



Engagemment Communautaire
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Komori ya leo na meso



Land Cover Mapping of the Comoros Islands: Methods and Results

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Bristol Conservation
& Science Foundation



About the ECDD project

The ECDD project was run by Bristol Conservation & Science Foundation (an operating unit of Bristol, Clifton & West of England Zoological Society Ltd.) in partnership with Durrell Wildlife Conservation Trust, the Government of the Union of the Comoros and the Administration of the Island of Anjouan, and with the support of Agronomes et Vétérinaires Sans Frontières.

ECDD began in 2008 and ended in April 2013. External funding came from the UK government through the Darwin Initiative scheme, the French Development Agency and the Global Environment Facility (through the PoWPA project), amongst others.

The project worked with consultants from the International Union for the Conservation of Nature and Cranfield University.

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1. Aim and objective

Aim: To provide spatial data on the land cover types on the islands of Grande Comore, Anjouan and Mohéli in the Comoros archipelago to inform conservation and development planning.

Objective: Produce high resolution GIS maps of terrestrial habitats and land-use across Grande Comore, Anjouan and Mohéli using satellite imagery.

2. Imagery and software

In January 2010 a collaboration was formed with [Planet Action](#), through which imagery and software were provided for producing the land cover maps. Unfortunately the imagery provided by Planet Action (Spot and Formosat from 2007 and 2006) did not cover the three islands of the Comoros completely so additional [RapidEye](#) imagery was purchased. Further imagery of Anjouan was provided by the [GeoEye Foundation](#).

The imagery that was available:

- RapidEye (5m resolution) of the three islands from April 2010, purchased using funds from the Darwin Initiative
- GeoEye (2m resolution) of the south of Anjouan, date unknown
- Aster Digital Elevation Model (30m resolution), across the three islands, date unknown

Software provided by Planet Action:

- ArcGIS 9.3.1 for map production
- ENVI 4.7 for image formatting and pixel-based classifications
- Definiens Ecognition Developer 8.0 for object-based classifications.

3. Land cover definitions

Table 1. Definitions of the land cover classes present on the three islands of the Comoros

| Land cover class | Land cover sub-class | Definitions |
|------------------------|----------------------|---|
| Natural Forest | | Little trace of human impact and a closed canopy. Heavy growth of moss on tree trunks and tree ferns present. |
| Degraded Forest | | Closed canopy consisting of native species but some signs of human pressure such as selective logging and/or clearing of understory vegetation for firewood and fodder. Some presence of non-native trees or crops. |
| Agroforestry | Dense Agroforestry | Dense canopy dominated by agroforestry species. Natural or non-natural understory. |
| | Open Agroforestry | More open canopy consisting agroforestry species. Natural or non-natural understory. |
| Mangrove Forest | | Forest consisting of Mangrove species (<i>Rhizophora</i> and <i>Avicennia</i> trees), found only on the coasts. |
| Montane Dry Vegetation | | Shrubland dominated by <i>Philippia (Erica) comorensis</i> , high altitude, low vegetation cover. |
| Eucalyptus Plantation | | Areas dominated by Eucalyptus species. |
| Non-Forest | Plantation | Few native and/or non-native trees present but dominated by crops. |
| | Pasture | Largely grassland used for grazing livestock. Some native and/or non-native trees may be present. |
| | Scrub | Low vegetation cover, natural or non-natural. Some agriculture and/or trees. |
| | Padza | Very degraded land with little nutrients, very little low vegetation cover. |

| | | |
|----------------------|---------------|---|
| Inland Water | | Large inland water bodies, such as lakes. |
| Volcanic Rock / Sand | Volcanic Rock | Rock formed from volcanic lava flows. |
| | Volcanic Sand | Areas covered by sand resulting from volcanic activity. |
| Beach | Rocky Beach | Beaches consisting of rocks. |
| | Sandy Beach | Beaches consisting of sand. |
| Urban | Urban Dense | Dense buildings and infrastructure with few trees/gardens. |
| | Urban Open | Open buildings and infrastructure with gardens, plantations, and trees. |

4. Groundtruthing

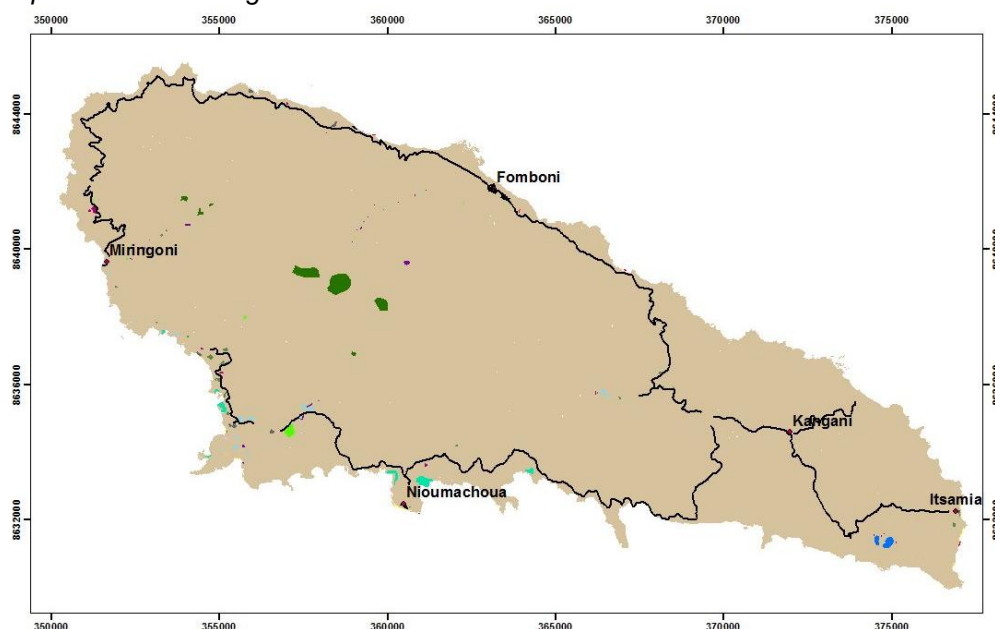
4.1. Data collection

Groundtruthing data was collected on the three islands in 2010; July in Mohéli, July-August in Anjouan, and September in Grande Comore. Sites were identified using unsupervised pixel-based classifications and visual inspection of the RapidEye imagery and GoogleEarth scenes to find areas of interest. However, sites were dependent on accessibility and time available, and many areas were excluded as going off paths in the extremely steep terrain was not possible. A hand held Garmin 60CSx GPS unit was used to mark specific locations and boundaries and printed GoogleEarth scenes were used as a reference in the field.

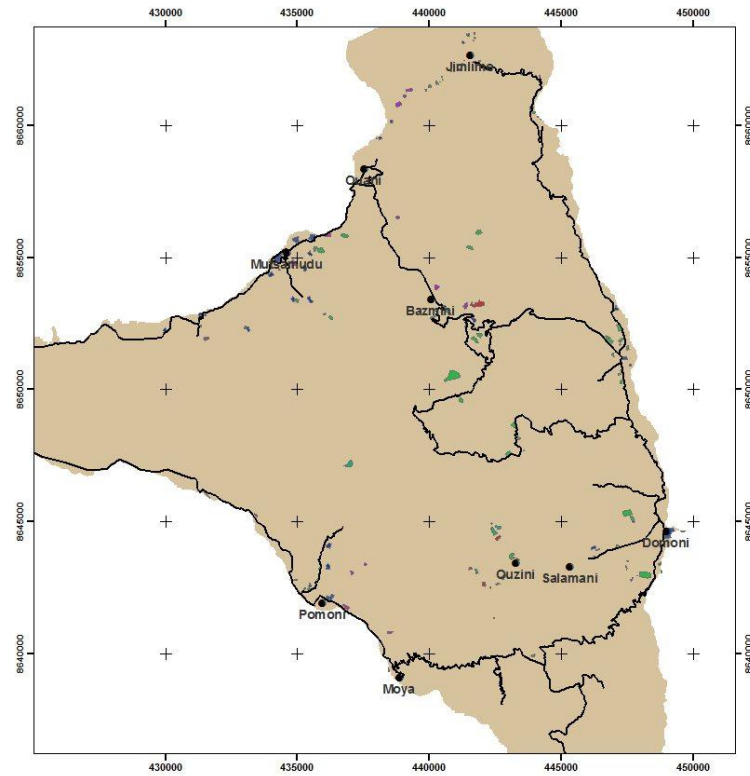
4.2. Data processing

GPS data was transferred to ArcGIS and then manually digitised into polygons of a particular habitat. RapidEye imagery and GoogleEarth scenes were used to ensure the location of the GPS data was correct and for digitising roads and urban areas. Maps 1-3 show the groundtruthing data collected.

