagery with technical details and orthorectifcation RMS.

Sensor	Date	Time	GSD (m)	% clouds	Incidence (°)	RMS (m)
SPOT 6/7	14/02/2017	15:02	1.5	0.37	12.9	0.350
SPOT 6/7	14/02/2017	15:03	1.5	0.27	17.9	0.269

- National Makaya Park

Due to the relief of national Makaya Park, satellite imagery are always more or less affected by clouds. Hence, it is quite impossible to catch the state of the vegetation at a unique date for the entire two AOI's, as seen below (Table 15).

Table 2-15: List of VHR1/2 imagery available over AOI2&3 Makaya Park.

Sensor Date	Spatial resolution (m)	Comment	Use	Image provision
SPOT 6/7 17/11/2014	1.5	Covers completely AOI2. Shadows due to relief. End of rainy season	This image was extensively used over AOI02	CDS SSO SDR
SPOT 6/7 08/01/2016	1.5	Shadows due to relief and dry season	Used for gap filling over AOI02	CNES-GEOSUD
SPOT 6/7 25/06/2016	1.5	Partially covers AOI2	This image was extensively used over AOI03	CNES-GEOSUD
SPOT 6/7 08/10/2016	1.5	Partially cloudy. Too close from the event	Not used	CDS SSO SDR
SPOT 6/7 23/12/2016	1.5	AOI3 is nearly cloud free	This image was extensively used over AOI03	CDS SSO SDR
GeoEye-1 08/01/2017	0.5	Covers only AOI2	This image was extensively used over AOI02	CDS SSO SDR
GeoEye-1 08/01/2017	0.5	Covers only the northern part of AOI3	Used	CDS SSO SDR
Pléiades 29/09/2017	0.5	Covers AOI2, and slightly cloudy	Not really used	CDS SSO SDR
Pléiades 18/10/2017	0.5	Covers AOI3, and cloudy	Not used	CDS SSO SDR
Pléiades 08/12/2017	0.5	Clear sky over AOI2.	This image was extensively used over AOI02	CDS SSO SDR
Pléiades 08/12/2017	0.5	AOI3 slightly cloudy	This image was extensively used over AOI03	CNES-GEOSUD

Table 2-16: List of VHR1/2 imagery used over AO2&3 Makaya Park with technical details and orthorectifcation RMS.

Sensor Date	Date	Time	GSD (m)	% clouds	Incidence (°)	RMS (m)
SPOT 6/7 (AOI2)	17/11/2014	15:12	1.5	0.27	13.0	1.89
SPOT 6/7 (AOI3)	08/01/2016	15:04	1.5	11.2	17.0	1.98
SPOT 6/7 (AOI3)	25/06/2016	15:03	1.5	0.7	14.9	1.74
SPOT 6/7 (AOI3)	23/12/2016	15:11	1.5	5.1	22.2	1.84
GeoEye-1 (AOI2)	08/01/2017	15:32	0.5	0.0	17.6	0.89
GeoEye-1 (AOI3)	08/01/2017	15:31	0.5	0.0	17.6	0.82
GeoEye-1 (AOI3)	08/01/2017	15:32	0.5	0.01	24.7	0.92
Pléiades (AOI2)	29/09/2017	15:34	0.5	22.1	21.4	0.84
Pléiades (AOI2)	08/12/2017	15:44	0.5	0.0	30.0	0.89
Pléiades (AOI3)	08/12/2017	15:45	0.5	5.2	21.9	Already ortho

- Mangrove

Table 2-17: List of VHR1 imagery available over AOI6 Pointe Abacou.

Date	Spatial resolution (m)	Comment	Use	Image provision
Worldview-2 17/01/2016	0.5		This image was extensively used	CDS SSO SDR
Worldview-2 25/02/2018	0.5	Clouds are out of the AOI. Most recent VHR1 acquisition	This image was extensively used	CDS SSO SDR

Table 2-18: List of VHR1/2 imagery used over AOI6 Pointe Abacou with technical details and orthorectifcation RMS.

Sensor Date	Date	Time	GSD (m)	% clouds	Incidence (°)	RMS (m)
Worldview-2	17/01/2016	15:46	0.5	0.0	27.0	0.83
Worldview-2	25/02/2018	15:57	0.5	0.0	24.3	0.92

Table 2-19: EO data ordering, availability and download dates

Image Name	AOI	Submitted	Image Date	Image	Availability FTP	SP Download	Comments
SP06_NAO_PMS_1A_20141002T151455_20141002T151501_TOU_1234_5d12	04PORTSALUT	09/05/18	02/10/2014	SPOT 6/7	14/05/2018	14/05/2018	
SP06_NAO_PMS_1A_20150703T150519_20150703T150534_TOU_1234_45c7	04PORTSALUT	09/05/18	03/07/2015	SPOT 6/7	10/05/2018	14/05/2018	
EW03_WV3_PSH_SO_20170307T155552_20170307T155604_DGI_13905_8D8C	04PORTSALUT	09/05/18	07/03/2017	WorldView 3	11/05/2018	14/05/2018	
EW02_WV1_PSH_SO_20170411T154133_20170411T154141_DGI_39393_EA01	04PORTSALUT	09/05/18	11/04/2017	WorldView 2	11/05/2018	14/05/2018	
EW02_WV1_PSH_SO_20170511T153420_20170511T153421_DGI_39824_7030	04PORTSALUT	09/05/18	11/05/2017	WorldView 2	12/05/2018	14/05/2018	
EW03_WV3_PSH_SO_20170307T155532_20170307T155545_DGI_13905_5962	05LESCAYES	11/05/18	07/03/2017	WorldView 3	14/05/2018	14/05/2018	
PH1B_PHR_FUS_1A_20171012T153425_20171012T153433_TOU_1234_4057	05LESCAYES	11/05/18	12/10/2017	Pléiades	14/05/2018	15/05/2018	
SP06_NAO_PMS_1A_20141002T151547_20141002T151553_TOU_1234_52d8	05LESCAYES	11/05/18	02/10/2014	SPOT 6/7	10/05/2018	15/05/2018	
SP07_NAO_PMS_1A_20141117T151150_20141117T151200_TOU_1234_b9e7	05LESCAYES	11/05/18	17/11/2014	SPOT 6/7	15/05/2018	15/05/2018	
SP06_NAO_PMS_1A_20150703T150519_20150703T150534_TOU_1234_bd29	05LESCAYES	11/05/18	03/07/2015	SPOT 6/7	15/05/2018	15/05/2018	
SP06_NAO_PMS_1A_20170904T150004_20170904T150014_TOU_1234_eea4	05LESCAYES	11/05/18	04/09/2017	SPOT 6/7	15/05/2018	15/05/2018	
EW02_WV1_PSH_SO_20150614T154209_20150614T154219_DGI_29809_CDEE	01JEREMIE	11/05/18	14/06/2015	WorldView 2	14/05/2018	14/05/2018	
EW02_WV1_PSH_SO_20151028T153253_20151028T153303_DGI_31763_0550	01JEREMIE	11/05/18	28/10/2015	WorldView 2	14/05/2018	re-ordered	
GY01_GIS_PSH_SO_20160607T152807_20160607T152833_DGI_41430_5309	01JEREMIE	11/05/18	07/06/2016	GeoEye-1	14/05/2018	re-ordered	
PH1B_PHR_FUS_1A_20171215T154105_20171215T154113_TOU_1234_e317	01JEREMIE	11/05/18	15/12/2017	Pléiades	14/05/2018	14/05/2018	
SP07_NAO_PMS_1A_20141117T151207_20141117T151217_TOU_1234_eee1	01JEREMIE	11/05/18	17/11/2014	SPOT 6/7	15/05/2018	re-ordered	
SP07_NAO_PMS_1A_20160126T151327_20160126T151336_TOU_1234_e45c	01JEREMIE	11/05/18	26/01/2016	SPOT 6/7	15/05/2018	15/06/2018	
SP06_NAO_PMS_1A_20170930T150033_20170930T150039_TOU_1234_a7ab	01JEREMIE	11/05/18	30/09/2017	SPOT 6/7	15/05/2018	15/05/2018	
SP07_NAO_PMS_1A_20141117T151207_20141117T151217_TOU_1234_2b2b	02MAKAYAWEST	11/05/18	17/11/2014	SPOT 6/7	15/05/2018	16/05/2018	
SP06_NAO_PMS_1A_20161223T151101_20161223T151114_TOU_1234_5870	03MAKAYAEAST	11/05/18	23/12/2016	SPOT 6/7	15/05/2018	re-ordered	
PH1A_PHR_FUS_1A_20170929T153432_20170929T153434_TOU_1234_a177	02MAKAYAWEST	11/05/18	29/09/2017	Pléiades	14/05/2018	15/05/2018	
EW02_WV1_PSH_SO_20160117T154608_20160117T154619_DGI_32927_AEF4	06POINTEABACOU	11/05/18	17/01/2016	WorldView 2	14/05/2018	14/05/2018	
EW02_WV1_PSH_SO_20180225T155732_20180225T155739_DGI_43991_F7B4	06POINTEABACOU	11/05/18	25/02/2018	WorldView 2	15/05/2018	15/05/2018	
GY01_GIS_PSH_SO_20170108T153152_20170108T153156_DGI_44576_21DD	03MAKAYAEAST	14/05/18	08/01/2017	GeoEye-1	18/05/2018	18/05/2018	**2 image segments delivered from one SPERF**
GY01_GIS_PSH_SO_20170108T153210_20170108T153214_DGI_44576_8387	03MAKAYAEAST		08/01/2017	GeoEye-1	18/05/2018	18/05/2018	

GY01_GIS_PSH_SO_20170108T153210_20170108T153214_DGI_44576_3FC2	02MAKAYAWEST	14/05/18	08/01/2017	GeoEye-1	18/05/2018	18/05/2018	
PH1B_PHR_FUS_1A_20171208T154425_20171208T154432_TOU_1234_30dc	02MAKAYAWEST	17/05/18	08/12/2017	Pléiades	18/05/2018	18/05/2018	
SP07_NAO_PMS_1A_20141117T151207_20141117T151217_TOU_1234_eee1	01JEREMIE	17/05/18	17/11/2014	SPOT 6/7	18/05/2018	18/05/2018	**4 images re-ordered because of AOI and geometry issues**
GY01_GIS_PSH_SO_20160607T152807_20160607T152833_DGI_41430_5309	01JEREMIE	30/05/18	07/06/2016	GeoEye-1	03/06/2018	04/06/2018	
EW02_WV1_PSH_SO_20151028T153253_20151028T153303_DGI_31763_0550	01JEREMIE	30/05/18	28/10/2015	WorldView 2	04/06/2018	04/06/2018	
SP06_NAO_PMS_1A_20161223T151101_20161223T151114_TOU_1234_5870	03MAKAYAEAST	04/06/18	23/12/2016	SPOT-6/7	07/06/2018	12/06/2018	

2.3 Structure of geospatial data

2.3.1 Content of the final Geodatabase

The final ESRI Geodatabase is defined in the UTM Zone 18N (WGS 1984) projection. Its organisation is structured by thematic (Figure 2). Reference, pre and post-event layers contain the corresponding object for all AOIs. A common table (EMSN051_data_source) is also present, to summarize the source data and their associated code (Figure 3). Figure 4 displays the complete list reference, pre and post-event layers, their origin and their associated code or name in the final ESRI Geodatabase.

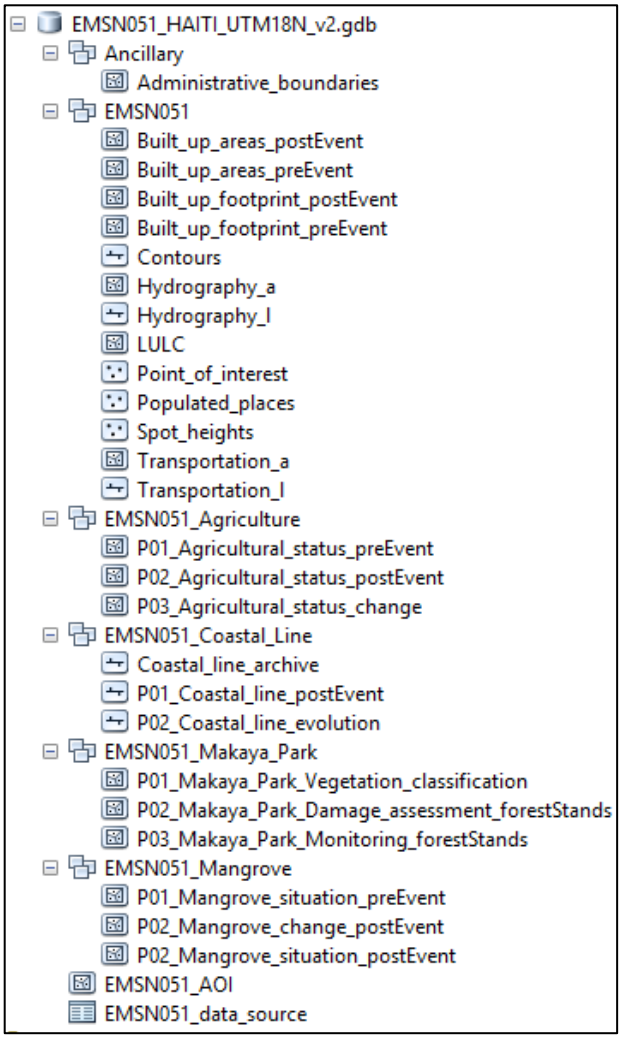


Figure 2-1: Structure of the final ESRI Geodatabase.

