BIOREDD+ Program

DELIVERABLE 7: BASELINE ASSESSMENT OF DEFORESTATION AND DEGRADATION IN PROJECT AREAS

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Development of REDD+ Forest Biomass and Carbon Stock and MRV System in Pacific Coastal Region of Colombia

Report # 7

Baseline Assessment of Deforestation and Degradation in Project Areas

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I. Description of task 7

The Baseline Assessment will focus on collective territories and nodes in the Pacific where REDD+ projects will be developed under BIOREDD+ and provide detailed information on historical changes in forest cover. Multi-temporal ALOSPALSAR data (minimum of 2 seasons per year) over the lifetime of ALOS-PALSAR (2007-2011) and any historical data such as JERS imagery (1992-1998), Landsat data (1980s-present), and GeoSAR data (2005) to quantify deforestation and degradation in the study areas. The objective is to develop a methodology to track and quantify the forest cover change. The overall product will include spatial distribution and statistical information of activities within each study region such as the extent of the area of land conversion, rate of forest loss, and the type of activity (forest to pasture, crops, abandonment to regrowth, etc.). Validation of the products will be performed in collaboration of the field experts who are collecting forest inventory and socio-economic data on the land management and conversions. The subcontractor will use the data from airborne lidar and optical imagery to improve and verify the products over the study areas. Deliverable includes: 1. Detailed map of land cover change at 0.25-1.0 ha documenting historical rate of deforestation and degradation in the BioREDD+ project areas. 2. Statistical information on area, rate of change, and type of change over project areas. 3. Uncertainty assessment of historical changes based on field and other ancillary data.

II. Background

The potential carbon assets that could be generated by the voluntary sector REDD+ projects to be developed through the BioREDD+ project depends on two factors: their carbon stocks at the project start date, and the reference level, that is to say the rate of loss of these stocks that would be expected without the project. Earlier reports have concentrated on estimating existing carbon stocks, whereas this report changes focus to concentrate on estimates of historic emission levels, using remote sensing imagery from the mid-1980's to 2011.

In Report 6, GeoSAR and ALOS PALSAR data were used to make a detailed and accurate landcover classification of the Pacific Coastal Region of Colombia. However, unfortunately GeoSAR data is available for one time point only, and no comparable data has been collected before or since, and thus we cannot use GeoSAR for mapping landcover change. This is unfortunate, as the multi-band interferometry and high resolution of GeoSAR make it the ideal tool for characterizing different vegetation types and detecting sub-canopy changes in forest structure over wide areas. However, data have been acquired from two other satellites with radar and optical sensors that in combination provide

useful information on the current and historical rates of deforestation and degradation in this landscape:

1) ALOS PALSAR is an L-band radar satellite sensor that collected data from Januray 2007 to March 2011. The cross-polarised long-wavelength radar data it provides gives information on vegetation structure and can thus differentiate intact, degraded and deforested land. Radar data has the additional advantage that it is unaffected by cloud cover. We have acquired and processed image mosaics across the whole Pacific coastal at a 50 m resolution from 2007 and 2010.
2) JERS-1 is the earlier version of the Japanese Space Agency, Earth Resources Satellite with synthetic aperture radar (SAR) sensor at L-band (1.25 GHz) and HH polarization, collecting data globally at the same frequency as ALOS but with only one channel and about similar spatial resolution. JERS-1 was launched in 1992 and collected operational data for 6 years and ended its mission in October 1998. We have used JERS-1 data collected as part of the global rainforest forest mapping (GRFM) project to combine with other data sets and to capture changes of forest cover before the year 2000.
3) The Landsat dataset is a unique record of the Earth's landcover derived from a set of 7 satellites that have provided consistent optical images from 1973 until the present day. Though Landsat imagery only provides information on the top of the canopy, its relatively high resolution (30 m from Landsat 4 onwards) allows easy discrimination of forest and non-forest classes, and some discrimination of degraded forest. Unfortunately due to the failure of Landsat 5 and a fault with Landsat 7, no useful data for these purposes has been available from 2012 onwards. Collating data is made more difficult by cloud cover, which is persistent in this region, and a paucity of data from the mid-1990's. We have succeeded in creating comparatively cloud-free mosaics from 1986, 1999 and 2011, and use these to provide a longer-term view of landcover change over the region.

III. Definitions

The primary focus of this report is the detection of *deforestation*, defined as a landcover change event where an area of land at least a hectare in size changes from forest to non-forest between time periods (GOFC-GOLD, 2012), and *degradation*, where trees are removed from a forest area that remains forest. In order to use either of those terms in a specific area, it is important to have a definition of forest itself. Forest is defined in Colombia as an area of wooded land:

- Greater than or equal to one hectare in extent
- With canopy cover greater than 30 %
- Containing trees greater than 5 m in height

Under the VCS and CCB standards it is possible for projects to define their own forest definition separate to the national definition, but we have no indication that this is likely to occur in this project, so we use this forest definition for the purpose of this report.