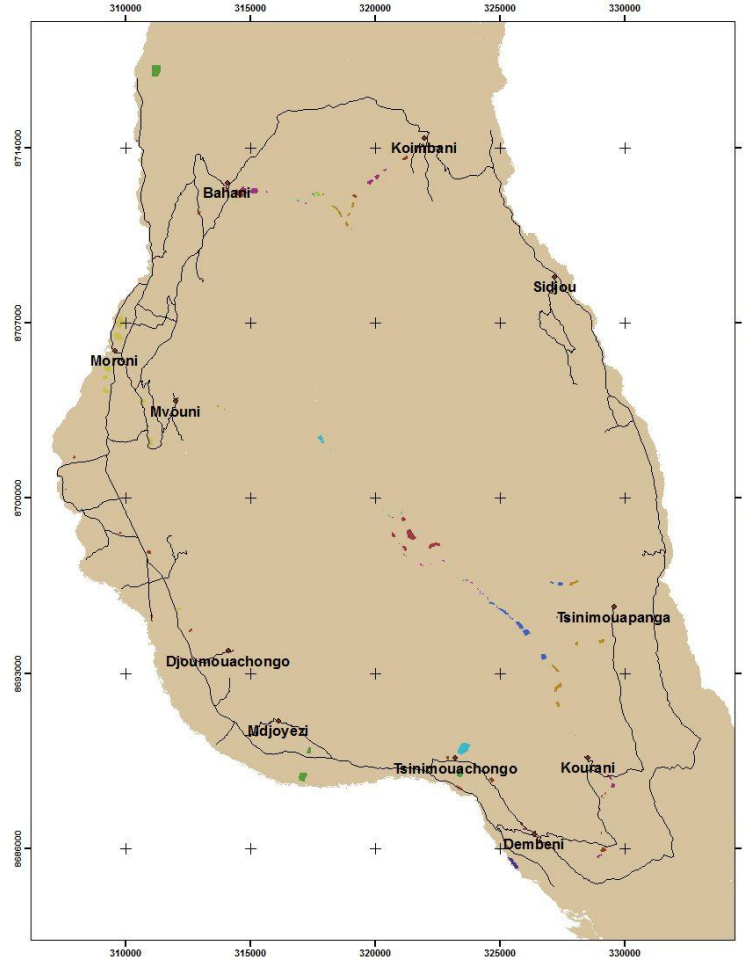
Map 1. Groundtruthing data collected on Mohéli



Map 2. Groundtruthing data collected on Anjouan



Map 3. Groundtruthing data collected on Grande Comore



5. Object-based classification

Object-based classification was conducted using the software Definiens eCognition Developer 8.0. RapidEye imagery was used for the classification, along with an Aster digital elevation model (DEM), and a calculated normalised difference vegetation index (NDVI) layer.

It should be noted that classifications are models and will not represent the reality on the ground 100%. Confusion between land cover classes will occur due to mixed pixels or strong similarity in spectral characteristics. The steep terrain of the Comoros islands, in particular Anjouan, added to these difficulties as some valleys sides were shaded and thus did not show the spectral characteristic of the landcover that was present. To reduce shadows the imagery was taken around midday, yet by this time of day there is considerable cloud cover. However, as described in the following sections, we performed several analyses and undertook several actions to ensure that the maps are as accurate as possible given the resources available.

5.1. Producing the cloud and shadow mask

Initial segmentation of the imagery was conducted at a scale of 150. This segmented layer was then exported as a shapefile and added to ArcGIS. Objects containing cloud cover and shadow were manually selected in ArcGIS. A buffer of 10m was added to these objects then exported as a new shapefile. This shapefile was added to the Definiens project and used as a mask.

5.2. Segmentation

Segmentation of the imagery was conducted with the following settings:

- Scale parameter 150
- Layer weights:
 - DEM – 1
 - Band 1 – 3
 - Band 2 – 1
 - Band 3 – 1
 - Band 4 – 5
 - Band 5 – 5
 - NDVI – 5
- Thematic layer cloud mask in use
- Composition of homogeneity criterion: shape – 0.1, compactness – 0.5.

The resulting segmented layer was then used in a spectral difference segmentation which had a maximum spectral difference setting of 10.

5.3. Masking cloud and shadow

To remove cloud and shadow from the classification it was pre-classified using the mask. The function 'assign class' was used with the threshold condition equal to the value of the mask.

5.4. Masking sea

The function 'assign class' was used to classify the sea and thus remove it from the classification. Threshold conditions were selected from the DEM and RapidEye bands and dependent on each island.

5.5. Selecting training objects

Training objects were selected from the groundtruthing data and visual interpretation of any obvious landscapes such as urban areas. 20% of the groundtruthing data was removed prior to selection to provide the required data for the accuracy assessment of the classification. A TTA mask of the training samples was created and exported to ArcGIS for use in the accuracy assessment.

5.6. Classification

A nearest neighbour classification was employed using the land cover defined in Table 1 and a minimum membership value of 0.2. Visual inspection of the resulting classification was conducted to identify any major errors. If there were major errors or large numbers of unclassified objects then the classification was re-run with the removal or addition of training objects. The final classification was exported as a shapefile to ArcGIS.

6. Initial resolution of clouded zones

Although high resolution imagery was available for the three islands, it was not cloud free so alternative solutions had to be explored to find a suitable classification for the clouded zones.

6.1. Previous classifications

For Grande Comore and Mohéli, no other high resolution imagery was available, so the solution for the classification of the clouded zones was the use of previous classifications completed by Oliver Hawlitschek (Hawlitschek *et al.* 2011) (Map 13 and 16). However, this classification was based on LandSat imagery of 15m resolution. Only the south of Grande Comore has been mapped as this area is the focus of the protected area planning.

6.2. GeoEye

In 2011 the GeoEye Foundation provided the project with two images of the southern half of Anjouan which were 2m resolution (Map 4). Object-based classifications were conducted, however the accuracy of the resulting classifications was quite low and the imagery also contained cloud and shadow (Table 2 and 3).

Map 4. GeoEye image and classification

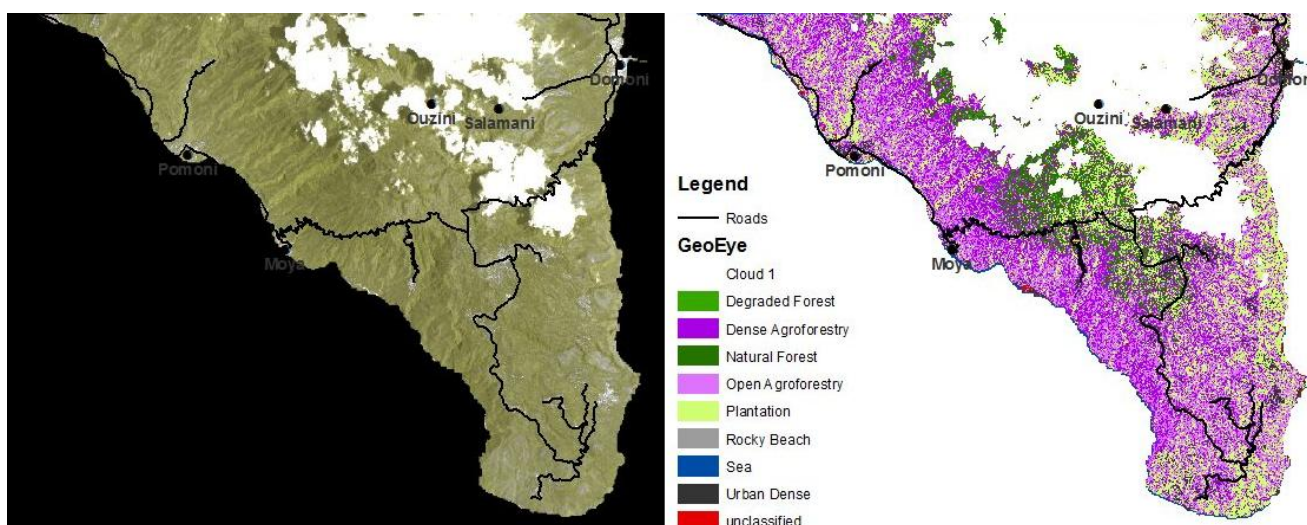


Table 2. Accuracy Assessment of the GeoEye classification in the Ouzini zone

| Row Labels | Degraded forest | Dense Agroforestry | Natural forest | Open Agroforestry | Pasture | Grand Total | User Accuracy |
|--------------------|-----------------|--------------------|----------------|-------------------|---------|-------------|---------------|
| Degraded Forest | | | 5 | | | 5 | 0.00 |
| Dense Agroforestry | 10 | | 7 | | | 17 | 0.59 |
| Natural Forest | 15 | | 19 | | | 34 | 0.44 |
| Open Agroforestry | 1 | | | | | 1 | 1.00 |
| Plantation | 13 | | 1 | | 1 | 15 | 0.87 |
| Grand Total | 39 | 0 | 32 | 0 | 1 | 72 | |
| | 0 | 0 | 0.5938 | 0 | 1 | | 0.28 |