EMSN051_data_source

OBJECTID *	Source Name	Source Date (UTC)	Source Time (UTC)	Sensor Resolution (GSD)	Event Phase	Source Identifier
1	Open Street Map	Not Applicable	Not Applicable	Not Applicable	Pre-event	994
4	Haiti National Data	2014	Not Applicable	Not Applicable	Pre-event	991
8	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	997
12	Haiti National Data	Not Applicable	Not Applicable	Not Applicable	Pre-event	1
13	Haiti National Data	2002	Not Applicable	Not Applicable	Pre-event	2
14	Haiti National Data	2010	Not Applicable	Not Applicable	Pre-event	3
15	Haiti National Data	07/01/1978	Not Applicable	Not Applicable	Pre-event	4
16	Haiti National Data	07/01/2002	Not Applicable	Not Applicable	Pre-event	5
17	Haiti National Data	07/01/2010	Not Applicable	Not Applicable	Pre-event	6
18	SPOT-6-7	14/02/2017	T15:03:06Z and T15:02:43Z	1.5 m	Post-event	7
19	WorldView-2	17/01/2016	T15:46:ssZ	0.5 m	Pre-event	8
20	SPOT-6-7	17/11/2014	T15:12:00Z	1.5 m	Pre-event	9
21	WorldView-2	25/02/2018	T15:57:ssZ	0.5 m	Post-event	10
22	GeoEye-1	08/01/2017	T15:32:10Z	0.5 m	Post-event	11
23	Pleiades-1A-1B	29/09/2017	T15:34:32Z	0.5 m	Post-event	12
24	Pleiades-1A-1B	08/12/2017	T15:44:29Z	0.5 m	Post-event	13
25	Haiti National Data	2014	Not Applicable	0.25 m	Pre-event	14
26	GeoEye-1	07/06/2016	T15:28:17Z	0.5 m	Pre-event	15
27	WorldView-2	28/10/2015	T15:32:59Z	0.5 m	Pre-event	16
28	SPOT-6-7	17/11/2014	T15:12:10Z	1.5 m	Pre-event	17
29	SPOT-6-7	26/01/2016	T15:13:29Z	1.5 m	Pre-event	18
30	SPOT-6-7	18/10/2017	T15:10:38Z	1.5 m	Post-event	19
31	SPOT-6-7	14/02/2017	T15:03:11Z	1.5 m	Post-event	20
32	SPOT-6-7	30/09/2017	T15:00:36Z	1.5 m	Post-event	21
33	Pleiades-1A-1B	15/12/2017	T15:41:07Z	0.5 m	Post-event	22
34	SPOT-6-7	02/10/2014	T15:14:55Z	1.5 m	Pre-event	23
35	SPOT-6-7	03/07/2015	T15:05:19Z	1.5 m	Pre-event	24
36	SPOT-6-7	08/01/2016	T15:04:37Z	1.5 m	Pre-event	25
37	SPOT-6-7	17/11/2014	T15:11:51Z	1.5 m	Pre-event	26
38	Pleiades-1A-1B	25/12/2015	T15:37:25Z	0.5 m	Pre-event	27
39	Pleiades-1A-1B	12/10/2017	T15:34:25Z	0.5 m	Post-event	28
40	SPOT-6-7	04/09/2017	T15:00:04Z	1.5 m	Post-event	29
41	SPOT-6-7	14/02/2017	T15:02:43Z	1.5 m	Post-event	30
42	SPOT-6-7	18/10/2017	T15:10:12Z	1.5 m	Post-event	31
43	SPOT-6-7	08/01/2016	T15:04:43Z	1.5 m	Pre-event	32
44	SPOT-6-7	25/06/2016	T15:03:48Z	1.5 m	Pre-event	33
45	SPOT-6-7	23/12/2016	T15:11:07Z	1.5 m	Post-event	34
46	GeoEye-1	08/01/2017	T15:31:53Z	0.5 m	Post-event	35
47	GeoEye-1	08/01/2017	T15:32:11Z	0.5 m	Post-event	36
48	Pleiades-1A-1B	08/12/2017	T15:45:39Z	0.5 m	Post-event	37
49	SPOT-6-7	02/10/2014	T15:14:55Z	1.5 m	Pre-event	38
50	SPOT-6-7	03/07/2015	T15:05:19Z	1.5 m	Pre-event	39
51	WorldView-3	07/03/2017	T15:55:32Z	0.5 m	Post-event	40
52	WorldView-2	11/04/2017	T15:41:40Z	0.5 m	Post-event	41
53	WorldView-2	11/05/2017	T15:34:20Z	0.5 m	Post-event	42
54	EMSN050	Not Applicable	Not Applicable	Not Applicable	Pre-event	43

Figure 2-2: Content of the EMSN051_data_source table.

	Haiti National Data (CIAT - CNIGS)	source code	OSM	Airbus DS	source code	imagery used	Layer name in final GDB
General Reference Information							
Topographic Elements (administratives units)	PC00_Limite_Communale PC00_Limite_Departementale PC00_Limite_Pays PC00_Limite_Section_Communale	1 = CNIGS - CIAT	-				Administrative_boundary
Physiography	-		-	Isolignes, pas de 5m Spot_heights	991		Isolines Spot heights
Populated Places	-		gis_osm_places_free_1		994		Populated_places
Building footprints	PC04_Bati2010 (point) du CIAT	3	gis_osm_buildings_a_free		994		Building_footprints
Settlements both formal /informal	-		gis_osm_pois_free_p		994		
Transport network	PC00_Reseau_Routier_Ortho_2002 du CNIGS-CIAT	2	gis_osm_railways | gis_osm_roads		994		Transport_network
			roadl (from EMSN050)		43		
Industry and Utilities			gis_osm_landuse_a_free_1		994		
Location and type of industry	-		-				
Land-use /Land cover			-		14	Aerial Ortho-photo 2014	
Risk & Recovery products							
Coastal line	Coastline.mdb (1978,2002,2010) du CNIGS	4 = 07/01/1978 5 = 07/01/2002 6 = 07/01/2010	-				Coastal_line_archive
					7	SPOT7 - 14/02/2017 de 15:03:06 et de 15:02:43 utc	Coastal_line_postEvent Coastal_line_evolution
National Makaya Park			-		9	SPOT7 - 17/11/2014 15:12:13 UTC	Makaya_Park_Vegetation_class (AOI2)
					32 33	SPOT6 - 08/01/2016 15:04:43 UTC SPOT7 - 25/06/2016 15:03:48 UTC	Makaya_Park_Vegetation_class (AOI3)
					34	SPOT-6 - 23/12/2016 15:11:07 UTC	Makaya_Park_Damage_assessment_forestStands (AOI3)
					11	GeoEye-1 - 08/01/2017 15:32:10 UTC	Makaya_Park_Damage_assessment_forestStands (AOI2)
					35 36	GeoEye-1 - 08/01/2017 15:31:53 UTC GeoEye-1 - 08/01/2017 15:32:11 UTC	Makaya_Park_Damage_assessment_forestStands (AOI3)
					12 13	Pleiades - 29/09/2017 15:34:32 UTC Pleiades - 08/12/2017 15:44:29 UTC	Makaya_Park_Monitoring_forestStands (AOI2)
					37	Pleiades - 08/12/2017 15:45:39 UTC	Makaya_Park_Monitoring_forestStands (AOI3)
Mangrove			-		8 10	WorldView-2 - 17/01/2016 - 15:46:18 UTC WorldView-2 - 25/02/2018 - 15:57:32 UTC	Mangrove_situation_preEvent Mangrove_Damage_Assessment_postEvent
Agricultural activities — Jérémie					18 16 15 17	GeoEye-1 - 07/06/2016 15:28:17 UTC WorldView-2 - 28/10/2015 15:32:59 UTC SPOT 7 - 17/11/2014 15:12:10 UTC SPOT 7 - 26/01/2016 15:13:29 UTC	Agricultural_activities_preEvent
					19 20 21 22	SPOT 7 - 18/10/2017 15:10:38 UTC SPOT 7 - 14/02/2017 15:03:11 UTC SPOT 6 - 30/09/2017 15:00:36 UTC Pleiades - 15/12/2017 15:41:07 UTC	Agricultural_activities_postEvent
					15 to 22		Agricultural_activities_evolution
Port-salut					38 39 32	SPOT 6 - 02/10/2014 15:14:55 UTC SPOT 6 - 03/07/2015 15:05:19 UTC SPOT 6 - 08/01/2016 15:04:37 UTC	Agricultural_activities_preEvent
					40 41 42	WorldView-3 - 07/03/2017 15:55:32 UTC WorldView-2 - 11/04/2017 15:41:40 UTC WorldView-2 - 11/05/2017 15:34:20 UTC	Agricultural_activities_postEvent
					32,38 to 42		Agricultural_activities_evolution
Les Cayes					23 24 25 26 27	SPOT-6 - 02/10/2014 15:14 UTC SPOT-6 - 03/07/2015 15:05 UTC SPOT-6 - 08/01/2016 15:04 UTC SPOT-7 - 17/11/2014 15:11 UTC Pleiades - 25/12/2015 15:37 UTC	Agricultural_activities_preEvent
					28 29 30 31	SPOT-7 - 14/02/2017 15:02 UTC SPOT-6 - 04/09/2017 15:00 UTC Pléiades - 12/10/2017 15:34 UTC SPOT-7 - 18/10/2017 15:10 UTC	Agricultural_activities_postEvent
					23 to 31		Agricultural_activities_evolution

Figure 2-3: List of the source data and their associated code.

2.3.2 List of ESRI layer files

All reference, and thematical pre/post-event layers present in the final Geodatabase are exported as ESRI layer files (i.e. .lyr) as detailed in Figure 6.

Figure 2-4: Preview of the exported ESRI layer files for each AOI.

3 Product output

3.1 Agricultural activities reference map (AOI1, 4 & 5)

Input layers

All imagery needed to produce the below layers were geometrically and radiometrically processed to at least satisfy Risk & Recovery ITT technical annex specifications. The geometric accuracy levels were reported in the data sources section. Geometrically, the reference layer was the CNIGS' ortho-photo from 2014.

All the required layers for the agricultural activities reference map products are listed below.

Table 3-1: Layers needed for the agricultural activities reference map.

Map layers	
Agricultural activities (reference)	✓
Agricultural activities (post-event)	
Change of agricultural activities	
General topography (infrastructure networks, urban, buildings, hydrographic network, Industry and facilities, contours and spot heights, shaded relief)	✓

Method

Given the fact that all three AOIs are mostly low-lying they are considered to be agricultural landscapes. Urban areas, road infrastructures and many agricultural fields are present within this protected area. All tree cover located in these AOIs are considered as part of the agricultural domain whether close to urban areas or not as they could be tree crops.

The agricultural activities reference mapping are applied to AOI1, AOI4 and AOI5, as requested. To proceed, urban areas, road infrastructure and hydrology will be removed along with extraction sites and industrial areas where observed.

During EMSN-051 the SP attempted to use the EMSN-050 LULC mapping covering AOI01 Jérémie and AOI05 Les Cayes to map most notably building footprints, urban areas, road infrastructure, forested, and shrub areas. This EMSN-050 LULC classification was produced for the same scale of use as the EMSN-051 work and, hence, seemed pertinent. Given the EMSN_050's pre-occupation with the built environment we re-used their urban areas and isolated buildings. For the V1 version of this delivery the forested area class from the EMSN-050 LULC classification was used to produce a background class to identify areas most likely to contain forests. Tree-cover was not detected in many of these areas and, hence, tree cover was mapped inside and outside this highly generalised LULC class. The shrub are class was

deemed too generalised and, hence, both forest area and shrub area classes from EMSN-050 were no longer used in the version 2 delivery.

The EMSN-050 classification was not available over AOI04 Port-Salut and, hence, building footprints were updated from Open Street Map (OSM), roads were obtained from OSM and modified, and urban areas were derived by grouping together the buildings in the densest areas. Most housing is dispersed in the Port Salut AOI. For the version 2 the mapped urban area class is similar in look and feel to the other AOI's urban areas. They include low-lying vegetation and infrastructure between dwellings, like all urban area mapping. Tree cover classes supersede the urban area class.

The classification nomenclature itself is derived from a CNIGS classification nomenclature document that can be found in Annex. The proportion of tree coverage in agricultural areas is one of the main classification criteria in this nomenclature. Then our classification method is built on the following two parts:

- Tree surface classification;
- Non-forested surface classification (persistent low-lying vegetation, crops, and persistent bare soils / outcrops).

Tree surface classification

The objective here is:

- To obtain a tree covered area classification;
- And then to derive a tree cover density based classification with woodland, copse and isolated tree classes;

as an input to an agricultural activities reference map.

Tree cover classification

The most optimal image was first of all selected based on the contrast between forested/tree high vegetation and low-lying persistent and/or agricultural crops. Image processing was applied to selected VHR1/VHR2 satellite data using pan-sharpened channels to obtain an NDVI, a Shadow Index (SI) and a texture channel per image per AOI. A principle image is chosen which is used to derive an initial tree-cover layer.

The classifications are validated by a second experienced operator.

Woodland, copses and isolated trees

Once the tree-cover classification has been accepted, geo-spatial analysis were applied to distinguish between woodlands, copses and isolated trees based on tree-cover density per 0.5 ha. The tree cover classes are attributed according to the criteria in the Table below.

Table 3-2: Tree cover geospatial classification criteria.

Class number	Tree cover class	Class criteria
313	Mixed forest	Density >= 10% Size >= 0.5 hectares

314	Mangrove	Initial area photo-interpreted from tree-cover classification
315	Copse	Size >= 0.02 hectares and <=0.5 hectares
316	Isolated trees	Trees outside the above classes

Woodland density classes

Secondly, the woodland class is sub-divided into further tree density classes as outlined in the Table below. The tree density classes are added as an extra attribute to the woodland class.

Table 3-3: Woodland density classification criteria.

Class Number	Tree density class	Class criteria
1	Low density trees within agricultural area	Density >= 10% and Density < 30%
2	Trees within agri-forestry system	Density >= 30% and Density < 65%
3	Dense woodland	Density >= 65%

Non-forested agricultural land classification

This part of the classification concerns low-lying vegetation, croplands and persistent bare soils/outcrops. It is the most challenging part as the LULC was not planned at the time and the agricultural patterns are complex to say the least being illustrated in the Figure below and described in the Table and text below which refers to the diagram.

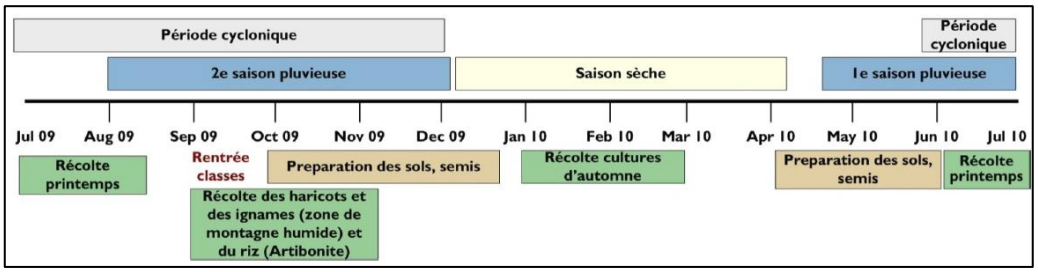


Figure 3-1: Cyclone, wet-dry season and agriculture time table in Haiti.

Unfortunately there are not enough images before Hurricane Matthew to follow all of these meteorological and agricultural seasons as this study was not foreseen at the time.

As there are not enough satellite data, the fact that the CNIGS classification nomenclature does not mention specific crops, and there are no recent field data was available at the time, a crop classification is not proposed. Hence, a compromise is proposed based on the CNIGS nomenclature.

Table 3-4: Low-lying LULC classes and method overview.

Class number	CNIGS Class	Proposed classification	Method overview and comments
324	Shrub (< 5m height)	Transitional Woodland Shrub	This class is especially prevalent in the AOI04 Port-Salut classification and is comprised of areas that have a certain similarity to forestry but have less texture/shadowing effects and also large areas where clumps of a high grass called vetiver is grown. Vetiver roots are a cash crop used in perfumery. The class is complex. Over Port-Salut it was extracted by a combination of NDVI, Shadow Index and texture derived from selected satellite imagery.Over AOI01 Jérémie and AOI05 Les Cayes the class corresponds to the EMSN-050 Shrub class.
213		Rice fields	Photo-interpreted from satellite imagery
232	Herbaceous Crops (prairies, grasslands)	Persistent low-lying vegetation	Non-tree low-lying vegetation in all images: this class was derived from areas of low vegetation changes and low texture throughout the pre Matthew period and was diminished slightly by taking into account post-Matthew croplands.
242	Cultivated and Managed Terrestrial Areas	Complex cultivation	Alternating vegetation / bare soils: a semi-automatic extraction was carried out to map areas that changed from mineral to vegetal and vice versa. Finally, given the doubt in the lack of imagery to fully map this class and the hypothesis that croplands won't change much due to Matthew (people still need to be fed) this class contains all areas seen to change from mineral to vegetal or vice versa per and post Matthew.
331		Beaches, dunes and sand plains	Coastal predominantly mineral surfaces
336	Bare soil	Bare soil	Bare soils in all images: this class is comprised of areas showing very low vegetation index values over the period of analysis. This can be rock outcrops, various mineral surfaces and cropland that wasn't seen covered in vegetation by the satellite images
411		Inland marshes	Wetland areas detected in Les Cayes
511		Water courses	River water bodies
512		Water bodies	Lake water bodies
523		Sea and ocean	Non-terrestrial water bodies

All classes were validated by an experienced second operator and the project management team. Given the complexity of the agricultural season in all AOI's, it is possible that the differentiation between low-lying agricultural classes is less sure than for the forestry classes. The separation of persistent low-lying vegetation from crops is quiet difficult depending on image coverage of seasonal variations. Bare soils may also persist if images do not cover the complete agricultural cycle. As such, fields that remain bare soils in essentially cropland area can be considered as predominantly cropland.