IV. Radar 2010 classification

The PALSAR 2010 data was classified in combination with layers from IDEAM to produce a highly accurate, 16-class classification for the year 2010. While this classification cannot be used to give the rate of deforestation and degradation, it can be used to produce an estimate of the area of previously deforested and degraded land in all the BIOREDD+ Project nodes, and the percentage of existing forest cover that is degraded or has been deforested. Details of the procedure involved in the production of this layer is described in Report 6.

In order to use this detailed layer for this purpose we need an 'intact forest' class that fitted the definition in III above, and thus we defined a new class, 'Intact forest', as the sum of the areas of 'Dense Forest', 'Open Forest' and 'Mangrove' classes. We then combined this intact forest class to the 'Deforested' and 'Degraded' classes.

The results are summarized in Tables 1 and 2.

Table 1 – Area of intact, degraded and deforested land in each BIOREDD+ area

Project node	BioREDD+ area	Area intact forest 2010 (ha)	Area deforested 2010 (ha)	Area degraded 2010 (ha)	Other land cover types 2010 (ha)	Total area (ha)
Uraba Darien	Apartadó Buenavista	12,294.4	91.7	0.0	6,451.7	18,837.8
Uraba Darien	Chicao	13,451.2	136.5	12.8	2,326.0	15,926.6
Uraba Darien	Chontadural Cañero	8,409.9	174.3	302.6	231.2	9,118.0
Uraba Darien	Jaikerazavi (Abibe Mutata)	29,691.7	3,117.4	1,581.2	928.8	35,319.2
Uraba Darien	La Madre	1,623.5	12.5	0.0	7,461.9	9,097.9
Uraba Darien	Los Ríos La Larga Y Tumaradó	8,378.0	212.2	1,393.8	100,177.8	110,161.8
Uraba Darien	Pedeguita Y Mancilla	5,934.0	34.5	531.5	43,112.0	49,612.0
Uraba Darien	Polines	1,627.5	108.5	144.8	683.2	2,564.1
Uraba Darien	Río Montaño	787.9	0.6	0.0	24,027.4	24,815.9
Uraba Darien	Vígia De Curvaradó Y Santa Rosa Limón	3,184.0	7.2	433.0	30,524.7	34,148.8
Uraba Darien	Yaberaradó (Abibe Chigorodó)	8,824.3	472.8	136.0	2,323.3	11,756.3
Uraba Darien	**Total**	**94,206.4**	**4,368.2**	**4,535.7**	**218,248.1**	**321,358.4**
Choco Sur	Bajo Grande	1,118.5	2.0	345.8	970.1	2,436.5
Choco Sur	Bellavista Y Unión Pitalito Río Siguiri Sua-Docampado	24,814.9	458.5	3,126.6	796.8	29,196.9
Choco Sur	La Costa - Concosta	36,763.0	7.6	7,626.6	25,055.1	69,452.4
Choco Sur	Mayor Del Cantón San Pablo "Acisanp"	32,625.5	515.4	2,020.5	1,477.7	36,639.1
Choco Sur	Ordo Siviru Aguaclara	2,454.4	0.0	48.6	0.0	2,503.0
Choco Sur	Pizarro	2,824.8	0.0	1,378.2	2,914.1	7,117.1
Choco Sur	Río Baudó Acaba	94,789.9	1,338.5	37,530.4	41,395.8	175,054.6
Choco Sur	Río Pepe	6,314.6	50.0	1,622.1	383.6	8,370.3
Choco Sur	Río Pilizá	11,067.0	0.0	1,284.1	5,969.3	18,320.4
Choco Sur	San Andrés Usaragá	7,288.9	0.0	2,336.7	2,853.0	12,478.6
Choco Sur	Santa Rosa De Ijua	6,806.7	0.0	806.3	136.2	7,749.3
Choco Sur	Sivirú	12,680.4	0.0	1,913.2	6,806.0	21,399.6
Choco Sur	**Total**	**239,548.6**	**2,372.1**	**60,039.2**	**88,757.8**	**390,717.7**
Buenaventura	Bahía Málaga -La Plata	6,120.6	47.8	19.3	1,707.1	7,894.8
Buenaventura	Río Cajambre	50,571.3	460.4	5,685.7	17,907.3	74,624.6
Buenaventura	Río Calima	45,763.2	1,853.2	2,683.7	16,891.2	67,191.3
Buenaventura	Río Yurumanguí	38,130.6	100.6	3,765.8	11,041.6	53,038.6
Buenaventura	**Total**	**140,585.7**	**2,462.1**	**12,154.5**	**47,547.1**	**202,749.4**
Tumaco	Acapa	19,400.8	451.6	9,017.3	54,295.6	83,165.3
Tumaco	Bajo Mira Y Frontera	423.8	0.8	3,986.3	43,093.4	47,504.2
Tumaco	**Total**	**19,824.6**	**452.4**	**13,003.6**	**97,388.9**	**130,669.6**