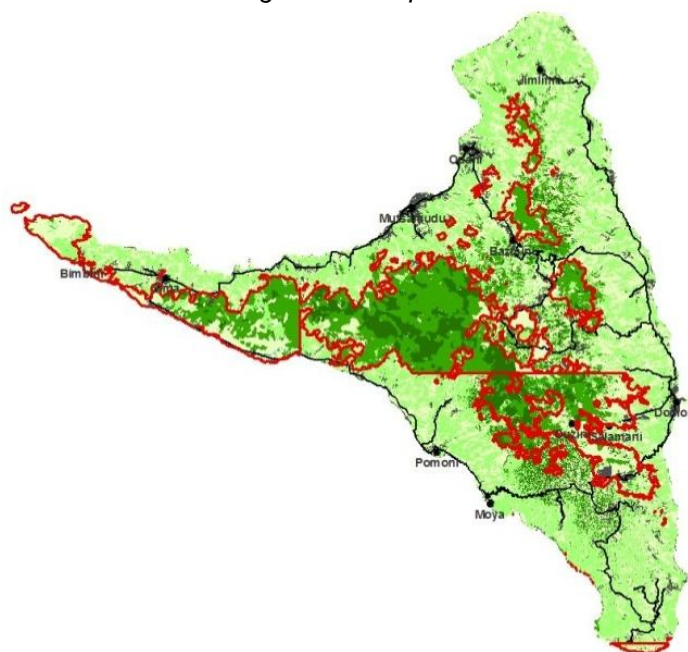
Table 3. Accuracy Assessment of the GeoEye classification in the Pomoni zone

| Row Labels | Dense Agroforestry | Open Agroforestry | Plantation | Urban | Grand Total | User Accuracy |
|--------------------|--------------------|-------------------|------------|--------|-------------|---------------|
| Dense Agroforestry | 16 | | 3 | 4 | 23 | 0.70 |
| Open Agroforestry | 25 | | 7 | 13 | 45 | 0.00 |
| Plantation | 8 | | 38 | 4 | 50 | 0.76 |
| Urban | 1 | | 2 | 27 | 30 | 0.90 |
| Grand Total | 50 | 0 | 50 | 48 | 148 | |
| | 0.32 | 0 | 0.76 | 0.5625 | | 0.55 |

6.3. Visual interpretation of Google Earth scenes

Map 5 shows the area of cloud cover remaining on Anjouan after the use of both the RapidEye and GeoEye images were used for classification. This remaining area was manually classified from visual interpretation of Google Earth scenes using the objects defined in the previous classification by Oliver Hawlitschek (Map 6). The accuracy assessment of this mosaic was calculated as 0.58 (Table 4).

Map 5. Clouded area classified using visual interpretation shown in red outline



Map 6. Land cover map of Anjouan using a mosaic of classifications from RapidEye and GeoEye imagery and visual interpretation

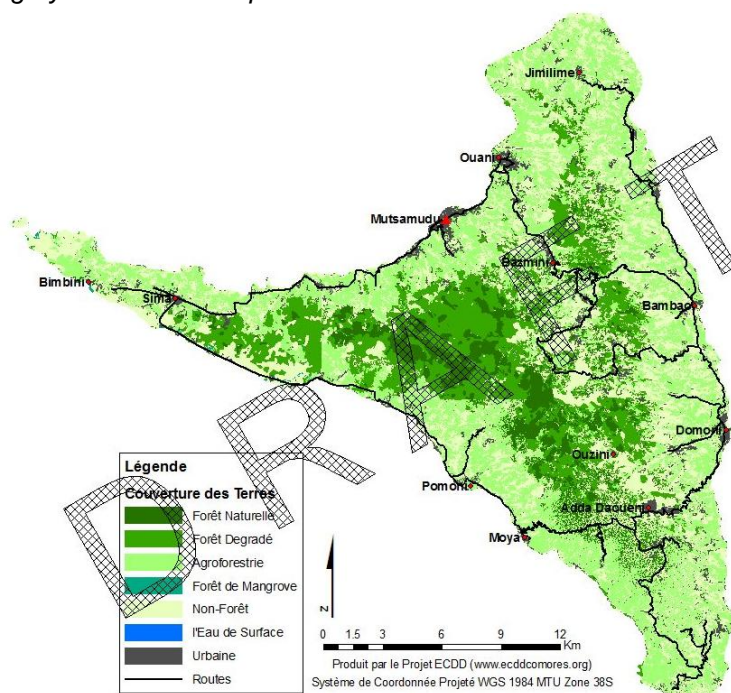


Table 4. Accuracy assessment of the Anjouan land cover classification

| | Agroforestry | Degraded Forest | Natural Forest | Non Forest | Urban | Total general | producer acc. |
|-----------------|--------------|-----------------|----------------|------------|-------|---------------|---------------|
| Agroforestry | 71 | 5 | 12 | 29 | 14 | 131 | 0.54 |
| Degraded Forest | 3 | 22 | 8 | 2 | | 35 | 0.63 |
| Natural Forest | | 18 | 19 | 2 | | 39 | 0.49 |
| Non Forest | 20 | 2 | 11 | 15 | 12 | 60 | 0.25 |
| unclassified | 1 | 3 | | | | 4 | |
| Urban | 1 | | | 1 | 72 | 74 | 0.97 |
| Total general | 96 | 50 | 50 | 49 | 98 | 343 | |
| user accuracy | 0.74 | 0.44 | 0.38 | 0.31 | 0.73 | | 0.58 |

7. Further improvements to Anjouan maps (2013)

Given the moderate accuracy of the landcover map of Anjouan, calculated at 0.58 (58%), and this island is of particular importance for the ECDD project, an analysis was conducted to assess whether any further improvements could be made to the maps.

7.1. GeoEye image and manual interpretation

The accuracy of the GeoEye classification was not very high: 0.28 and 0.55. Two options were available for this area: 1 - remove the GeoEye classification and instead use visual interpretation of Google Earth scenes, or 2 - reclassification using a smaller area, thus reducing the possible confusion. In addition, the objects used for the visual interpretation were larger than the rest of the objects in the classification so interpretation without objects was experimented.

7.2. Revised visual interpretation

Visual interpretation from Google Earth scenes without objects was found to be too difficult. It was hard to distinguish natural and degraded forest and too time consuming to identify both agroforestry and non-forest. Thus maps of forest (natural and degraded) and non-forest (all other land cover classes) were produced – one with the inclusion of the GeoEye classification and one without (Map 7). The map without the GeoEye classification was visually more accurate. The accuracy assessment for this map was calculated as 0.89 (Table 5).