Lastly, to break-up the complex cultivation class, that is pre-dominant particularly in the Les Cayes, an indication of the field structure has been inserted into the class using object oriented classification.

The resulting classifications presented in the 3 Figures below.

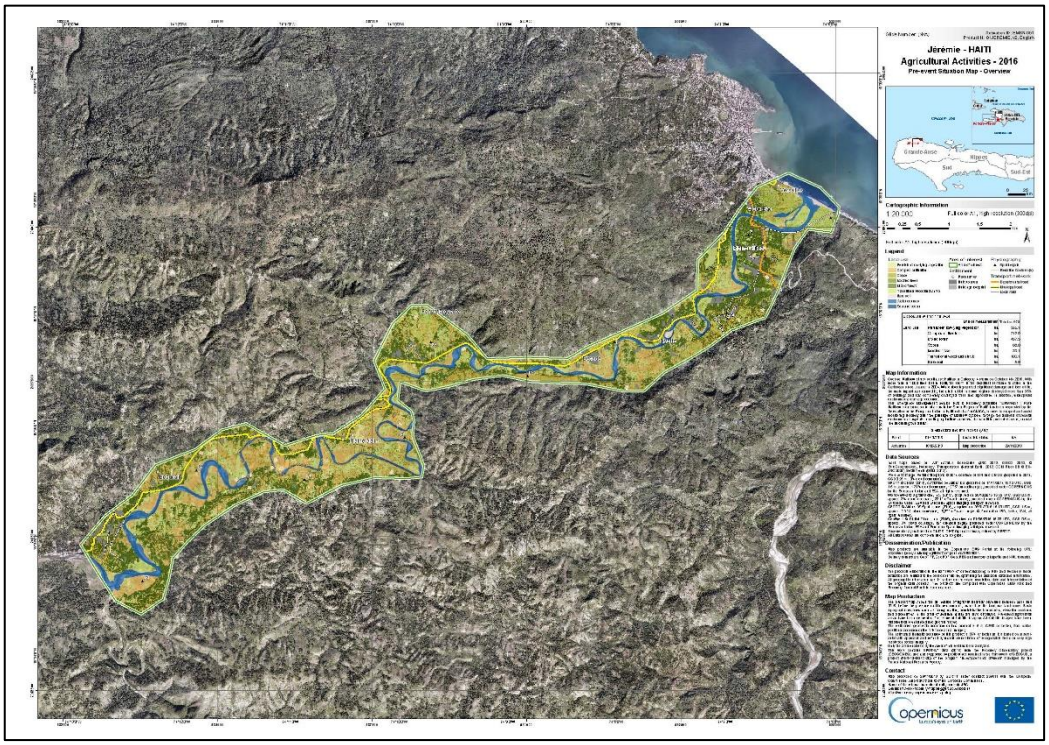


Figure 3-2: Pre Matthew agricultural classification over AOI01 Jérémie.

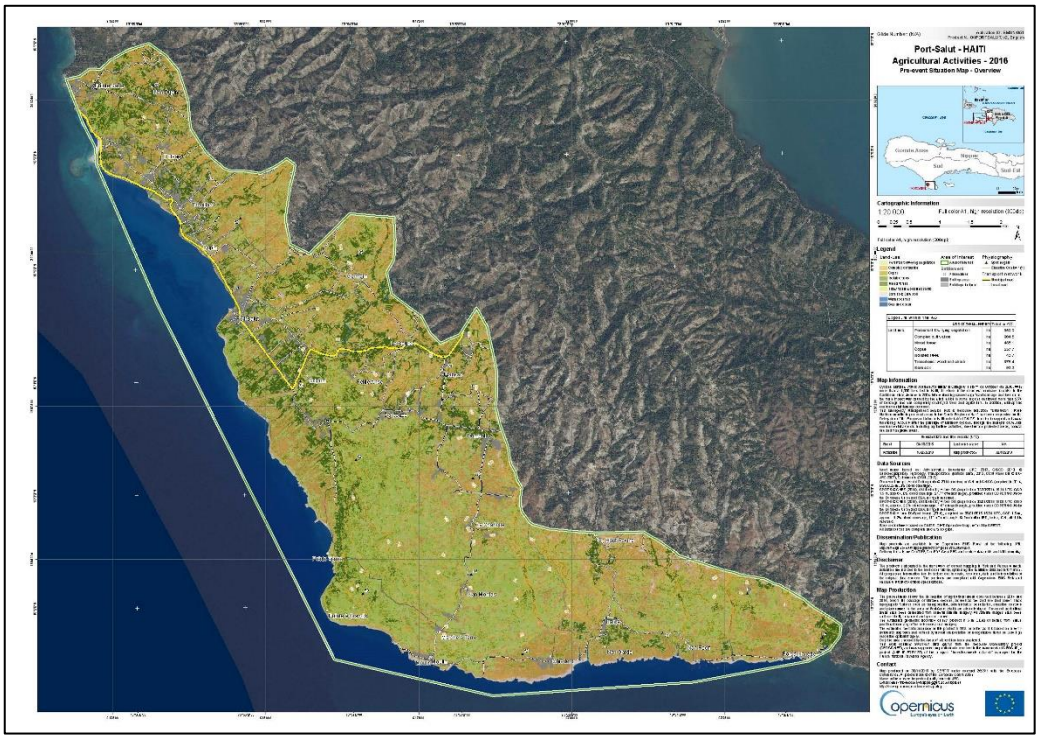


Figure 3-3: Pre Matthew agricultural classification over AOI04 Port-Salut.

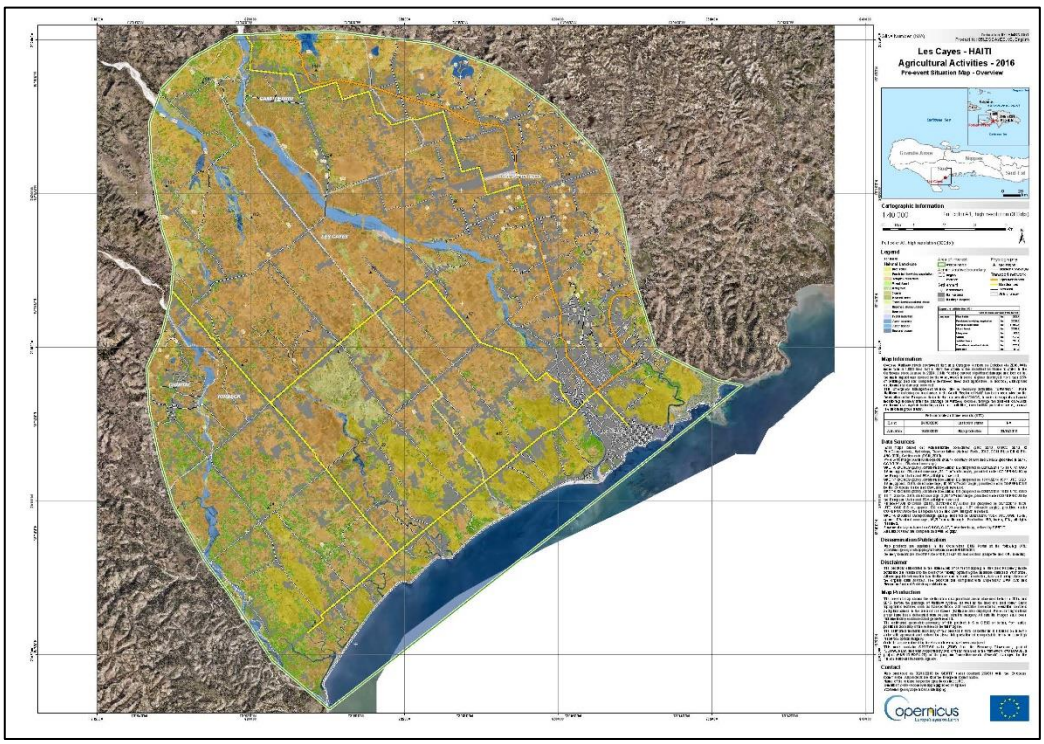


Figure 3-4: Pre Matthew agricultural classification over AOI05 Les Cayes.

3.2 Post-Matthew agricultural activities map (AOI1, 4 & 5)

Input layers

All imagery needed to produce the below layers are geometrically and radiometrically processed to at least satisfy Risk & Recovery ITT technical annex specifications. The geometric accuracy levels per contributing image were reported in the data sources section. For imagery the reference layer will be the CNIG's ortho-photo from 2014.

All the required layers for the post-Matthew agricultural activities map products are listed below.

Table 3-5: Layers needed for the post-Matthew agricultural activities map.

Map layers	
Agricultural activities (reference)	
Agricultural activities (post-event)	✓
Change of agricultural activities	
General topography (infrastructure networks, urban, buildings, hydrographic network, Industry and facilities, contours and spot heights, shaded relief)	✓

Method

The post-Matthew agricultural activities mapping was applied to AOI1, AOI4 and AOI5, as requested. To proceed, urban areas, road infrastructure and hydrology were removed along with extraction sites and industrial areas.

The classification methodology and nomenclature is the same as for the pre Matthew agricultural classification. This concerns the forested and non-forested classes.

Non-forested agricultural land classification

The same classes are used as in the pre-Matthew section.

All classes were manually validated by an experienced second operator and project management.

All technical steps work under the "4-eye principal" where the project manager or another experienced operator inspects the results of each step before passing onto the next stage.

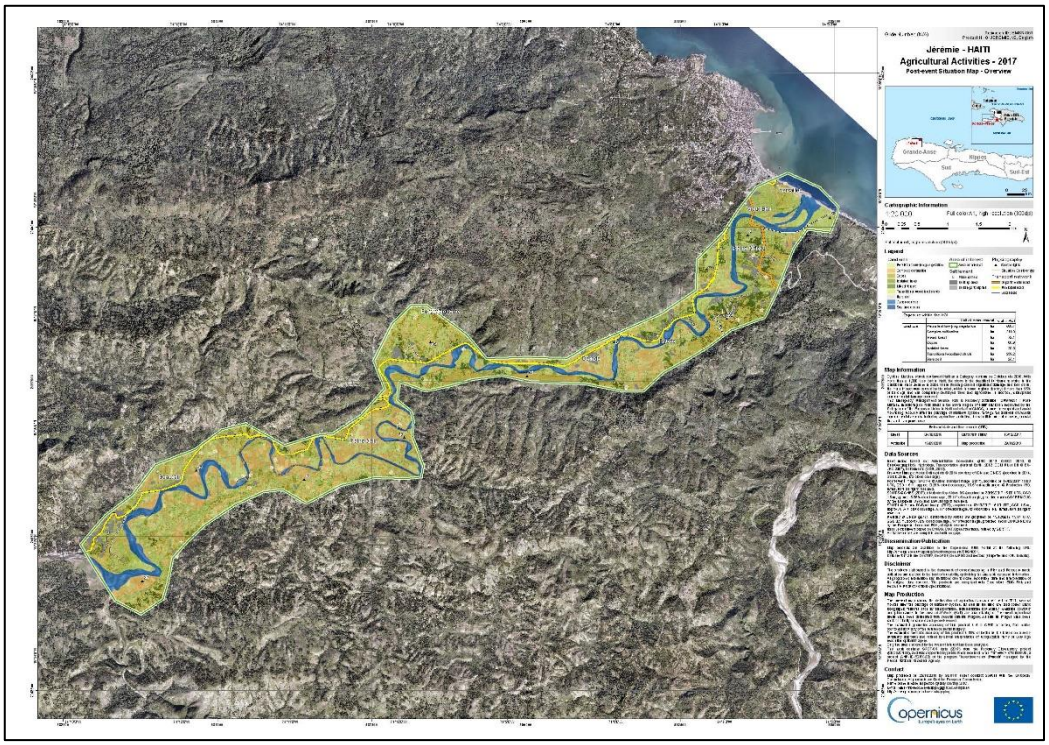


Figure 3-5: Post Matthew agricultural classification over AOI01 Jérémie.

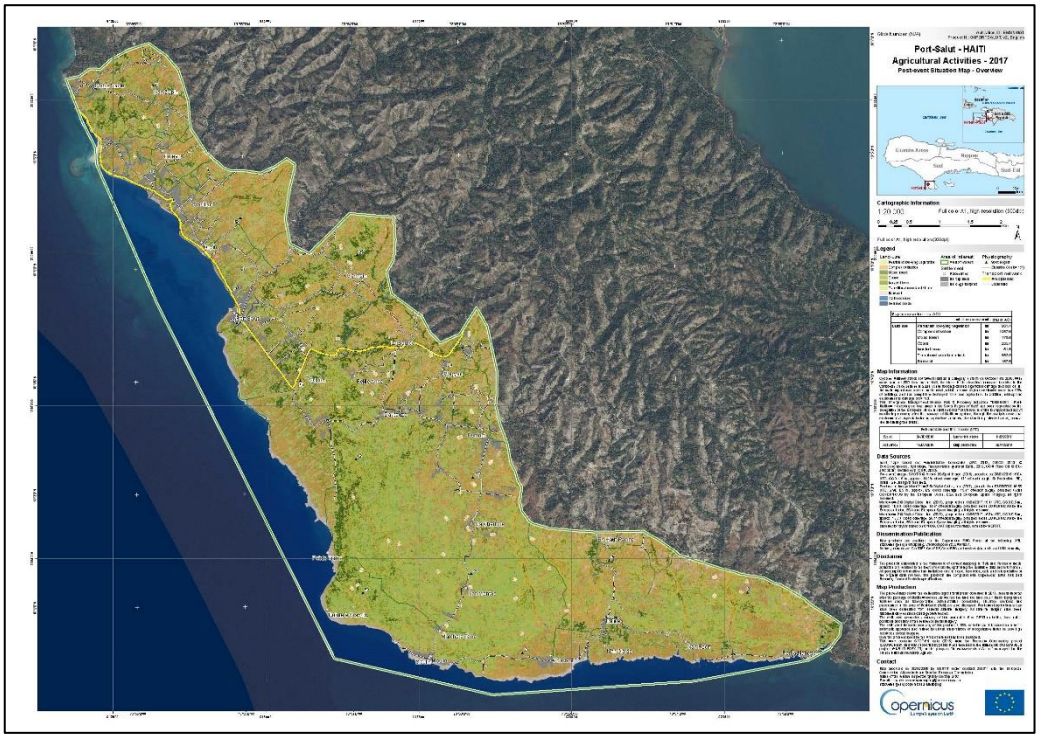


Figure 3-6: Post Matthew agricultural classification over AOI04 Port-Salut.

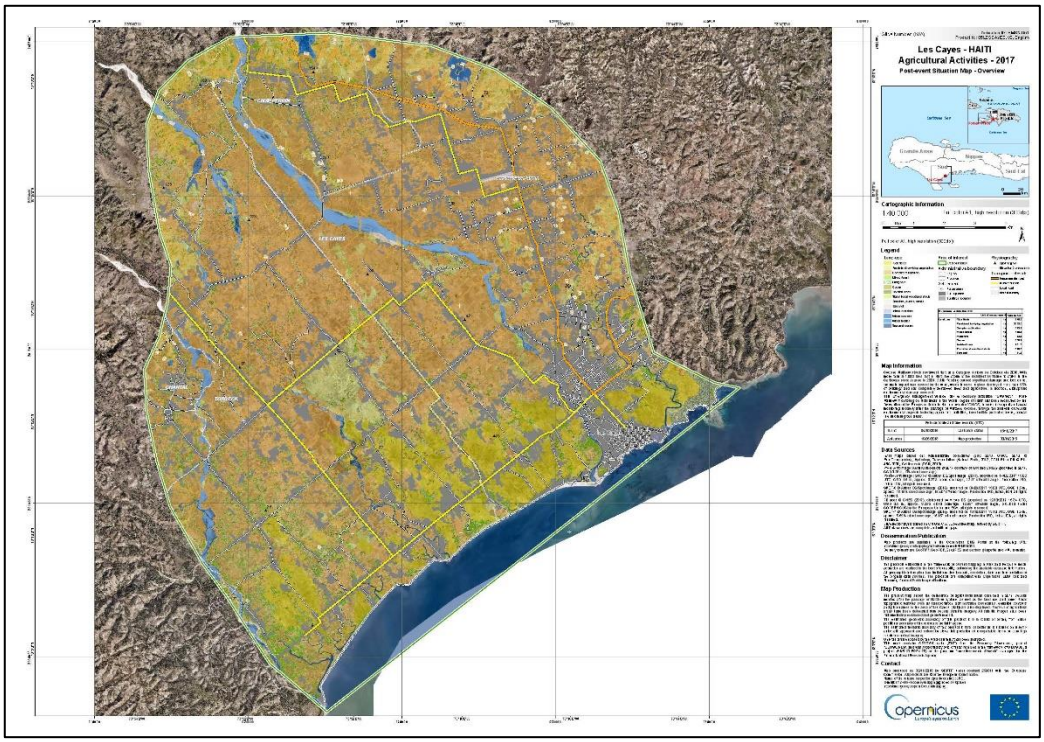


Figure 3-7: Post Matthew agricultural classification over AOI05 Les Cayes.

3.3 Pre and post Matthew Agricultural AOI LULC Validation

Methodology: Validation of agricultural AOI classifications

In order to ascertain the accuracy of the classification and to find out the classes that might need adjustment, a validation exercise was carried out over the AOI's 1, 4 and 5. This involved the generation of random points throughout the AOI's and visually validating the classification at these points using the set of imagery used for the generation of the classification.

The number of random points depends on the size of the AOIs: 200 points were created over AOI1 Jérémie, 400 points over AOI4 Port-Salut, and 600 points over AOI5 Les Cayes. The points were proportionally distributed according to the area taken up by regouped LULC classes.

Table 3-6: Agricultural AOI sizes (ha).

AOI	Size (ha)
01 Jérémie	1422
04 Port Salut	4705
05 Les Cayes	27406

In order to simplify the validation process, several classes were grouped as follow:

Table 3-7: Class regrouping for validation procedure.

Validation classes	Original classes
Bare soils	331 - Beaches, dunes and sand plains 336 - Bare soils
Built areas	111 - Continuous urban fabric 112 - Discontinuous urban fabric 122 - Road and rail networks and associated land 124 - Airports
Cropland	242 - Complex cultivation
Persistent low-lying vegetation	232 - Persistent low-lying vegetation
Shrubs	324 - Transitional woodland shrubs
Woodland	313 - Mixed forest 314 - Mangrove 315 - Copse 316 - Isolated trees
Rice fields	213 - Rice fields

Hereafter are presented the validation results for the pre- and post-event agricultural classifications over AOIs 1, 4 and 5.

Three types of accuracy assessment were calculated:

- the Producer's accuracy, highlighting the possible classification errors;
- the User's accuracy, showing the possible confusions of each class with others;
- and the Overall accuracy.

After a first validation, adjustments were carried out in post-event classifications, in particular on bare soils, cropland, and shrubs classes. A second classification quality control was then realised on the same sets of points, in order to verify if the required modifications were applied. The table hereafter present the final classification accuracy, after adjustments.

The overall accuracy is very high for all pre- and post-event classifications, with a minimum of 0.89. It can be noticed that the accuracy of post-event classifications is a bit lower than the pre-event ones, certainly due to the confusion between vegetation classes after the disaster event.

The limits between cropland and low-lying vegetation, shrubs and woodland, shrubs and low-lying vegetation are sometimes difficult to define, generating confusion between classes and then remaining classification / interpretation errors.

The pre and post classifications were validated and, hence, it was considered not necessary to validate the change detection mapping as they are derived from the LULC classifications.

All results are comfortably above the 80% contractually specifications.

Table 3-8: Validation results for the agricultural classification over AOI1 Jérémie.

Pre-event classification		Classification: Bare soils	Built areas	Cropland	Low-lying vegetation	Shrubs	Woodland	Totals		
PI	Bare soils	1	0	0	0	0	0	1	100%	Producer's accuracy
	Urban areas	0	5	0	0	0	0	5	100%	
	Cropland	0	0	32	2	0	0	34	94%	
	Low-lying	1	0	0	48	2	2	53	91%	
	Shrubs	0	0	0	1	14	1	16	88%	
	Woodland	0	0	0	0	2	89	91	98%	
	Totals	2	5	32	51	18	92	200		
		50%	100%	100%	94%	78%	97%		0,95	
		User's accuracy							Overall accuracy	

Post-event classification		Classification: Bare soils	Built areas	Cropland	Low-lying vegetation	Shrubs	Woodland	Totals		
PI	Bare soils	6	0	0	0	0	0	6	100%	Producer's accuracy
	Urban areas	0	7	0	0	0	1	8	88%	
	Cropland	1	0	34	2	0	0	37	92%	
	Low-lying	0	0	4	81	7	2	94	86%	
	Shrubs	0	0	1	0	20	5	26	77%	
	Woodland	0	0	0	0	0	29	29	100%	
	Totals	7	7	39	83	27	37	200		
		86%	100%	87%	98%	74%	78%		0,89	
		User's accuracy							Overall accuracy	

Table 3-9: Validation results for the agricultural classification over AOI04 Port-Salut.

Pre-event classification		Classification: Bare soils	Built areas	Cropland	Low-lying vegetation	Shrubs	Woodland	Totals		
PI	Bare soils	9	0	0	0	0	0	9	100%	Producer's accuracy
	Urban areas	0	21	0	0	0	0	21	100%	
	Cropland	0	1	97	0	2	0	100	97%	
	Low-lying	0	0	0	85	7	0	92	92%	
	Shrubs	0	0	1	1	88	11	101	87%	
	Woodland	0	0	0	1	3	73	77	95%	
	Totals	9	22	98	87	100	84	400		
		100%	95%	99%	98%	88%	87%		0,93	
		User's accuracy							Overall accuracy	

Post-event classification		Classification: Bare soils	Built areas	Cropland	Low-lying vegetation	Shrubs	Woodland	Totals		
PI	Bare soils	14	0	2	1	0	0	17	82%	Producer's accuracy
	Urban areas	0	22	0	0	0	0	22	100%	
	Cropland	1	1	100	4	7	0	113	88%	
	Low-lying	0	0	5	88	4	0	97	91%	
	Shrubs	0	0	1	3	89	9	102	87%	
	Woodland	0	0	0	0	7	42	49	86%	
	Totals	15	23	108	96	107	51	400		
		93%	96%	93%	92%	83%	82%		0,89	
		User's accuracy							Overall accuracy	

Table 3-10: Validation results for the agricultural classification over AOI05 Les Cayes.

Pre-event classification		Classification: Bare soils	Built areas	Cropland	Low-lying vegetation	Shrubs	Woodland	Rice field	Totals	
PI	Bare soils	4	0	0	0	0	0	0	4	100%
	Urban areas	0	79	0	0	0	0	0	79	100%
	Cropland	0	0	275	2	0	0	0	277	99%
	Low-lying	0	0	0	62	0	0	1	63	98%
	Shrubs	0	0	1	0	25	1	0	27	93%
	Woodland	0	0	0	1	2	100	1	104	96%
	Rice field	0	0	0	0	0	0	46	46	100%
	Totals	4	79	276	65	27	101	48	600	
		100%	100%	100%	95%	93%	99%	96%		0,99
		User's accuracy								Overall accuracy

Producer's accuracy

Post-event classification		Classification: Bare soils	Built areas	Cropland	Low-lying vegetation	Shrubs	Woodland	Rice field	Totals	
PI	Bare soils	3	0	0	0	0	0	0	3	100%
	Urban areas	0	95	2	2	0	0	0	99	96%
	Cropland	0	0	289	2	0	0	0	291	99%
	Low-lying	0	0	7	68	0	0	0	75	91%
	Shrubs	0	0	0	3	42	0	1	46	91%
	Woodland	0	0	0	0	0	39	0	39	100%
	Rice field	0	0	0	0	0	0	47	47	100%
	Totals	3	95	298	75	42	39	48	600	
		100%	100%	97%	91%	100%	100%	98%		0,97
		User's accuracy								Overall accuracy

Producer's accuracy

3.4 Pre and post Matthew Agricultural AOI LULC change analysis

AOI01 – Jérémie

The landscape changes in Jérémie have been analysed both in terms of basic classification percentage comparison (Tables 3-11) and on a class by class basis (Table 3-14). What can be noticed are the quite marked changes to tree cover (313, 315, 316) between pre and post Matthew LULC's but also for Jérémie damage related to the river bed having changed its course.

The additional agricultural type class (232, 242, 336 – +249ha) and transitional woodland shrub (324 - +139ha) areas nearly completely compensate the reduced tree cover (313, 315, 316 - -418ha), or vice versa. Basically tree cover has been redistributed.

The main mixed forest class has been redistributed to the persistent low-lying vegetation, transitional woodland shrub and the copse (smaller woodlands) classes. The river changing its bed has affected forested areas but also agricultural complex cultivation and transitional woodland shrub. The new shrubland is related to the woodland damage category, which makes sense as the undergrowth and remaining trees in damaged woodland resemble shrubland. Urban fabric areas have increased as they are no longer masked by tree cover. Bare soils which is over time an often transitional phase shows change too.

Table 3-11: AOI01 - Jérémie - Comparison between pre and post Matthew LULCs.

AOI01 - Jérémie			
Code	LULC Classes	Pre Matthew Surface (ha)	Post Matthew Surface (ha)
111	Continuous urban fabric	15.61	23.06
112	Discontinuous urban fabric	3.00	4.65
122	Road and rail networks	12.18	12.73
232	Persistent low-lying vegetation	337.21	568.41
242	Complex cultivation	212.05	211.02
313	Mixed forest	488.42	72.12
315	Copse	68.69	66.90
316	Isolated trees	20.12	20.33
324	Transitional woodland shrub	100.16	239.38
336	Bare soil	5.89	25.11
511	Water courses	141.25	162.49
523	Sea and ocean	17.98	16.27
		1422.55	1422.46

AOI04 – Port Salut

The landscape changes in Port Salut have been analysed both in terms of basic classification percentage comparison (Tables 3-12) and on a class by class basis (Table 3-15). What can be noticed are the quite marked changes to tree cover (313, 315, 316) between pre and post Matthew LULC's and fairly consequential changes between complex cultivation (242), transitional woodland shrub (324) and persistent low-lying vegetation (232). This is related to cropland rotation and a shrub crop called vetiver.

The additional agricultural type class (232, 242, 336 – +249ha) and transitional woodland shrub (324 - +6ha) areas nearly completely compensate the reduced tree cover (313, 315, 316 - -264ha), or vice versa. Basically tree cover has been redistributed.

Due to Matthew storm damage the main forest classes (313, 315, 316) have been redistributed to the persistent low-lying vegetation and complex cultivation with strangely little shrub-land.

The overall transitional woodland shrub does not change much but does exchange with complex cultivation and persistent low-lying vegetation. This is also related to crop rotation most likely due to the vetiver crop.

Over Port Salut complex cultivation areas have increased quite a bit (123ha) but this is perhaps due in part to tree cover being blown away and local people re-working the land. It may revert to tree cover later after replanting or fallow.

The urban fabric areas have increased as they are no longer masked by tree cover. Bare soils which is over time an often transitional phase shows change too.

With the tree fall and the normal flux between persistent low-lying vegetation, complex cultivation, transitional woodland shrub (vetiver crop), and bare soil it is hard to draw any conclusion except to highlight tree cover elimination which is extensive.

Table 3-12: AOI04 – Port Salut - Comparison between pre and post Matthew LULCs.

AOI04 - Port Salut			
Code	LULC Classes	Pre-Matthew Surface (ha)	Post-Matthew Surface (ha)
111	Continuous urban fabric	82.72	90.52
112	Discontinuous urban fabric	10.62	11.81
122	Road and rail networks	111.32	112.15
232	Persistent low-lying vegetation	879.98	931.37
242	Complex cultivation	964.47	1087.64
313	Mixed forest	438.14	178.63
315	Copse	257.70	235.73
316	Isolated trees	43.73	61.60
324	Transitional woodland shrub	976.37	981.97
336	Bare soil	93.31	167.64
511	Water courses	9.00	9.88
523	Sea and ocean	836.55	836.55
		4703.91	4705.49

AOI05 – Les Cayes

Les Cayes is the biggest agricultural AOI and also has the most diverse LULC coverage, in fact the other 'agricultural areas have little seasonal cropland.

The landscape changes in Port Salut have been analysed both in terms of basic classification percentage comparison (Tables 3-13) and on a class by class basis (Table 3-16). The additional agricultural type class (232, 242, 336 – +957ha), transitional woodland shrub (324 - +813ha) and urban fabric (111+112 – 838ha) areas nearly completely compensate the reduced tree cover (313, 315, 316 - -264ha), or vice versa. Basically tree cover has been redistributed. What can be noticed are the quite marked changes to tree cover (313, 315, 316) between pre and post Matthew LULC's with significant re-distribution to complex cultivation (242), transitional woodland shrub (324), persistent low-lying vegetation (232) and even urban fabric classes (111, 112). This is related to the Matthew storm. The urban fabric areas have increased as they are no longer masked by tree cover. Bare soils which over time an often transitional phase shows change too with much moving to persistent low-lying vegetation (232). The complex cultivation class remain very stable.

With the tree fall and the normal flux between persistent low-lying vegetation, complex cultivation, transitional woodland shrub (vetiver crop), and bare soil it is hard to draw any conclusion except to highlight tree cover elimination which is extensive.

Table 3-13: AOI05 – Les Cayes - Comparison between pre and post Matthew LULCs.

AOI05 - Les Cayes			
Code	Classes	Pre-Matthew Surface (ha)	Post-Matthew Surface (ha)
111	Continuous urban fabric	2745.54	3571.87
112	Discontinuous urban fabric	53.69	64.88
122	Road and rail networks	373.35	374.65
124	Airports	63.00	63.34
213	Rice fields	1883.43	1940.17
232	Persistent low-lying vegetation	2626.64	3058.97
242	Complex cultivation	11354.36	11895.69
313	Mixed forest	2330.13	456.53
314	Mangrove	83.55	83.58
315	Copse	1447.05	856.90
316	Isolated trees	391.46	181.29
324	Transitional woodland shrub	1077.66	1890.80
331	Beaches, dunes and sand plains	60.37	57.82
336	Bare soil	91.24	74.27
411	Inland marshes	6.35	6.35
511	Water courses	969.87	977.45
512	Water bodies	88.59	92.17
523	Sea and ocean	1760.64	1760.47
		27406.90	27407.19

Table 3-14: AOI01 Jérémie – Class by class comparison between pre and post Matthew LULCs.