Map 7. Land cover map of Anjouan using the revised visual interpretation and both the inclusion and exclusion of the GeoEye classification

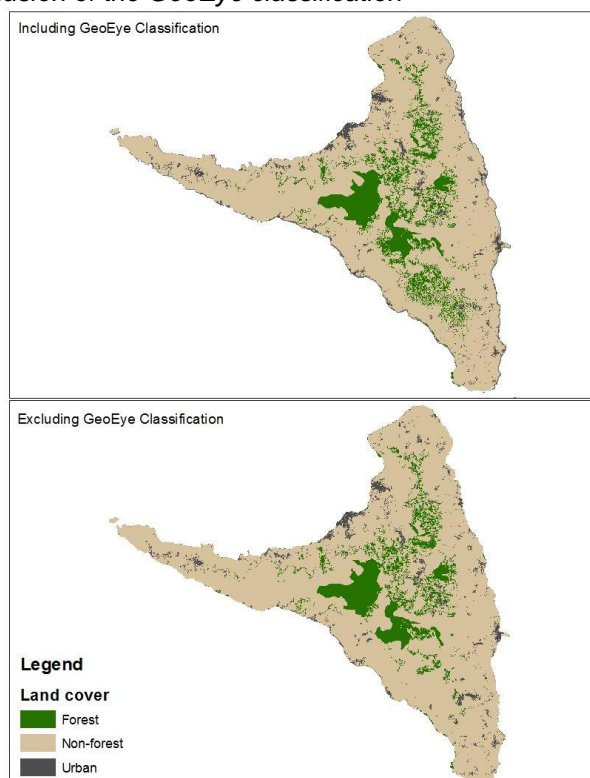


Table 5. Accuracy assessment of the land cover map of Anjouan with revised manual interpretation and does not include the GeoEye image

| Row Labels | Forest | Nonforest | Total | User Acc | |
|--------------------|--------|-----------|-------|----------|-------------|
| Forest | 34 | 1 | 35 | 0.97 | |
| Non-Forest | 16 | 99 | 115 | 0.86 | |
| Total | 50 | 100 | 150 | | |
| Producer Acc | 0.68 | 0.99 | | | |
| Overall Acc | | | | | 0.89 |

7.3. Reclassification of a subset of the GeoEye imagery

Given the low accuracy of the GeoEye image reclassification was conducted but using a small area to reduce the amount of confusion. The cloud and shadow mask for the GeoEye image was used to clip the imagery so that only the area to be used in the land cover map was classified (Map 8). The accuracy of the resulting map was calculated at 0.52 (Table 6).

Map 8. The map on the left shows the area of the GeoEye image which was reclassified and the map on the right shows the resulting land cover map

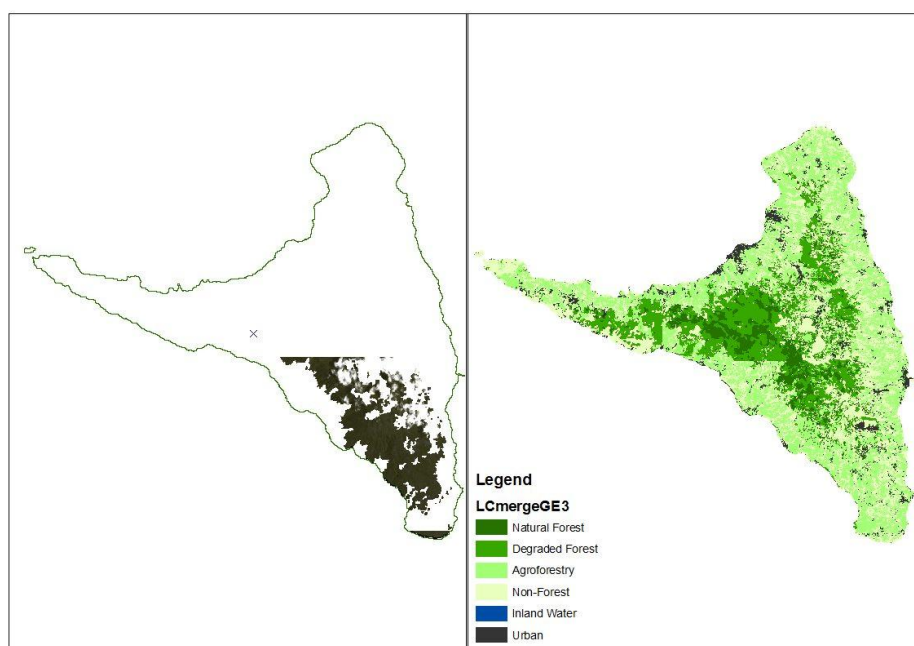


Table 6. Accuracy assessment of the Anjouan land cover map which includes the reclassified zone of the GeoEye image

| Row Labels | Agroforestry | Degraded forest | Natural forest | Non Forest | Grand Total | |
|-----------------|--------------|-----------------|----------------|------------|-------------|-------------|
| Agroforestry | 127 | 25 | 6 | 48 | 206 | 0.61 |
| Degraded Forest | 2 | 29 | 19 | 5 | 55 | 0.52 |
| Natural Forest | | 19 | 13 | 2 | 34 | 0.38 |
| Non-Forest | 21 | 7 | 1 | 49 | 78 | 0.62 |
| Grand Total | 150 | 80 | 40 | 148 | 418 | |
| | 0.846 | 0.3625 | 0.325 | 0.331 | | 0.52 |

7.4. Revised visual interpretation of west of Anjouan

Although accuracy of the southern section of Anjouan had been improved there remained some obvious errors in the west where there was cloud cover in the RapidEye imagery (Map 9). To improve this section visual interpretation of Google Earth scenes was carried out by modifying and reclassifying the existing objects. The accuracy assessment result was 0.52 (Table 7)

Map 9. Visual interpretation used to improve the accuracy of the western section of Anjouan - shown in the red circle

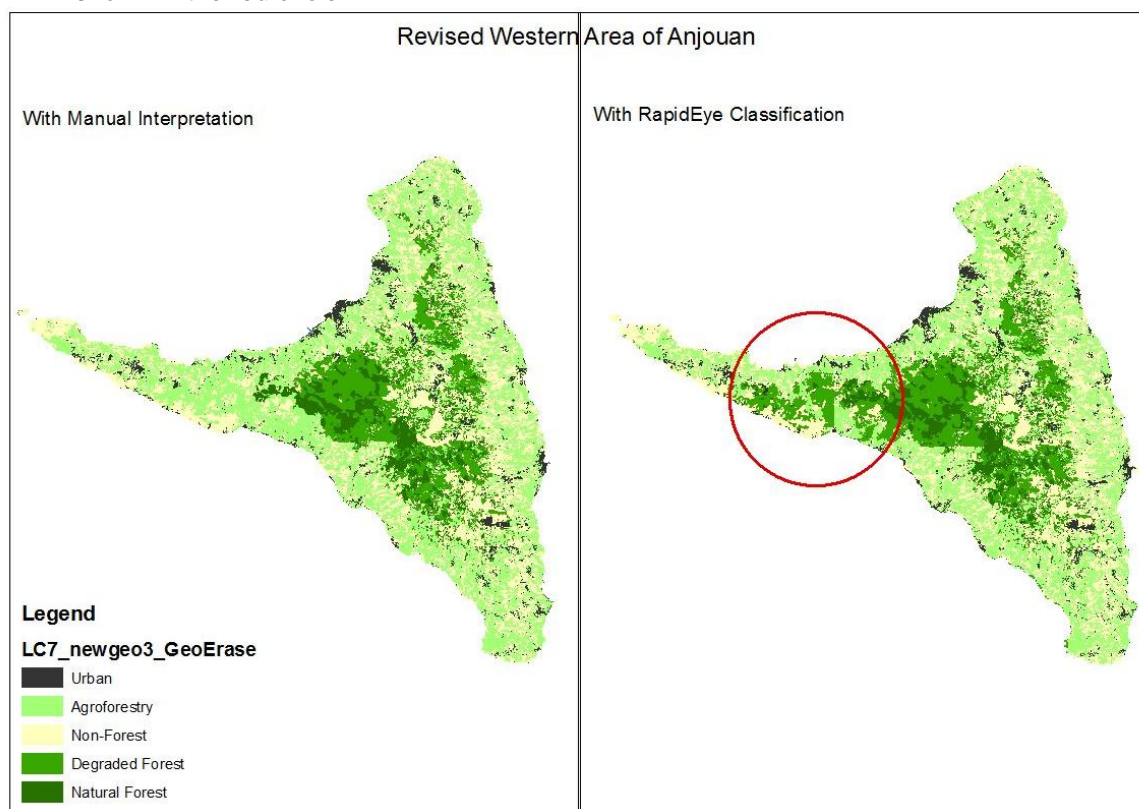


Table 7. Accuracy assessment of the Anjouan land cover map which includes the improvements to the western section

| Row Labels | Agroforestry | Degraded Forest | Natural Forest | Non-Forest | Grand Total | |
|-----------------|--------------|-----------------|----------------|------------|-------------|-------------|
| Agroforestry | 41 | 6 | 1 | 14 | 62 | 0.66 |
| Degraded forest | 9 | 16 | 8 | 4 | 37 | 0.24 |
| Natural forest | 4 | 13 | 15 | 1 | 33 | 0.12 |
| Non Forest | 20 | 6 | 4 | 25 | 55 | 0.36 |
| Grand Total | 74 | 41 | 28 | 44 | 187 | |
| | 0.55 | 0.39 | 0.54 | 0.57 | | 0.52 |