			Pre-Matthew										
	Code	Classes	**313**	324	111	112	122	232	242	**315**	**316**	336	511
Post-Matthew	313	Woodlands	**14.8%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	324	Transitional woodland shrub	**20.8%**	99.9%	1.0%	0.0%	1.0%	5.1%	0.5%	**21.0%**	**21.9%**	0.0%	0.1%
	111	Continuous urban fabric	1.2%	0.0%	94.8%	0.0%	0.0%	0.7%	0.0%	0.1%	0.0%	0.0%	0.0%
	112	Discontinuous urban fabric	0.3%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%
	122	Roads	0.2%	0.0%	0.0%	0.0%	93.8%	0.1%	0.0%	0.0%	0.0%	0.3%	0.0%
	232	Persistent low-lying vegetation	**44.5%**	0.1%	2.5%	0.0%	4.0%	87.5%	0.2%	**58.7%**	**63.6%**	3.4%	0.9%
	242	Complex cultivation	0.2%	0.0%	0.2%	0.0%	0.9%	0.5%	96.9%	0.6%	0.2%	0.5%	1.4%
	315	Copse	**12.7%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**7.4%**	0.0%	0.0%	0.0%
	316	Isolated trees	2.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**7.2%**	**9.9%**	0.0%	0.0%
	336	Bare soil	2.4%	0.0%	1.6%	0.0%	0.2%	1.0%	2.4%	**4.8%**	**4.3%**	50.6%	0.6%
	511	Water courses	0.1%	0.0%	0.0%	0.0%	0.0%	5.0%	0.0%	0.0%	0.1%	45.2%	96.9%
			100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

			Pre-Matthew							
		Classes	**Bare** soil	**Complex** cultivation	**Persist-ent** low-lying veg.	**Shrubs**	**Trees**	Hydro-logy	Urban	Roads
Post-Matthew	336	Bare soil	**87.5%**	1.9%	**5.7%**	1.3%	1.3%	0.0%	0.0%	0.0%
	242	Complex cultivation	3.1%	**89.3%**	**4.2%**	**8.3%**	**14.0%**	0.0%	0.0%	0.0%
	232	Persistent	**7.3%**	3.6%	**64.5%**	**18.2%**	**19.3%**	0.0%	0.0%	0.0%
	324	Shrubs	1.0%	**5.4%**	**25.6%**	**71.5%**	0.3%	**10.0%**	2.4%	0.0%
	313	Trees	0.0%	0.0%	0.0%	0.0%	**64.2%**	0.0%	0.0%	0.0%
	511	Water courses	0.0%	0.0%	0.0%	0.2%	0.0%	**90.0%**	0.0%	0.0%
	111	Urban	0.0%	0.0%	0.0%	0.5%	0.7%	0.0%	**97.6%**	0.0%
	122	Roads	0.0%	0.0%	0.0%	0.1%	0.1%	0.0%	0.0%	**99.1%**
			99.0%	100.1%	100.0%	100.2%	100.0%	100.0%	100.0%	99.1%

			Pre-Matthew																
	Code	Classes	111	112	122	124	213	232	242	313	314	315	316	324	331	336	411	511	512	523
Post Matthew	111	Continuous urban fabric	**94.28**	4.27	0.01	0.00	0.03	0.27	0.01	**22.96**	0.00	**22.84**	**19.82**	0.73	0.00	1.24	0.00	0.00	0.00	0.00
	112	Discontinuous urban fabric	0.21	**94.99**	0.00	0.00	0.00	0.00	0.00	0.21	0.00	0.18	0.22	0.02	0.00	0.00	0.00	0.00	0.00	0.00
	122	Road and rail networks	0.01	0.00	**99.62**	0.00	0.00	0.00	0.00	0.03	0.00	0.05	0.16	0.02	0.00	0.08	0.00	0.00	0.00	0.00
	124	Airports	0.00	0.00	0.00	**99.94**	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.23	0.00	0.00	0.00	0.00
	213	Rice fields	0.00	0.02	0.00	0.00	**98.20**	0.63	0.39	0.28	0.00	1.06	1.33	0.05	0.00	0.09	0.00	0.00	0.00	0.00
	232	Persistent low-lying vegetation	0.23	0.05	0.01	0.00	0.16	**94.31**	0.03	**6.28**	0.00	**18.04**	**22.91**	0.65	**6.92**	**54.62**	0.00	0.68	0.00	0.00
	242	Complex cultivation	0.01	0.19	0.03	0.06	0.74	0.01	**99.21**	**6.27**	0.00	**20.33**	**36.72**	1.46	0.00	0.09	0.00	0.02	0.00	0.00
	313	Mixed forest	0.46	0.10	0.04	0.00	0.09	0.18	0.01	**17.26**	0.00	0.79	0.52	2.44	0.01	0.04	0.00	0.02	0.00	0.00
	314	Mangrove	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**99.96**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	315	Copse	1.51	0.29	0.14	0.00	0.37	0.96	0.09	**18.73**	0.02	**21.02**	**2.78**	3.29	0.10	0.44	0.00	0.06	0.01	0.00
	316	Isolated trees	0.41	0.04	0.09	0.00	0.11	0.44	0.06	2.14	0.00	**4.51**	**7.62**	0.78	0.02	0.19	0.00	0.03	0.00	0.00
	324	Transitional woodland shrub	2.50	0.02	0.01	0.00	0.29	1.71	0.16	**25.82**	0.02	**11.05**	**7.61**	**90.54**	0.02	1.83	0.00	0.02	0.00	0.00
	331	Beaches, dunes and sand plains	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.04	0.04	0.00	**91.71**	0.00	0.00	0.00	0.00	0.00
	336	Bare soil	0.34	0.00	0.00	0.00	0.00	1.10	0.01	0.01	0.00	0.08	0.20	0.01	0.73	**33.99**	0.00	0.03	0.00	0.00
	411	Inland marshes	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**####**	0.00	0.00	0.00
	511	Water courses	0.03	0.04	0.05	0.00	0.00	0.37	0.00	0.00	0.00	0.02	0.06	0.02	0.49	3.56	0.00	**99.14**	0.00	0.01
	512	Water bodies	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.61	0.00	0.00	**99.99**	0.00
	523	Sea and ocean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**99.99**
			100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

3.5 Agricultural change map (AOI1, 4 & 5)

Input layers

All imagery needed to produce the below layers are geometrically and radiometrically processed to at least satisfy Risk & Recovery ITT technical annex specifications. The accuracy levels will be reported. For imagery the reference layer will be the CNIG's ortho-photo from 2014.

All the required layers for the agricultural change map products are listed below.

Table 3-15: Layers needed for agricultural change map.

Map layers	
Agricultural activities (reference)	✓
Agricultural activities (post-event)	✓
Change of agricultural activities	✓
General topography (infrastructure networks, urban, buildings, hydrographic network, Industry and facilities, contours and spot heights, shaded relief)	✓

Method

Before building the final change product, the pre and post Matthew agricultural area LULC classifications were validated (Section 3.4) and both visually and statistically compared (Section 3.4) to insure as much homogeneity as possible in the allocation of agricultural classes. The most important and reliable trends have been selected and chosen to be highlighted in comparative maps.

These products will be delivered as maps per agricultural AOI, where pertinent, and in any case as statistics with further analysis and conclusions given in the report.

Table 3-16: Change mapping per agricultural AOI.

Map	Damaged Woodland	Damaged cropland	Damaged/changed schrubland
AOI01 Jérémie Change	✓	✓	✓
AOI04 Port-Salut Change	✓		✓
AOI05 Les Cayes Change	✓		

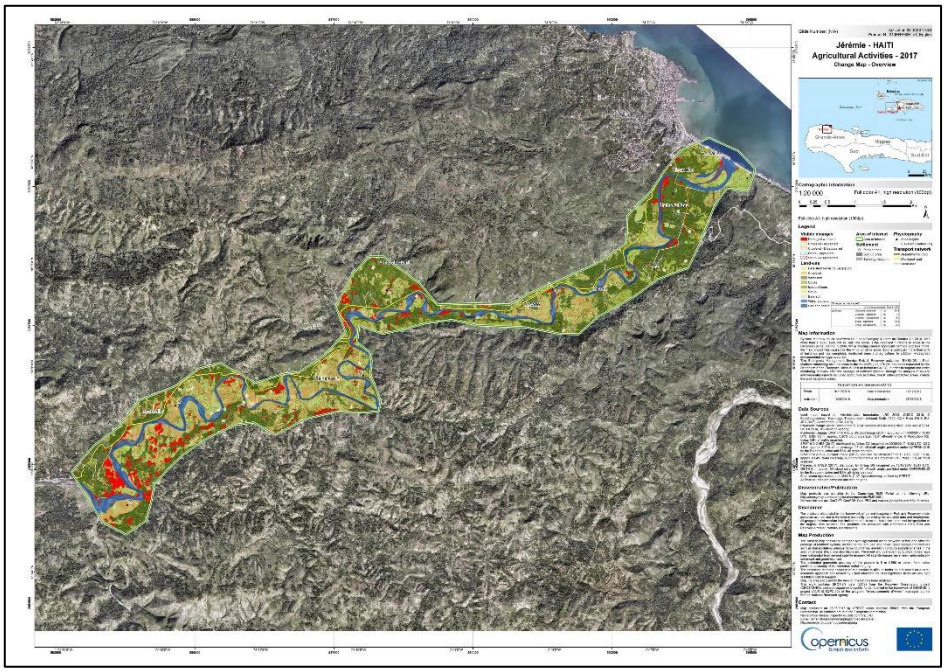


Figure 3-8: Matthew storm damage mapping and landscape changes over AOI01 Jérémie.

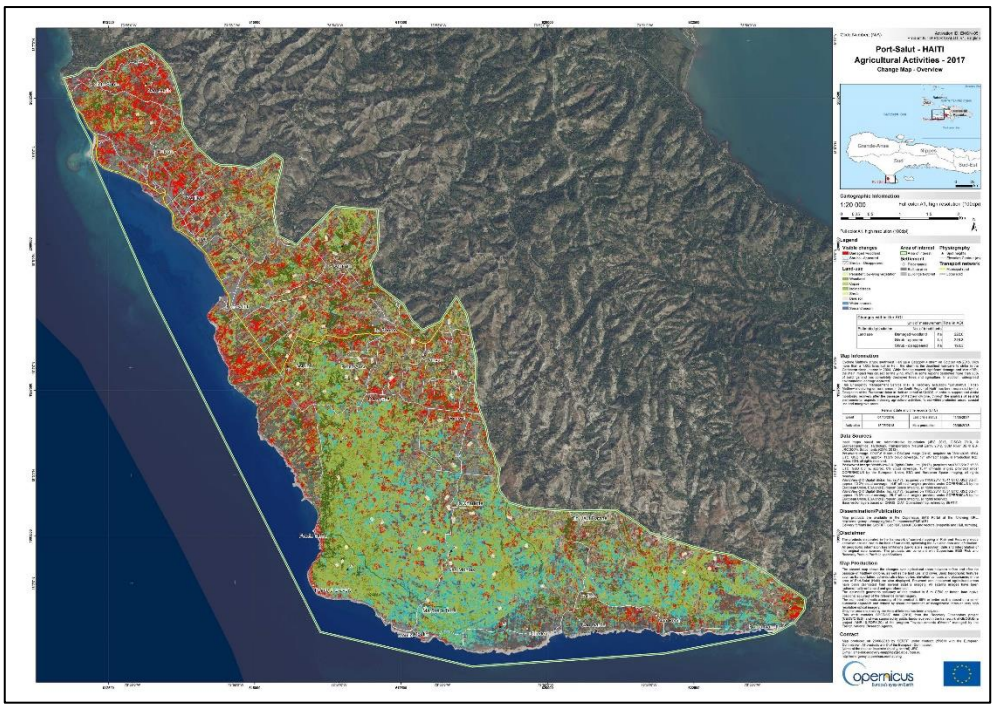


Figure 3-9: Matthew storm damage mapping and landscape changes over AOI04 Port-Salut.

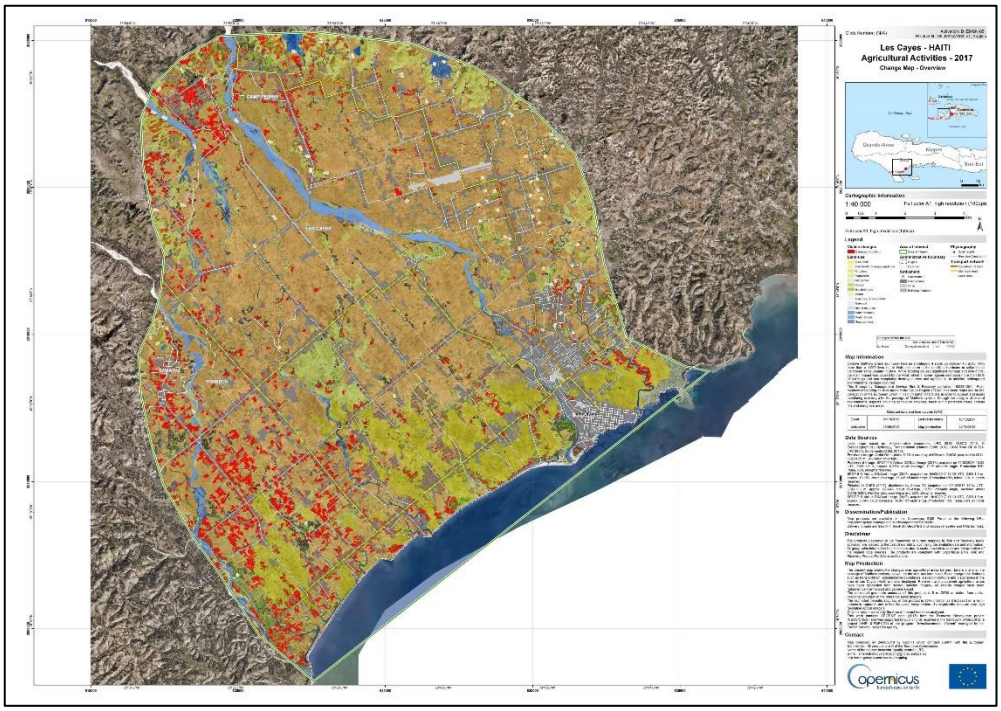


Figure 3-10: Matthew storm damage mapping and landscape changes over AOI05 Les Cayes.

3.6 Coastal line delineation map (AOI7)

Input layers

All the required layers for coastal line evolution map product are listed below. For imagery the reference (i.e. post-event) layer will be the SPOT-6/7 coverage acquired the 14th February 2017.

Table 3-17: Layers needed for the coastal line delineation map product.

Map layers	
Coastal line 1978, 2002, 2010	✓
Post-Matthew coastal line	✓
Coastal line evolution	
General topography (infrastructure networks, urban, buildings, hydrographic network, Industry and facilities, contours and spot heights, shaded relief)	✓

Method

The delineation coastal line was performed by mean of photo-interpretation of SPOT-6/7 data acquired the 14th February 2017 and covering the shore between Jérémie and Les Cayes. This data ensures a consistent state of the seashore due to the synchronous acquisition.

Also, as no precise definition has been reported by CNIGS, Airbus DS consortium proposed to consider as coastal line the upper limit of the foreshore, given by the apparition of perennial vegetation, cliff or infrastructures. Mangrove was considered as land only when the continental continuity is observable. This mapping strategy is in respect with the coastal line archive produced by CNGIS (Figure 20). Moreover, it has been decided to draw a unique object, and to interpolate the line across a river by linking the two banks.

Figure 3-11: Detailed view of the coastal line 2010 over Pointe Abacou.

Since the exact limits for this coastal line study have not been precisely defined, Airbus DS consortium proposed to end the delineation to the eastern limit of the Jérémie's communal boundary, and to the eastern limit of Les Cayes' communal boundary too (Figure 3-12). Delineation of coastal line was performed manually by an operator, and was then checked by a second operator, reshaping the layer when necessary and after discussion. On the basis of 100 randomly selected points, the overall accuracy of the produced layer is 91% (Figure 3-13).

Figure 3-12: Eastern administrative limit of Jérémie (left) and Les Cayes (right).

		Classification				
		0	1	Totals		
PI	0	0	9	9	0.00%	Producer's accuracy
	1	0	91	91	100.00%	
	Totals	0	100	100		
		0.00%	91.00%		Overall accuracy	
		User's accuracy			0.91	

Figure 3-13 : Confusion matrix for coastalline delineation over AOI07.

The delineation map product display the coastal line position for 2017, but also for 2010, 2002 and 1978. Table 29 shows the length of coastal line for 1978, 2002, 2010 and 2017. For this later, 247.9 km have been delineated. It has to be noticed that the comparison of coastal length with archives is quite tricky, since sometimes the line is continuous and sometimes not (i.e. river mouths).

Table 3-18: Length of coastal line for 1978, 2002, 2010 and 2017.

Coastal line	Length (km)
2017	247.8
2010	247.6
2002	256.4
1978	241.9

3.7 Coastal line evolution map (AOI7)

Input layers

All the required layers for the coastal line evolution map product are listed below. The calculation of evolution rate is based on the newly produced coastal line for 2017, and also on archives for 1978, 2002 and 2010.

Table 3-21: Layers needed for the coastal line evolution map product.

Map layers	
Coastal line 1978, 2002, 2010	
Post-Matthew coastal line	
Coastal line evolution	✓
General topography (infrastructure networks, urban, buildings, hydrographic network, Industry and facilities, contours and spot heights, shaded relief)	✓

Method

After digitalization and superposition of the vector dataset extracted from of SPOT-6/7 coverage of 14th February 2017, shoreline evolution rate was then calculated using the Digital Shore Analysis System[1] (DSAS) from USGS that runs under the ArcGIS software environment. This extension creates a baseline and orthogonal transects that cut the coastline to perfectly measure its displacement. The baseline is printed on the mainland using the buffering and smoothing technique in order to reflect the coastline shape. Transects are spaced every 200m and those with insignificant intersections are eliminated. For each transect, rates of shoreline evolution are calculated using the following model: a linear regression model (LRR) for a study period covering several dates (i.e. 1978, 2002, 2010 and 2017).

The complete distribution of evolution rates is shown in Figure 22. For the sake of simplicity, extreme values are bounded to 5m into the map legend, in order to have regular classes (Table 31).

[1] Thieler, E.R., Himmelstoss, E.A., Zichichi, J.L., and Ergul, Ayhan, 2017, Digital Shoreline Analysis System (DSAS) version 4.0—An ArcGIS extension for calculating shoreline change (ver. 4.4, July 2017): U.S. Geological Survey Open-File Report 2008-1278, https://pubs.er.usgs.gov/publication/ofr20081278

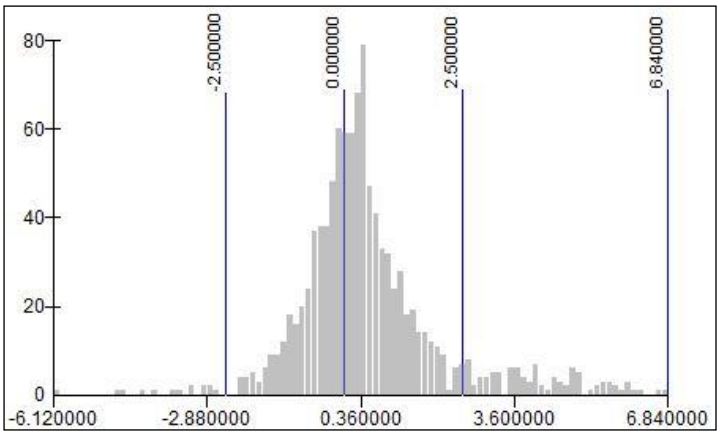


Figure 3-14: Distribution of evolution rates.

Table 3-19: Distribution of evolution rates.

Coastal line evolution rate (m/year)	Number of transects
-5.0 to -2.5	14
-2.5 to 0.0	368
0.0 to 2.5	565
2.5 to 5.0	95

Figures 23 and 24 show the result of evolution rates over the whole AOI and a detailed view. It can be noted that the highest evolution rates are mainly due to a shift that can locally appear between the different coastal lines. This regular offset does not correspond to natural evolution of coastal line, but is explained by the geometrical uncertainty of former images used for delineation. Hence, the presented results should not be considered as a rigorous reality.

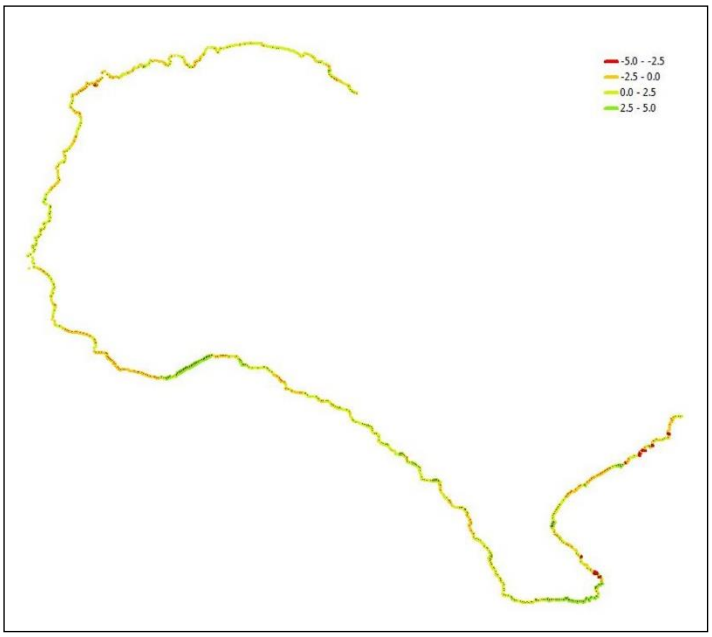


Figure 3-15: Classes of evolution rates over AOI7.

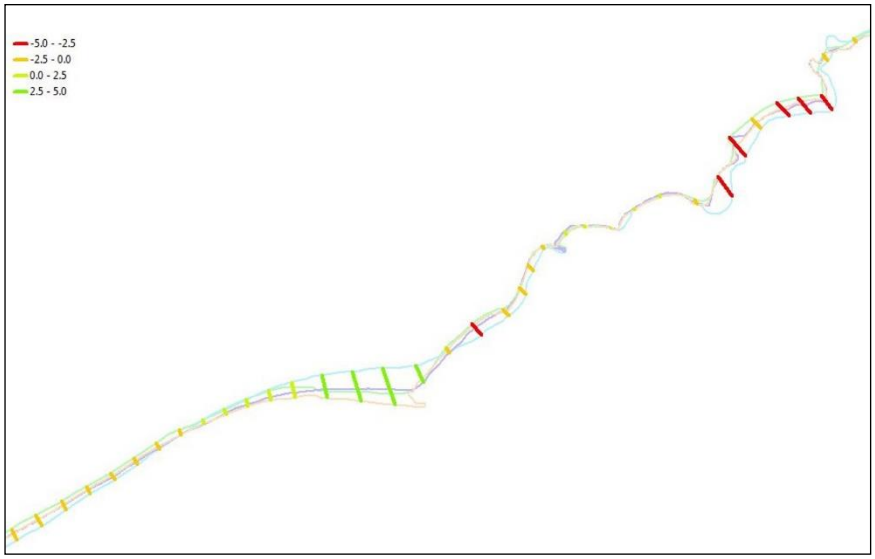


Figure 3-16: Detailed view of evolution rates.

3.8 Pre-Matthew vegetation classification in Makaya Park (AOI2 & 3)

Input layers

All the required layers for the pre-Matthew vegetation classification map product are listed below. For imagery the reference layers are the SPOT-6/7 images acquired the 17th November 2014 for AOI2, and mainly the SPOT-6/7 image acquired the 25th June 2016 for AOI3.

Table 3-20: Layers needed for the pre-Matthew vegetation classification map product.

Map layers	
Vegetation classification (pre-event)	✓
Damage assessment of forest stands	
Monitoring of forest stands	
General topography (infrastructure networks, urban, buildings, hydrographic network, Industry and facilities, contours and spot heights, shaded relief)	✓

Method

First, it has to be noted that there is no existing current vegetation classification for Makaya Park, nor current land cover map over Haiti. The last land cover maps were published in 1998 by the CNIGS in which classes for vegetation were limited to forest and savanna. Another map was released by the FAO in 2010, but data layers are not at this time accessible.

Even if it not possible to ensure the same data for AOI2 and AOI3, the same methodology was applied for each part of Makaya Park. In this densely forested natural area, Airbus DS consortium proposes to perform a vegetation classification based on a supervised machine learning algorithm as forest cover is widespread, and homogeneous. Furthermore, it is considered that to map the forestry VHR2 data suffices in the area. This is quite the opposite in the agricultural areas which in which VHR1 data are preferred, when available, to precisely map smaller wooded entities.

This supervised approach requires an existing reference database which is used to extract labelled samples, on one hand train the classification model (i.e. learning phase), and on the other hand to perform a statistical validation of the resulting classification.

After an evaluation of the reference ortho-photo 2014, and according to the CNIGS nomenclature, the land cover within the Makaya Park is composed of:

- Natural and semi-natural vegetation, i.e. class 3 in CNIGS' nomenclature, and precisely all subclasses are present:
  - Woodland (class 3.1)
  - Shrubs (class 3.2)
  - Herbaceous vegetation (class 3.3)
- Areas without vegetation (class 5), and precisely the unique subclass:

- Open spaces with little or no vegetation (subclass 5.1)

Initially, it was planned to produce our own regular spaced grid over the AOI2&3 extent, and regularly assign a code of the corresponding LULC class as an attribute. The final result would be a homogeneous layer of LULC polygons. In the meantime, CNIGS provided its own regular points dataset with 125m spacing of describing LULC (RENOP). However, sometimes this dataset is not up to date, or does not correspond anymore to the aggregation effect of SPOT-6/7 data, and outliers have been recoded using strict thresholds on radiometric and spectral index values. This dataset corresponds to 968 points for AOI2 and 5595 points for AOI3.

The SPOT 6/7 data were then processed as follows:

- Creation of a binary cloud mask by photo-interpretation (for AOI3);
- Calculation of NDVI based on red and near-infrared bands;
- Calculation of Shadow Index (SI) based on red and green bands;
- Layer stack of blue, green, red, NDVI, and SI bands.

A sample selection (points) was performed from the reference database created previously. A set of 868 samples for AOI2, and 4995 samples for AOI3 were used (roughly 90%).

These samples were crossed with the prepared SPOT 6/7 derived layer stack, in order to associate measurements in each channel as attribute values. The ‘’updated’’ samples were then provided to a Random Forest algorithm for the construction of a classification model.

This model was then applied to the whole SPOT 6/7 derived layer stack, associated to the cloud mask for AOI3, in order to classify the Makaya Park extent. Classification result was filtered by removing and filling objects with an area less than 0.01 ha. A confusion matrix and an associated overall accuracy was then computed by crossing a second sample set (roughly 10%) with the final labelled image: 100 points for validation in AOI2 and 600 points for AOI3.

Methodological validation of vegetation classification

The validation step presents an overall accuracy for AOI2 of 88%, and an associated Kappa coefficient of 0.81.

		Classification						
		31	32	33	51	Totals		
RENOP	31	48	1	2	0	51	94.12%	Producer's accuracy
	32	1	11	3	0	15	73.33%	
	33	1	1	24	1	27	88.89%	
	51	0	0	2	5	7	71.43%	
	Totals	50	13	31	6	100		
		96.00%	84.62%	77.42%	83.33%		Overall accuracy	
		User's accuracy					0.88	

Figure 3-17: Confusion matrix for vegetation classification over AOI2.

The validation step presents an overall accuracy for AOI3 of 86%, and an associated Kappa coefficient of 0.76.

		Classification						
		31	32	33	51	Totals		
RENOP	31	313	24	2	0	339	92.33%	Producer's accuracy
	32	15	103	6	3	127	81.10%	
	33	6	16	66	2	90	73.33%	
	51	3	6	3	32	44	72.73%	
	Totals	337	149	77	37	600		
		92.88%	69.13%	85.71%	86.49%		Overall accuracy	
		User's accuracy					0.86	

Figure 3-18: Confusion matrix for vegetation classification over AOI3.

The Table below summarizes the total areas for each vegetation class over AOIs 2 and 3. The vegetation classification map product is presented in Figure 3-19.

Table 3-21: Surface of each vegetation class for AOI2&3.

Class	Surface AOI2 (ha)	Surface AOI3 (ha)
Woodland	855.3	4704.5
Shrubs	153.4	2258.6
Herbaceous vegetation	438.9	1379.6
Open spaces with little or no vegetation	82.8	376.5

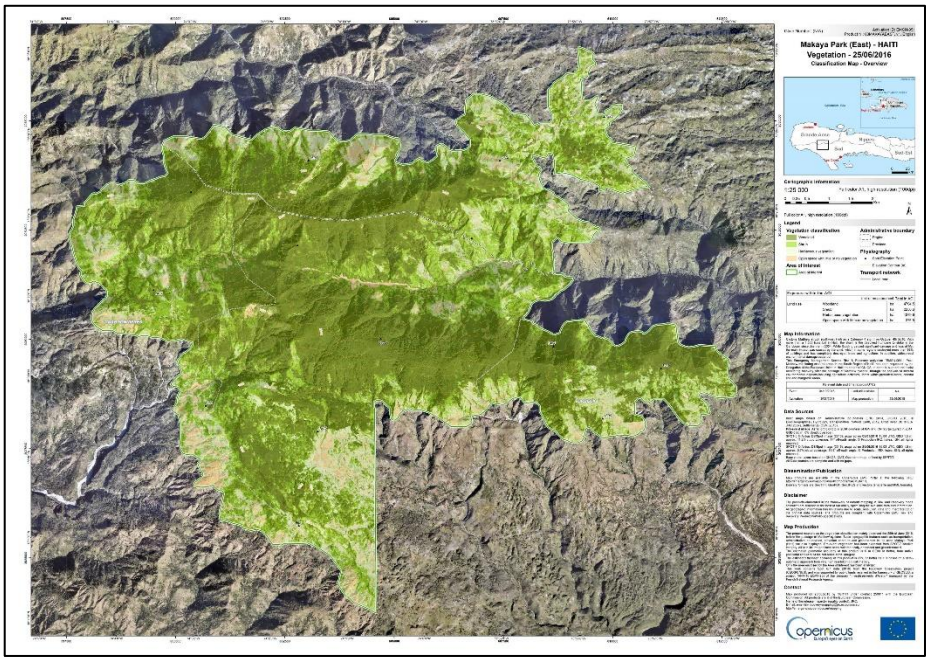


Figure 3-19: Vegetation classification over AOI3.

3.9 Damage assessment of forest stands in Makaya Park (AOI2 & 3)

Input layers

All the required layers for the forest stands damage assessment map product are listed below. For imagery the reference layer will be the VHR1/2 (SPOT-6/7 and GeoEye-1) data acquired the 23rd December 2016 and 8th January 2017.

Table 3-22: Layers needed for the forest stands damage assessment map product.

Map layers	
Vegetation classification (pre-event)	✓
Damage assessment of forest stands	✓
Monitoring of forest stands	
General topography (infrastructure networks, urban, buildings, hydrographic network, Industry and facilities, contours and spot heights, shaded relief)	✓

Method

After a visual analysis of VHR1 imagery (Geo-Eye) over AOI2 based on a near infrared false colour composition, it has been concluded that all the forest stands were damaged by the Matthew cyclone. Only very few areas were partially affected, mainly due to the shelter effect

of relief.