8. Results: final maps and land class areas

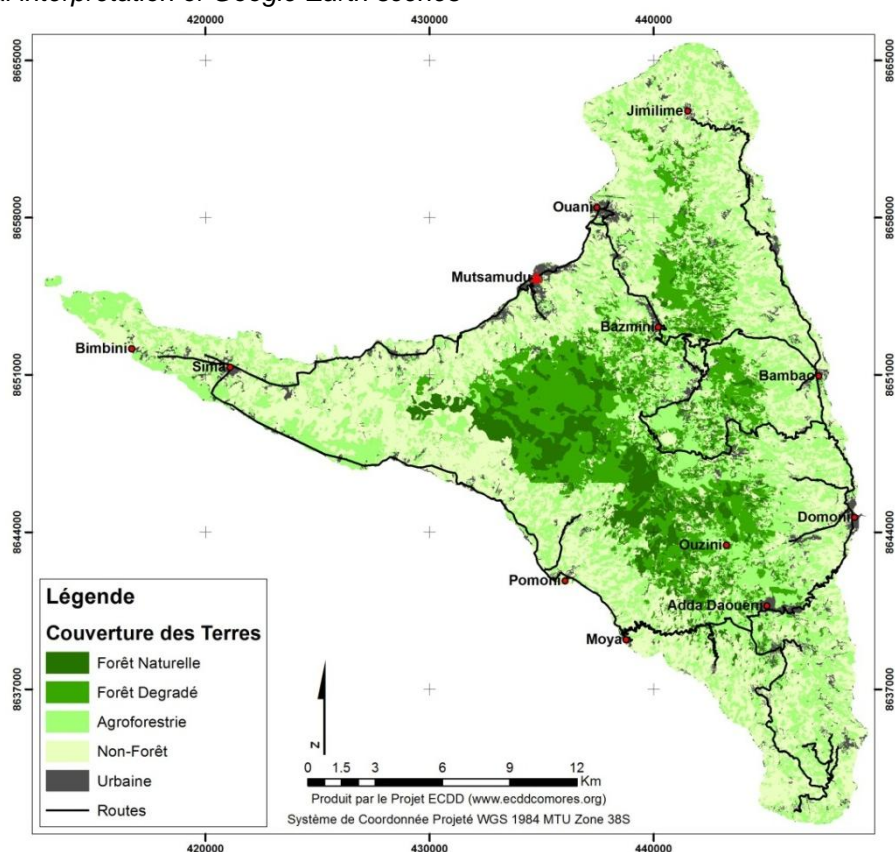
Table 8. Land class areas on the different islands

| Grande Comore (south) | Area (km²) |
|------------------------------|------------------------------|
| Natural Forest | 86.29 |
| Degraded Forest | 182.72 |
| Agroforestry | 148.60 |
| Non-Forest | 480.64 |
| Mangrove | 0.07 |
| Montane Dry Vegetation | 9.61 |
| Inland Water | 0.19 |
| Volcanic Rock/Sand | 69.96 |
| Urban | 40.76 |
| All classes | 1018.85 |

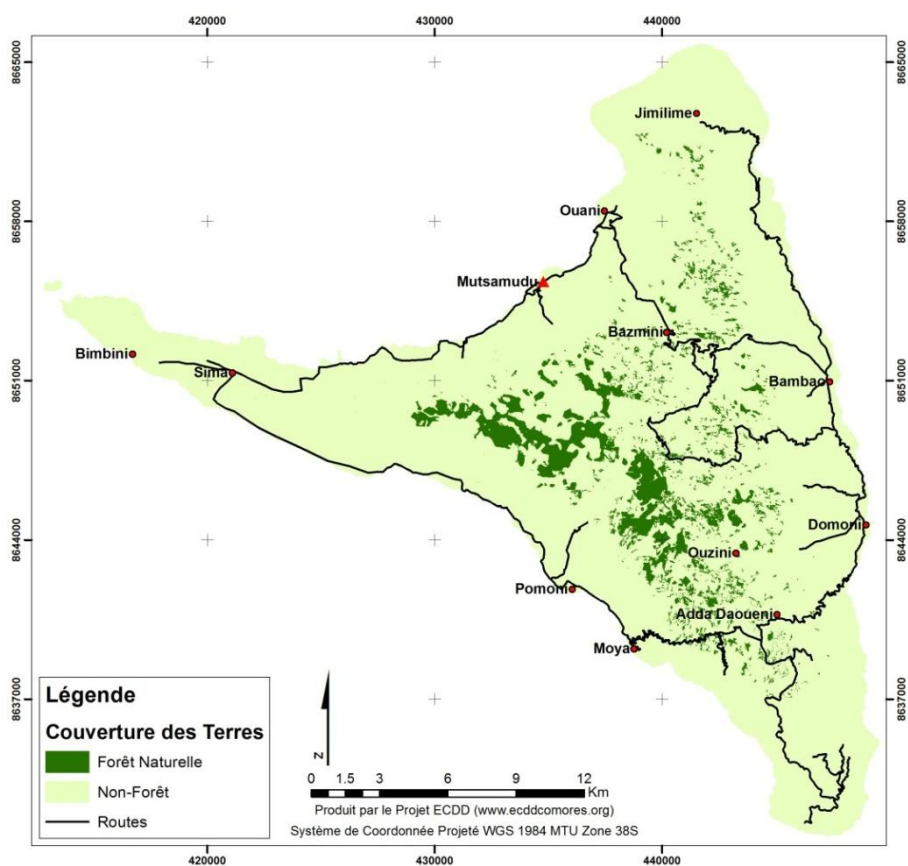
| Mohéli | Area (km²) |
|-----------------|------------------------------|
| Natural Forest | 25.10 |
| Degraded Forest | 29.27 |
| Agroforestry | 86.34 |
| Non-Forest | 55.89 |
| Mangrove | 1.28 |
| Inland Forest | 0.18 |
| Urban | 5.62 |
| All classes | 203.68 |

| Anjouan | Area (km²) |
|-----------------|------------------------------|
| Natural Forest | 29.56 |
| Degraded Forest | 59.13 |
| Agroforestry | 138.25 |
| Non-Forest | 173.56 |
| Urban | 20.36 |
| All classes | 420.86 |

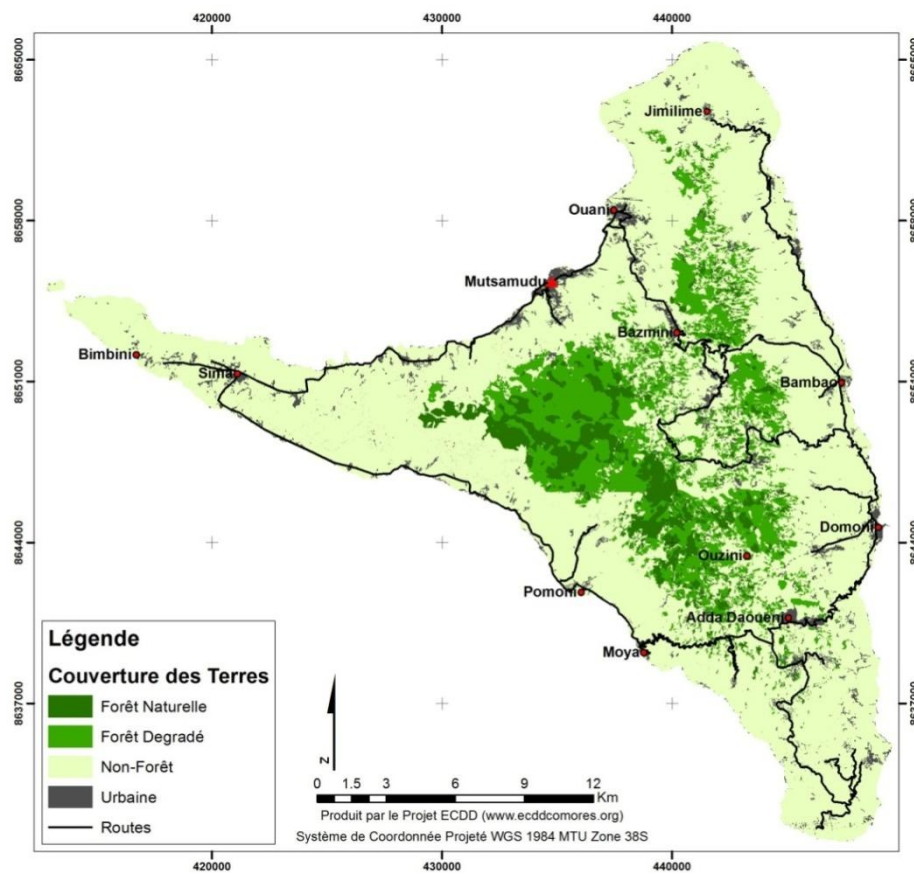
Map 10. Anjouan – A mosaic of a RapidEye classification, clipped GeoEye classification, and visual interpretation of Google Earth scenes