The image has been resampled to the same spatial resolution as VHR data for the computation of NDVI (i.e. 1.5m) in order to avoid too much detailed and meaningless information. Since, the acquisition was performed during winter, shadows due to relief are quite important. That is why a hillshade layer was created using Lidar DTM and ephemeris provided by Geo-Eye metadata. This layer was then converted into a binary mask for shadow/non shadow separation. Both inside this mask and inside the forest class, two different thresholds on NDVI values were applied accounting for terrain illumination. The thresholding results correspond to the distinction between damaged and partially damaged areas.

For AOI3, the analysis revealed the same effect and the same methodology was applied to the SPOT6/7 data, at the native spatial resolution.

Over both AOIs, no unaffected forest stands have been visually detected. Also, clouds and their associated shadows were taken into account during the analysis, and the corresponding forest stands are labelled as “not analysed”. The Table below summarizes the total areas for each vegetation class over AOIs 2 and 3.

Table 3-23: Surface of damaged forest areas over AOI2&3.

Class	Surface AOI2 (ha)	Surface AOI3 (ha)
Not affected	0.0	0.0
Partially damaged	92.6	684.3
Damaged	722.9	3925.8
Not analysed	19.8	94.5

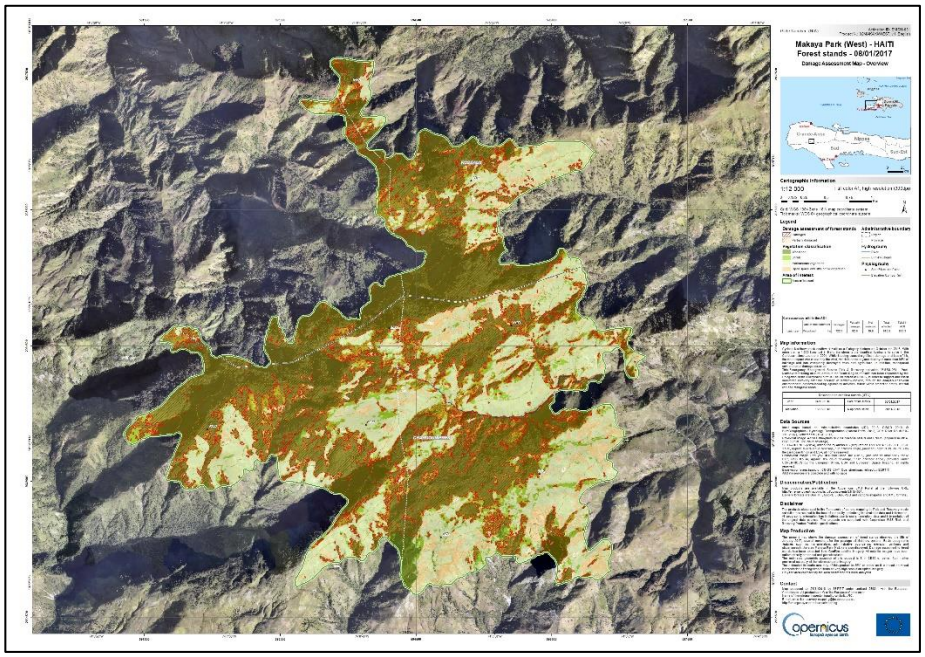


Figure 3-20: Damage assessment map over AOI2.

Methodological validation of forest damage assessment

The AOI2 was taken to validate the damage assessment of forest stands mapping methodology. The validation step for damage assessment is based on 100 randomly selected points. The overall accuracy is equal to 92%, with an associated Kappa index of 0.81.

		Classification				
		Damaged	Partly damaged	Totals		
PI	Damaged	76	7	83	91.57%	Producer
	Partly damaged	1	16	17	94.12%	
	Totals	77	23	100		
		98.70%	69.57%		Overall accuracy	
		User's accuracy			0.92	

Figure 3-21: Confusion matrix for damage assessment validation over AOI2.

3.10 Monitoring of forest stands in Makaya Park (AOI2 & 3)

Input layers

All the required layers for the forest stands monitoring map product are listed below. The accuracy levels will be reported. For imagery the reference layer will be the VHR1 Pléiades images acquired between September and December 2017.

Table 3-24: Layers needed for the forest stands monitoring map product.

Map layers	
Vegetation classification (pre-event)	
Damage assessment of forest stands	✓
Monitoring of forest stands	✓
General topography (infrastructure networks, urban, buildings, hydrographic network, Industry and facilities, contours and spot heights, shaded relief)	✓

Method

The same methodology as proposed previously for damage assessment of forest stands was adopted. The images acquired the 8th December have the advantage to cover the entire AOI's with a minimum of clouds.

Considering that illumination conditions are very similar between the GeoEye data used for damaged assessment over AOI2 and the Pléiades data for monitoring, and that these two sensors are similar, a difference of NDVI values was applied for the western part of Makaya Park. After the production of a hillshade according to ephemeris, two thresholding of NDVI difference was performed inside the shadow/non shadow mask for the forest class, in order to consider the terrain illumination and associated spectral response. The result provides a two-class layer, distinguishing the areas with no visible change in damaged vegetation (or invisible due to shadow) and the active vegetation. A deep visual analysis of VHR1 data revealed that this active vegetation corresponds to a regeneration under old stands, which explain that this term is used in the map legend.

Since the Pléiades imagery is slightly cloudy, and is the unique available data for the monitoring phase, some areas are labelled as not analysed in the map product and its associated vector layer. The Table below summarizes the total areas for each vegetation class over AOI's 2 and 3.

Table 3-25: Surface of change classes for forest areas over AOI2&3.

Class	Surface AOI2 (ha)	Surface AOI3 (ha)
No visible change	297.6	1759.2
Regeneration under old stands	515.6	2336.5
Not analysed	22.2	608.8

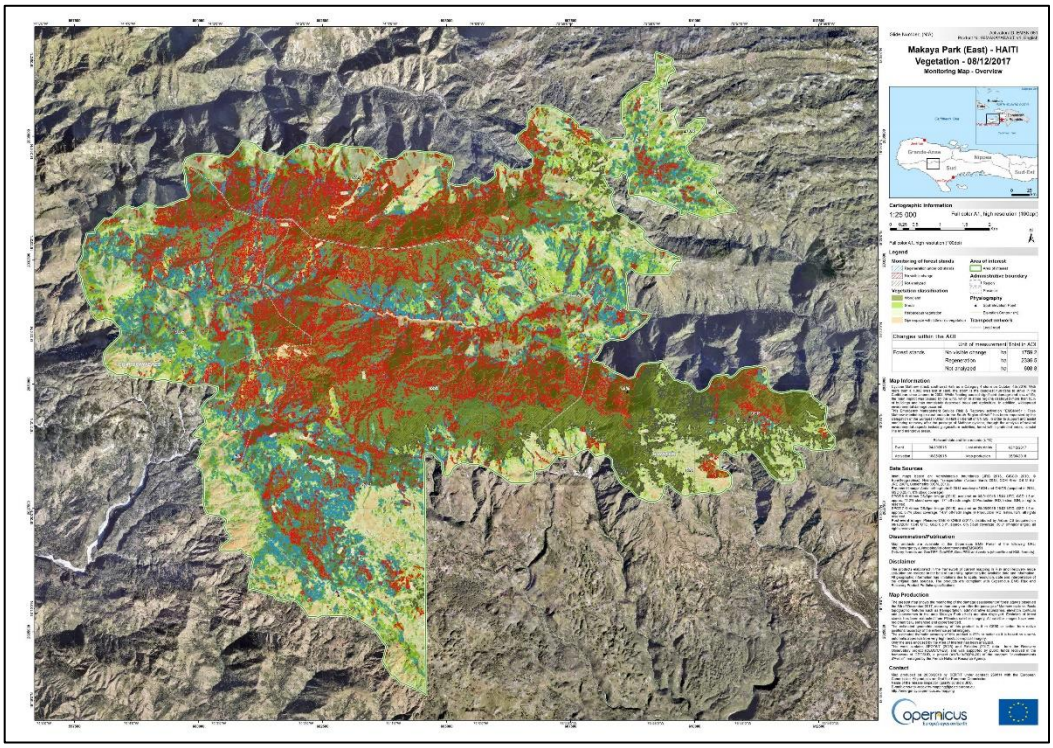


Figure 3-22: Monitoring map of forest stands over AOI3.

Methodological validation of forest stand monitoring

AOI2 was taken to validate the monitoring of forest stands' mapping methodology. The validation step for damage assessment is based on 100 randomly selected points. The overall accuracy is equal to 92%, with an associated Kappa index of 0.82.

		Classification			
		No visible change	Regeneration under old stands	Totals	
PI	No visible change	28	5	33	84.85%
	Regeneration under old stands	3	64	67	95.52%
	Totals	31	69	100	
		90.32%	92.75%		Overall accuracy
		User's accuracy			0.92

Figure 3-23 : Confusion matrix for forest stands monitoring over AOI2

3.11 Pre-Matthew situation of the mangrove at Pointe Abacou (AOI6)

Input layers

All the required layers for the pre-Matthew mangrove delineation map product are listed below. For imagery the reference layer is the Worldview-2 satellite imagery from 17th January 2016. Please note that UNEP has performed some UAV-based imagery acquisitions over mangrove in the area of Pointe-Abacou (the access has been provided by CIAT). However, Airbus DS had no information concerning the exact localization and date of this field campaign. These data were useful to understand the landscape structure and to better recognize mangrove areas from satellite imagery.

Table 3-26: Layers needed for the Pre-Matthew mangrove delineation map product.

Map layers	
Mangrove (pre-event)	✓
Mangrove (post-event)	
Changes into the mangrove	
General topography (infrastructure networks, urban, buildings, hydrographic network, Industry and facilities, contours and spot heights, shaded relief)	✓

Method

The complete workflow for mangrove delineation is summarized on Figure 3-27.

After a precise ortho-rectification, the mangrove areas were first roughly delineated from Worldview-2 imagery. This step was performed with the help of the aerial ortho-photo coverage acquired in 2014, since the spatial resolution is more detailed. It facilitates the exclusion of areas which are asource of confusion in the process of mangrove extraction: vegetation that do not correspond to mangrove, and algae bloom or deposits in bays (Figure 3-24).

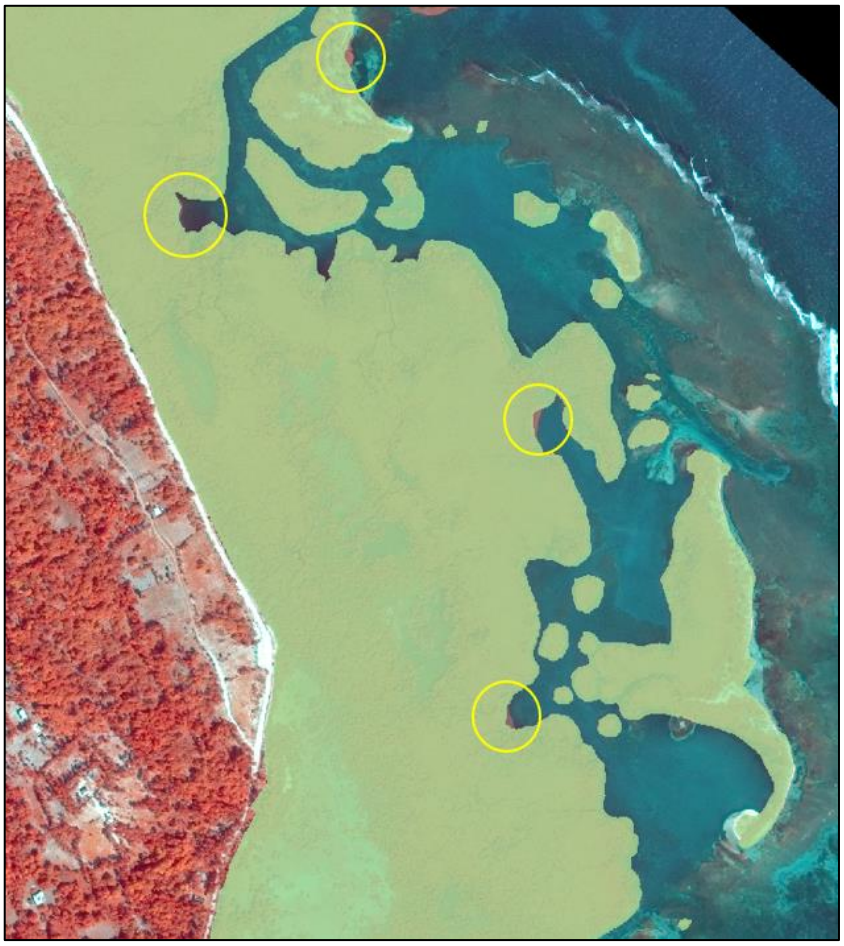


Figure 3-24 : Binary mask produced after the rough delineation mangrove areas. Yellow circles show the exclusion of algae bloom/deposits.

Then the vector layer was converted into a binary raster in order to be used as mask. Inside this mask, a multiple threshold was performed on the near-infrared channel, NDVI and Shadow Index (Figure 3-25). This step helps separate vegetation from water using NIR and NDVI values. However, water areas where the mangrove is sparse are not deep, and the seabed has a similar spectral behaviour as vegetation. Also, due to the water reflection, the behaviour of NDVI values is not sharp, but presents a halo pattern, which do not enable the precise extraction of isolated mangrove. The addition of the Shadow Index in the multi-conditional thresholding leads to a better separation with bare soil, sand and lagoons from mangrove.

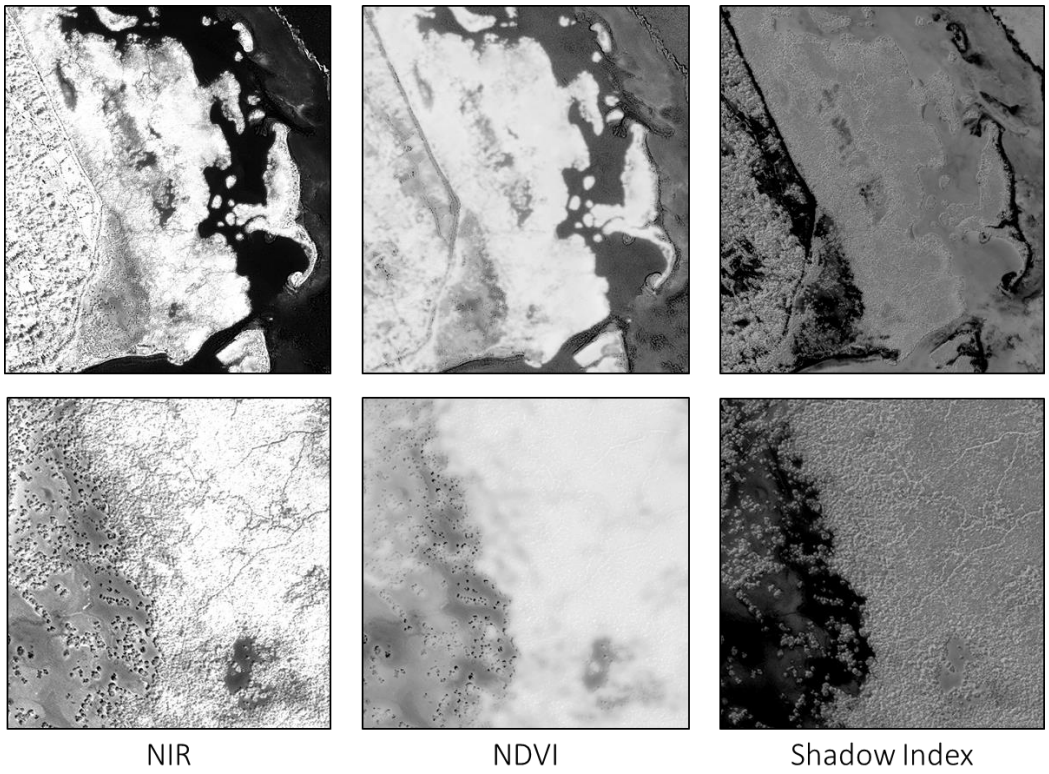


Figure 3-25 : Overview (upper row) and detailed view (lower row) of the mangrove for NIR channel, NDVI and Shadow Index.

A post-processing 3x3 kernel filter (erosion/dilatation) was applied in order to fill very small holes and remove isolated pixels. The size of the filter, and only one pass, helps keep information about the mangrove density, as seen in Figure 3-26.

Figure 3-26 : Example of the resulting extraction over non continuous mangrove.

The resulting layer corresponding to mangrove was then converted into a vector shapefile. Some objects could were manually reshaped due to the presence of other vegetation at the periphery. The area of each object was calculated and then objects of less than 4m² (0.0004 ha, or 16 pixels) were removed. A total of 100.7 ha of mangrove were delineated from the pre-event imagery.

The final vector layer quality was then visually validated by an operator who was not involved during the production process. On the basis of 100 randomly selected points from the mangrove layer, the overall accuracy is of 96% (Figure 3-28).

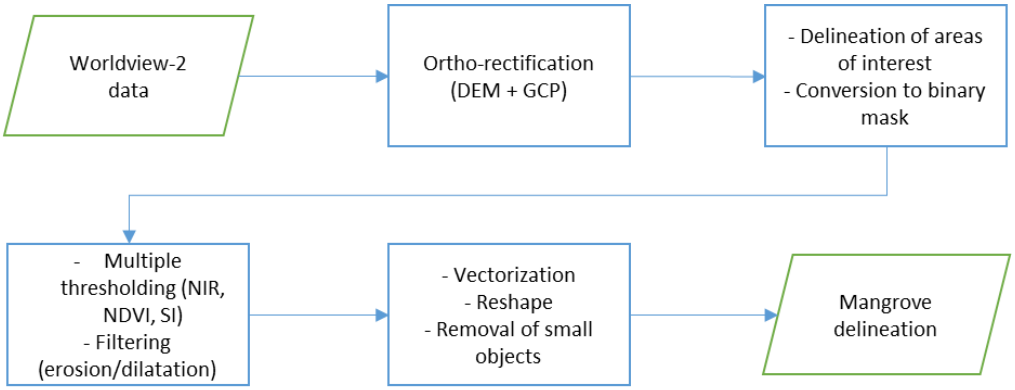


Figure 3-27: Workflow for mangrove delineation.

		Classification				
		0	1	Totals		
PI	0	0	4	4	0.00%	Producer
	1	0	96	96	100.00%	
	Totals	0	100	100		
		0.00%	96.00%		Overall accuracy	
		User's accuracy			0.96	

Figure 3-28 : Confusion matrix for mangrove delineation validation over AOI6.

3.12 Post-Matthew situation and changes into the mangrove at Pointe Abacou (AOI6)

Input layers

All the required layers for the post-Matthew mangrove delineation and change map product are listed below. For the post-event layer the reference is the Worldview-2 satellite imagery from 25th February 2018.

Table 3-30: Layers needed for the mangrove delineation and change map product.

Map layers	
Mangrove (pre-event)	
Mangrove (post-event)	✓
Changes into the mangrove	✓
General topography (infrastructure networks, urban, buildings, hydrographic network, Industry and facilities, contours and spot heights, shaded relief)	✓

Method

After a precise ortho-rectification of the post-event Worldview-2 imagery, a first visual analysis helps determine that the mangrove areas have not significatively grown between the two dates.

Then, a new extraction of mangrove was performed following the previously describe methodology, and using the same rough binary mask. The extracted layer was converted as a vector file, and small objects less than 0.0004 ha have been removed. Some objects were manually reshaped due to the presence of other vegetation at the periphery. A total of 96.2 ha of mangrove were delineated from the post-event imagery.

The resulting pre and post-event delineations were then used to determine both gain and loss of mangrove cover. A simple erase operation between the two layers performed in two ways, as illustrated in Figure 3-29, isolate the appeared and disappeared mangrover areas. The

extracted layers were converted into vector files, and small objects of less than 0.0004 ha have been removed.

A total of 3.1 ha of mangrove gain, and 8.6 ha of mangrove loss have been extracted from the pre and post-event imagery (Figure 3-30).

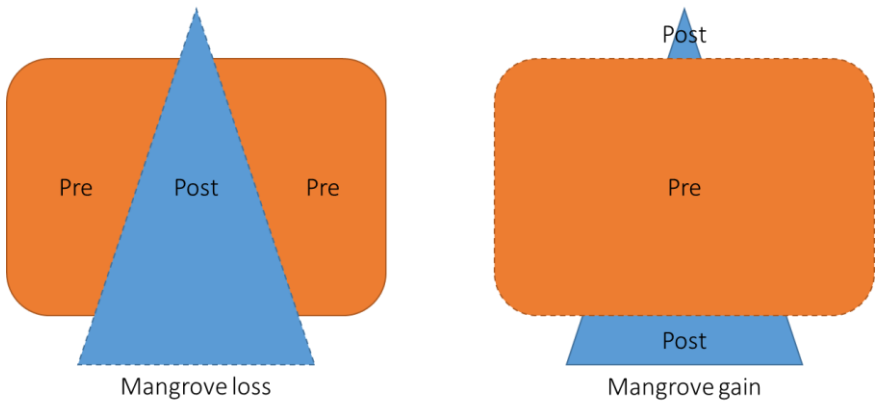


Figure 3-29: Vector erase process for the creation of change layers (gain & loss).

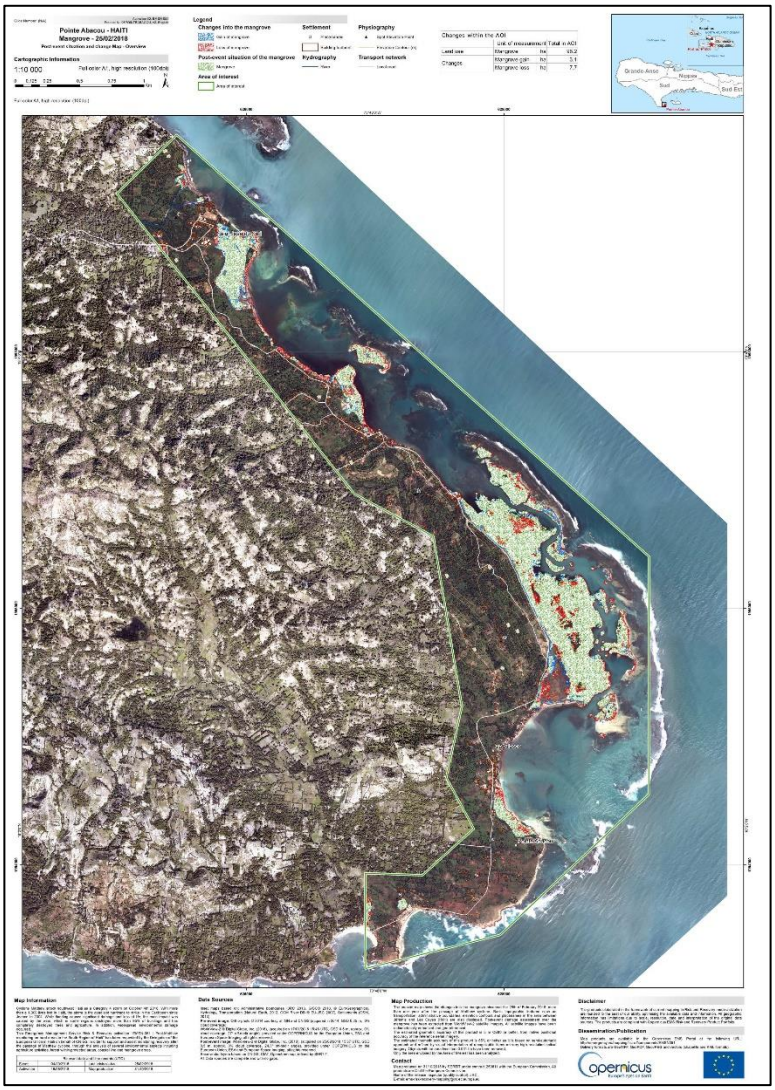


Figure 3-30: Post-Matthew situation and changes into the mangrove over AOI6.

APPENDIX 1 – Haitian LULC nomenclature (CNIGS)

Légende - Carte de la couverture terrestre Bassin Versant Grand Rivière du Nord	
Territoires artificialisés - *Surfaces édifiées, pavées ou profondément modifiées par l'homme, avec les zones associées*	
1.1 Zones urbanisées (Zones bâties) *Surfaces occupées principalement par des aires édifiées, pavées ou profondément altérées par l'homme pour l'habitation, le commerce, l'industrie, le transport, les services publics.*	Primarly Non-Vegetated Areas Terrestrial Artificial Surfaces and Associated Areas Built-Up Non-linear Urban Areas
1.2 Zones industrielles, commerciales ou publiques *Territoires occupés strictement par des activités industrielles; Territoires commerciaux accueillant du public; Territoire publiques*	Primarly Non-Vegetated Areas Terrestrial Artificial Surfaces and Associated Areas Built-Up Non-linear Industrial and Other Areas
1.3 Réseaux de communication *Ensemble de voie de communication ayant une largeur admissible (> = 3m environ). Le réseau routier, les routes urbaines, les canalisations urbaines, les réseaux d'assainissement, les gares etc. en font partie.*	Primarly Non-Vegetated Areas Terrestrial Artificial Surfaces and Associated Areas Built-Up Linear
1.4 Mines, décharges et chantiers *Zone de gisement naturel ou zone d'exploitation des matériaux de construction, ou de sites reservés à l'entreposage des déchets, ou des sites en construction. Salines.*	Primarly Non-Vegetated Areas Terrestrial Artificial Surfaces and Associated Areas Non Built Up
1.5 Espaces verts artificialisés et autres espaces urbains *Surface aménagée en milieu urbain, essentiellement constituée par de la végétation, mais aussi par des équipements pour le public (aire de jeux).*	Primarly Non-Vegetated Areas Terrestrial Artificial Surfaces and Associated Areas Built-Up Non-linear Urban Areas Other Espaces verts artificialisés et autres espaces urbains
Territoires agricoles - *L'ensemble des surfaces à terres arables, cultures ligneuses agraires, fourragères permanentes, jardins et vergers de famille annexes aux entreprises agricoles.*	
2.1 Cultures agricoles sans couvert arboré *Zones utilisées pour les cultures ou en jachère, généralement selon un schéma de rotation : cultures vivrières ou alimentaire. Ces espaces peuvent contenir quelques arbres d'un pourcentage maximum de 5%*	Primarly Vegetated Areas Terrestrial Cultivated and Managed Terrestrial Areas Herbaceous Crops
2.2 Cultures agricoles avec couvert arboré *Zones contenant quelques arbres épars pouvant être estimés entre 5% et 30%, utilisées pour les cultures ou en jachère, généralement selon un schéma de rotation : cultures vivrières ou alimentaire. Cette surface se diffère des systèmes agro-forestiers par la fréquence des arbres.*	Primarly Vegetated Areas Terrestrial Cultivated and Managed Terrestrial Areas Herbaceous Crops // Primarly Vegetated Areas Terrestrial Natural and Seminatural Terrestrial Vegetation Trees Sparse (4 - 20%)

2.3 Systèmes agro-forestiers *Ensemble de systèmes et de techniques d'utilisation des terres où des plantes ligneuses sont délibérément associées aux cultures ou à la production animale sous forme d'un arrangement spatial ou d'une séquence temporelle prenant place sur une même unité de gestion de la terre.*	Primarly Vegetated Areas Terrestrial Natural and Seminatural Terrestrial Vegetation Trees Closed to Open (40 -100)% > 30 - 3m (Trees Height) + Primarly Vegetated Areas Terrestrial Cultivated and Managed Terrestrial Areas Shrub Crops Multiple Crops One Additional Crop Herbaceous Terrestrial Crop With Simultaneous Period
2.4 Arboriculture *Surfaces occupées par cultures ligneuses agraires arborées ou arbustives, généralement denses, permanentes, regulièrement disposées, avec une couverture à plus de 65%.*	Primarly Vegetated Areas Terrestrial Cultivated and Managed Terrestrial Areas Tree Crops Plantations
Végetation naturels et semi-naturels terrestre - *Surfaces essentiellement occupées par une végétation naturelle ou semi-naturelle*	
3.1 Végétation arboree *Surfaces occupées par une végétation naturelle ou semi-naturelle arborée représentant une proportion à plus de 40%*	Primarly Vegetated Areas Terrestrial Natural and Seminatural Terrestrial Vegetation Trees Closed to Open (40 -100)% > 30 - 3m (Trees Height)
3.2 Végétations arbustives *Surfaces occupées par une végétation naturelle ou semi-naturelle de type arbustive à plus de 40 % et occupées par moins de 40 % d'arbres*	Primarly Vegetated Areas Terrestrial Natural and Seminatural Terrestrial Vegetation Shrubs Closed to Open (40 -100)% 5 - 0.3m (Shrubs Height)
3.3 Végétation a dominance herbacée *Surfaces occupées par une végétation naturelle ou semi-naturelle de type herbacée à plus de 4% moyennant que arbres et arbustes sont inférieurs à 40% chacun.*	Primarly Vegetated Areas Terrestrial Natural and Seminatural Terrestrial Vegetation Herbaceous Vegetation Closed to Open (15 - 100)% 3 - 0.03m (Herbaceous Height
Végétation des zones humides	
4.1 Zones humides intérieures *Surface impregnée d'eau et occupée à plus de 4% par une végétation qui peut être arbustive ou herbacée en dehors des zones de balancement des marées des cotes basses.*	Primarly Vegetated Areas Aquatic or Regularly Flooded Natural And Semi-Natural Aquatic or Regularly Flooded Vegetation Zones intérieures
4.2 Zones humides cotières et marines *Surface imprégnée d'eau, occupée à plus de 4%, par une végétation qui se developpe dans la zone de balancement des marées des cotes basses*	Primarly Vegetated Areas Aquatic or Regularly Flooded Natural And Semi-Natural Aquatic or Regularly Flooded Vegetation Zones cotières et marines

Zones sans végétation		
5.1	**Espace ouvert sans ou avec très peu de végétation** *Sols nu et/ou zones couvertes par affleurements de roches, cailloux, «badlands», etc; Zones occupées par les lits des rivières et les dépôts alluvionnaires associés; Zones occupées par les plages et du sable, en général au bord de la mer.*	Primarily Non-Vegetated Terrestrial Bare Areas
Surfaces en eau		
6.1	**Eaux continentales** *Surfaces correspondantes à des cours d'eau situés au dessus du niveau moyen des marées. Dans le cas des rivières l'extension est définie par le lit du cours d'eau*	Primarily Non-Vegetated Aquatic or Regularly Flooded Natural Waterbodies Eaux continentales
6.2	**Eaux marines**	Primarily Non-Vegetated Aquatic or Regularly Flooded Natural Waterbodies Eaux marines
6.3	**Zones intertidales** *Zones affectées par une régulière augmentation et diminution du niveau de la mer. En l'absence d'eau la surface est occupée par un sol nu.*	Primarily Non-Vegetated Aquatic or Regularly Flooded Natural Waterbodies Water Tidal Area (Surface Aspect: Bare Soil)