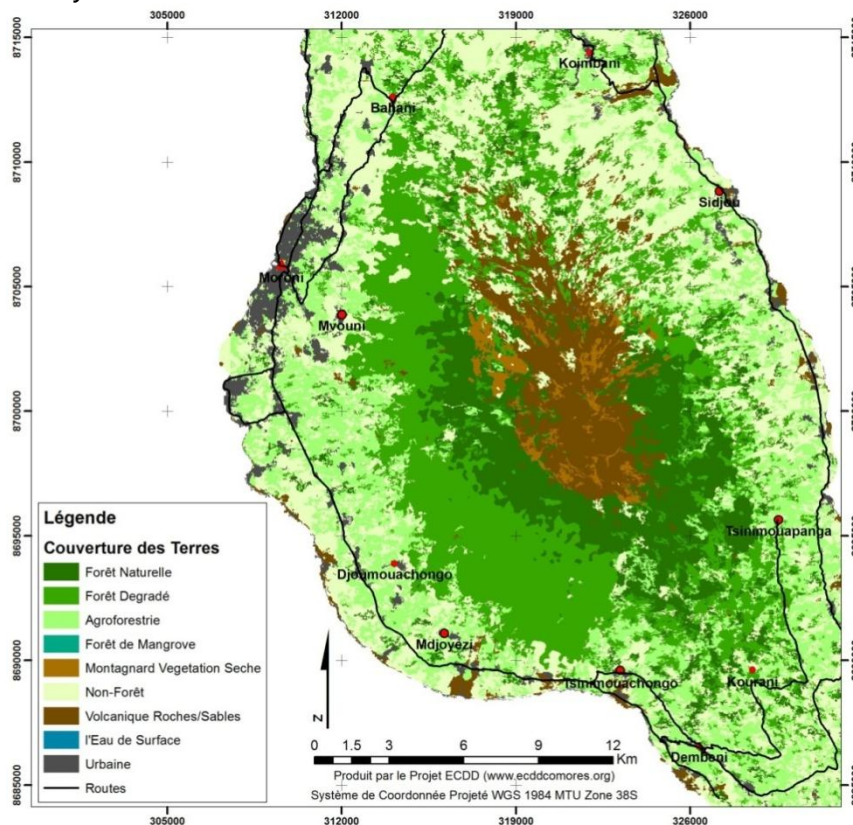
Map 11. Anjouan – A mosaic of a RapidEye classification, clipped GeoEye classification, and visual interpretation of Google Earth scenes. Showing natural forest only, however this class was found to be confused with degraded forest so there will be added error



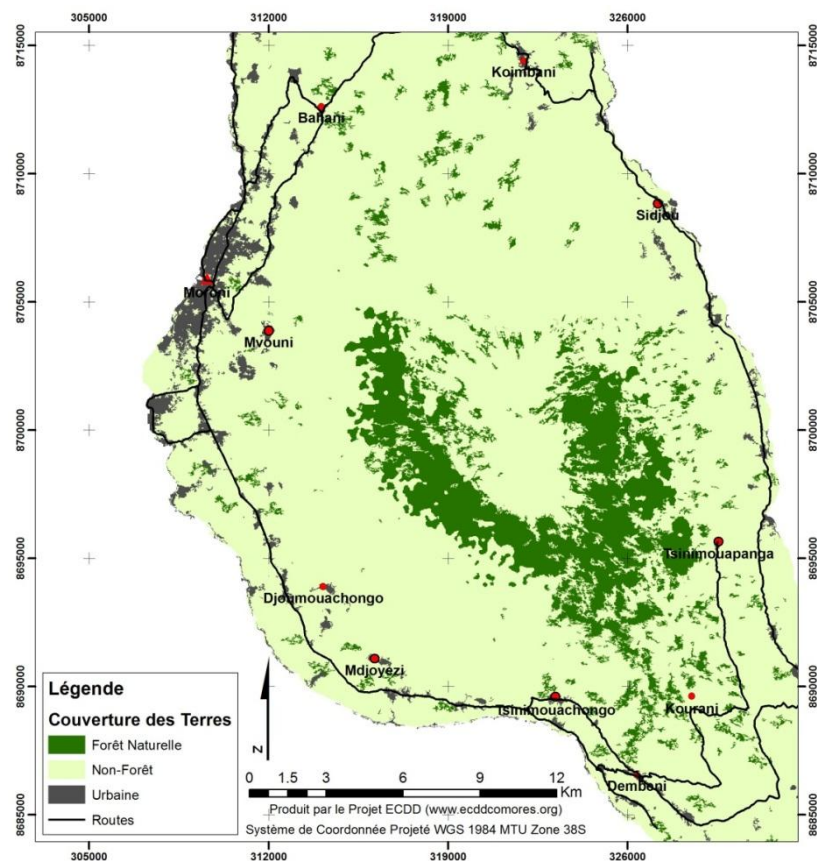
Map 12. Anjouan – A mosaic of a RapidEye classification, clipped GeoEye classification, and visual interpretation of Google Earth scenes. Showing natural and degraded forest only, which are two classes found to be spectrally similar and so some confusion between them will have occurred



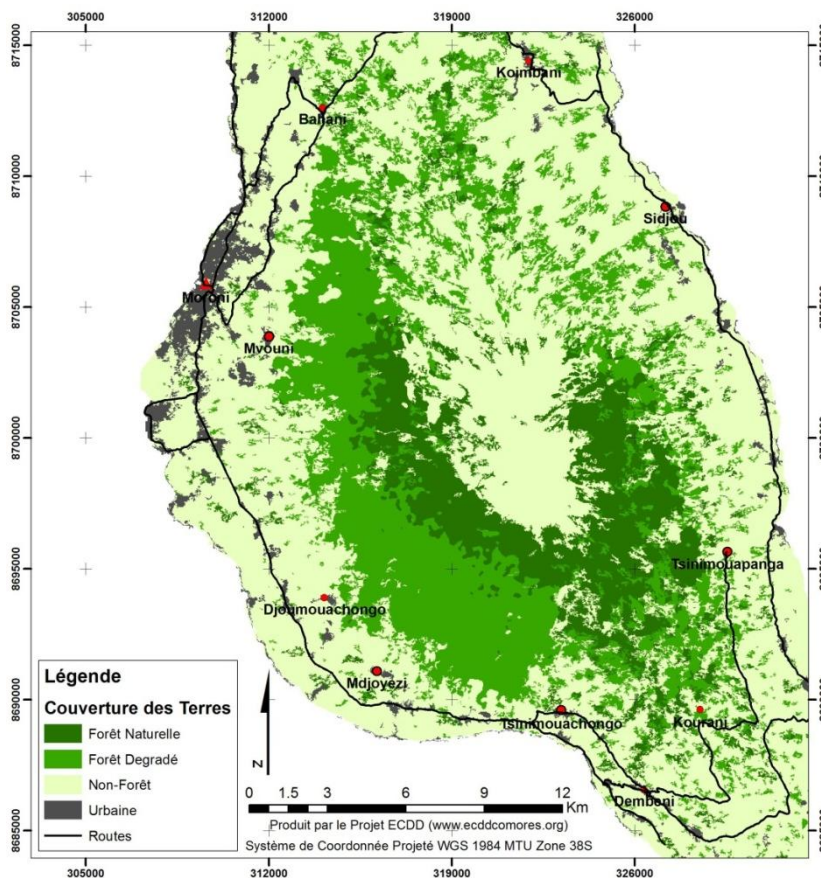
Map 13. Grande Comore – A mosaic of a RapidEye classification and a classification completed by O. Hawlitschek



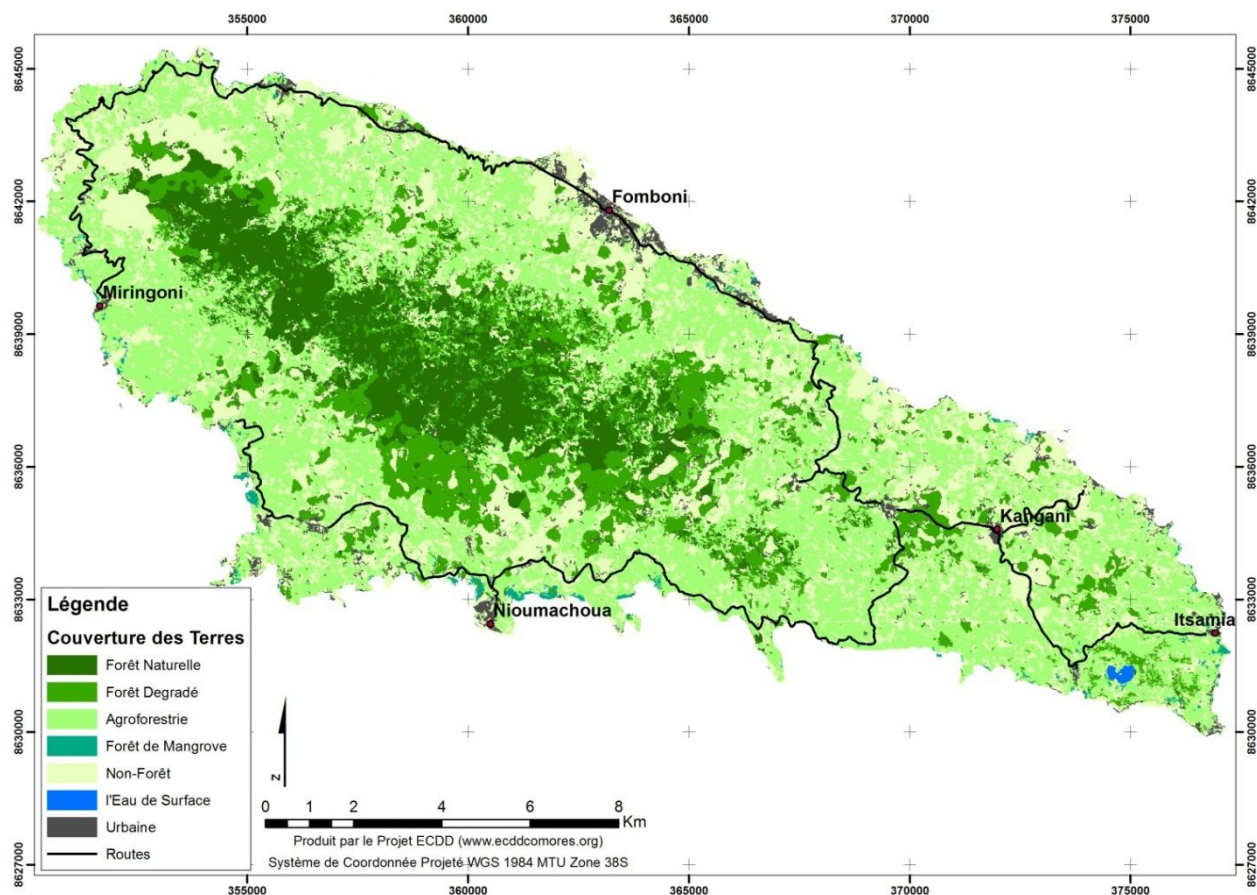
Map 14. Grande Comore – A mosaic of a RapidEye classification and a classification completed by O. Hawlitschek; showing natural forest



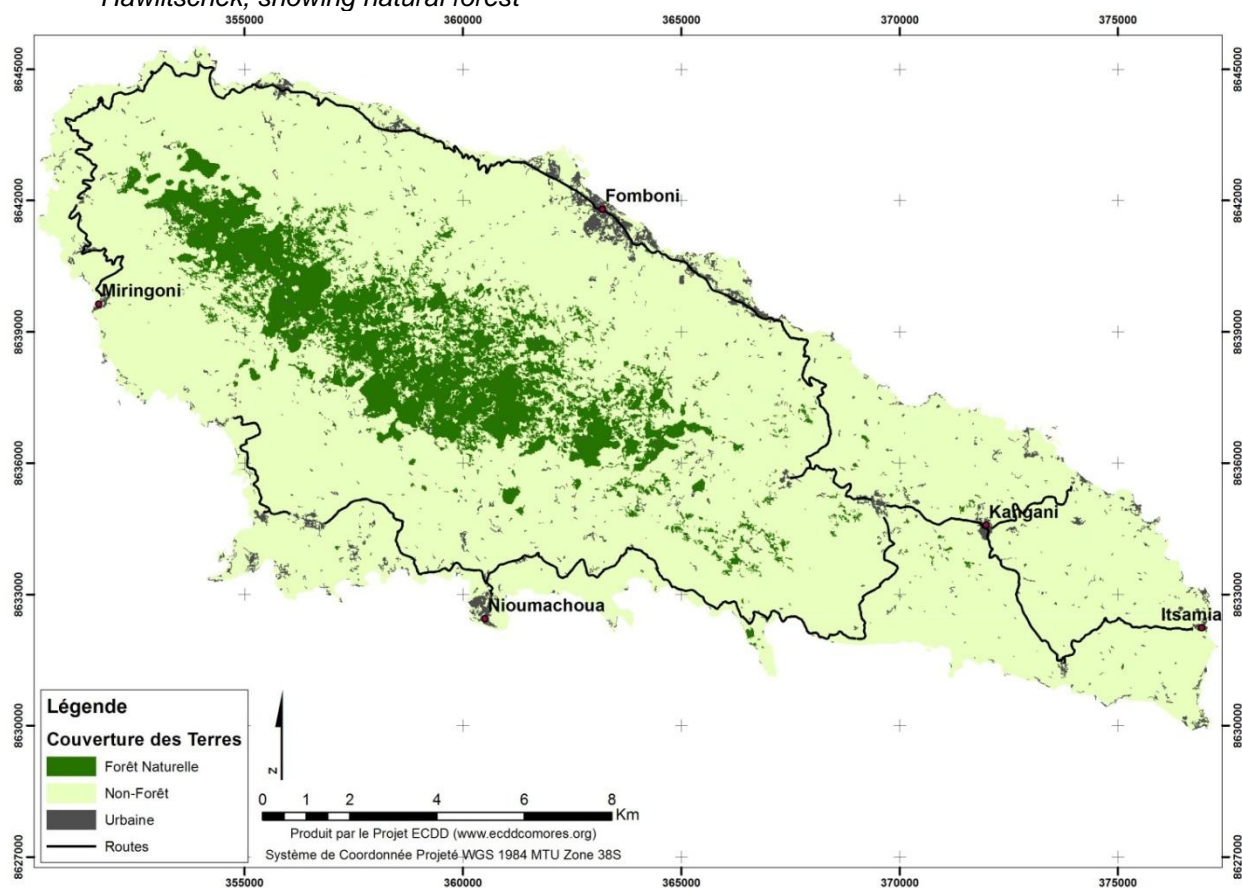
Map 15. Grande Comore – A mosaic of a RapidEye classification and a classification completed by O. Hawlitschek; showing natural and degraded forest



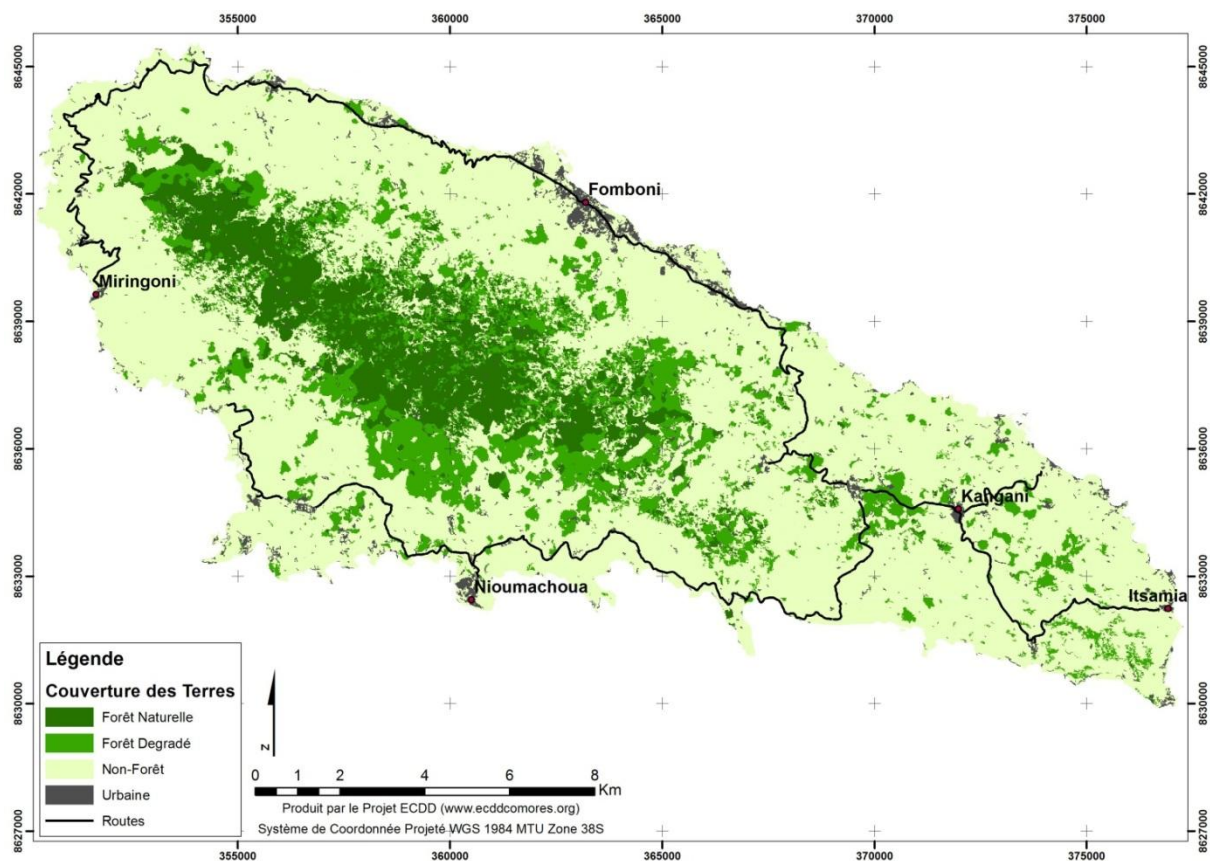
Map 16. Mohéli – A mosaic of a RapidEye classification and a classification completed by O. Hawlitschek.



Map 17. Mohéli – A mosaic of a RapidEye classification and a classification completed by O. Hawlitschek; showing natural forest



Map 18. Mohéli – A mosaic of a RapidEye classification and a classification completed by O. Hawlitschek; showing natural and degraded forest



9. Discussion

These are the first maps of different forest types and land-use produced for Grande Comore, Anjouan and Mohéli, based on high-resolution satellite images. As such they form an invaluable record of the current extent of natural and degraded forest.

The maps and land class areas show that, relative to the size of each island, Mohéli has the most intact remaining area of natural forest (over 12% of its land area), with field surveys revealing tracts of good quality old growth forest. For Grande Comore, given the size of the island, there is relatively little continuous natural forest left. The remaining forest is in the large part restricted to high altitudes at long distance from human settlements. Anjouan has the least remaining area of natural forest (7% of its land area), and all remaining natural and degraded forest is located in the highlands in areas too steep to be accessible to humans.

These differences in the quality and area of remaining forest between the three islands reflect different land-use practices, population densities, and pressure on forest across the three islands. The differing extent of deforestation and forest degradation on each island has had consequent varying impacts on the human population in terms of reductions in soil fertility and water availability, and on threat levels to biodiversity. These impacts are discussed in other reports produced by ECDD and available through the website, including on distribution patterns of biodiversity.

These results are intended to inform conservation and development planning and interventions across the three islands. The proposed terrestrial protected areas cover all the remaining areas of forest across the three islands other than the area surrounding La Grille to the north of Grande Comore (not covered by these maps), and the Moya massif towards the south of Anjouan. This last area is the zone of interventions for the community work of ECDD, and remains the core area of intervention for the new NGO Dahari, which has taken over from ECDD (www.daharicomores.org).

The maps can assist zoning of protection schemes and conservation planning with local communities, both for habitat, and, through integration with ecological data, for biodiversity. They also form a baseline to enable assessments of land cover changes in the future, and to evaluate the impact of different conservation interventions on forest habitat.

However, care should be taken with the use of these maps. The maps are based on imagery taken for the main part in 2010, so some areas will have changed since then. The maps are models based on projections from a limited dataset, and as such, they are only as good as the data that they are based on and the methods used in the classification. Particular difficulties with cloud cover were encountered during the modelling, which has affected the accuracy of the maps. The large area being classified also necessarily reduces the accuracy of the maps. That said, the results of the accuracy assessments are adequate given these constraints.

The results will be made available through the project website www.ecddcomoros.org, and will be exploitable by all interested parties through an open source license. All data and GIS layers are also being transferred to the government, and are available to researchers through signing a memorandum – see contact details on page 2.

Appendix 1. Data available

| Data | Details | Name of file/folder |
|------------------|--|----------------------------------|
| Imagery | RapidEye | RapidEye |
| | GeoEye | GeoEye |
| | Formosat | Planet Action |
| | Spot | Planet Action |
| | Aster DEM | ASTGTM_S1..... |
| | GeoEye RGB | WeTransfer-CC4yFgR1 |
| Groundtruthing | Anjouan (Anj) | An_GT.shp |
| | Grande Comore (GC) | GC_GT.shp |
| | Mohéli (Mo) | Mo_GT.shp |
| Classification | Anj RapidEye cloud mask | Noclo3_2_recl.shp |
| | Anj GeoEye cloud mask | GE_cloud2.shp |
| | TTA mask Anj | tta3.shp |
| | TTA mask GC | tta2_2.shp |
| | TTA mask Mo | Tta_mask2 |
| | GC land cover map merge | GC_ALL_EN.shp |
| | Mo land cover map | Mo8_tidy.shp |
| | Mo land cover map merge | Mo_landcover.shp |
| | O. Hawlitscheks map - Anjouan | Anjouan_1626820030814.shp |
| | O. Hawlitscheks map - Moheli | Moheli_1626920010520.shp |
| | O. Hawlitscheks map - GC | Grande_Comore_1626820030814.shp |
| | Anj GeoEye classification | Geo10.shp |
| | Anj GeoEye classification clipped | Geo10_clip.shp |
| | Anj land cover map (GeoEye classification and Miguel's manual) | Anj_lc_merge_dissolve_merge.shp |
| | Anj land cover map (No GeoEye classification and Katie's Forest/Non-Forest Manual class) | GE_LC |
| | Anj land cover map (GeoEye classification and Katie's Forest/Non-Forest Manual class) | LC_erase4_merge |
| | Anj clipped GeoEye classification | Geo12.shp |
| | Anj clipped GeoEye classification clipped | Geo12_clip.shp |
| | Anj land cover map (clipped GeoEye and Miguel's manual) | LCmergeGE3.shp |
| | Anj manual classification WEST (Katie) | LC_clip_new3_merge.shp |
| | Anj land cover map (clipped GeoEye, Katie's manual x2) | LC7_newgeo3_geoerase.shp |
| Final Maps | Anjouan – all classes | Anjouan_landcover2013.jpg |
| | Anjouan – Natural and degraded forest | Anjouan_landcover2013_natdeg.jpg |
| | Anjouan – Natural forest | Anjouan_landcover2013_nat.jpg |
| | Mohéli – all classes | Moheli_Landcover.jpg |
| | Mohéli - Natural and degraded forest | Moheli_Landcover_natdeg.jpg |
| | Mohéli - Natural forest | Moheli_Landcover_nat.jpg |
| | GC – all classes | GC_Landcover.jpg |
| | GC - Natural and degraded forest | GC_Landcover_natdeg.jpg |
| | GC - Natural forest | GC_Landcover_nat.jpg |
| Final GIS Layers | Anjouan | Anjouan_LC.shp |
| | Mohéli | Moheli_LC.shp |
| | Grande Comore | Grande_Comore_LC.shp |