Table 2 – Percentage of intact, degraded and deforested land in each BIOREDD+ area

Project node	BioREDD+ area	Percentage intact forest 2010	Percentage deforested 2010	Percentage degraded 2010	Percentage other land cover 2010	Total area (ha)
Uraba Darien	Apartadó Buenavista	65.3%	0.5%	0.0%	34.2%	18,837.8
Uraba Darien	Chicao	84.5%	0.9%	0.1%	14.6%	15,926.6
Uraba Darien	Chontadural Cañero	92.2%	1.9%	3.3%	2.5%	9,118.0
Uraba Darien	Jaikerazavi (Abibe Mutata)	84.1%	8.8%	4.5%	2.6%	35,319.2
Uraba Darien	La Madre	17.8%	0.1%	0.0%	82.0%	9,097.9
Uraba Darien	Los Ríos La Larga Y Tumaradó	7.6%	0.2%	1.3%	90.9%	110,161.8
Uraba Darien	Pedeguita Y Mancilla	12.0%	0.1%	1.1%	86.9%	49,612.0
Uraba Darien	Polines	63.5%	4.2%	5.6%	26.6%	2,564.1
Uraba Darien	Río Montaño	3.2%	0.0%	0.0%	96.8%	24,815.9
Uraba Darien	Vígia De Curvaradó Y Santa Rosa Limón	9.3%	0.0%	1.3%	89.4%	34,148.8
Uraba Darien	Yaberaradó (Abibe Chigorodó)	75.1%	4.0%	1.2%	19.8%	11,756.3
Uraba Darien	**Total**	**29.3%**	**1.4%**	**1.4%**	**67.9%**	**321,358.4**
Choco Sur	Bajo Grande	45.9%	0.1%	14.2%	39.8%	2,436.5
Choco Sur	Bellavista Y Unión Pitalito Río Siguiri Sua-Docampado	85.0%	1.6%	10.7%	2.7%	29,196.9
Choco Sur	La Costa - Concosta	52.9%	0.0%	11.0%	36.1%	69,452.4
Choco Sur	Mayor Del Cantón San Pablo "Acisanp"	89.0%	1.4%	5.5%	4.0%	36,639.1
Choco Sur	Ordo Siviru Aguaclara	98.1%	0.0%	1.9%	0.0%	2,503.0
Choco Sur	Pizarro	39.7%	0.0%	19.4%	40.9%	7,117.1
Choco Sur	Río Baudó Acaba	54.1%	0.8%	21.4%	23.6%	175,054.6
Choco Sur	Río Pepe	75.4%	0.6%	19.4%	4.6%	8,370.3
Choco Sur	Río Pilizá	60.4%	0.0%	7.0%	32.6%	18,320.4
Choco Sur	San Andrés Usaragá	58.4%	0.0%	18.7%	22.9%	12,478.6
Choco Sur	Santa Rosa De Ijua	87.8%	0.0%	10.4%	1.8%	7,749.3
Choco Sur	Sivirú	59.3%	0.0%	8.9%	31.8%	21,399.6
Choco Sur	**Total**	**61.3%**	**0.6%**	**15.4%**	**22.7%**	**390,717.7**
Buenaventura	Bahía Málaga -La Plata	77.5%	0.6%	0.2%	21.6%	7,894.8
Buenaventura	Río Cajambre	67.8%	0.6%	7.6%	24.0%	74,624.6
Buenaventura	Río Calima	68.1%	2.8%	4.0%	25.1%	67,191.3
Buenaventura	Río Yurumanguí	71.9%	0.2%	7.1%	20.8%	53,038.6
Buenaventura	**Total**	**69.3%**	**1.2%**	**6.0%**	**23.5%**	**202,749.4**
Tumaco	Acapa	23.3%	0.5%	10.8%	65.3%	83,165.3
Tumaco	Bajo Mira Y Frontera	0.9%	0.0%	8.4%	90.7%	47,504.2
Tumaco	**Total**	**15.2%**	**0.3%**	**10.0%**	**74.5%**	**130,669.6**

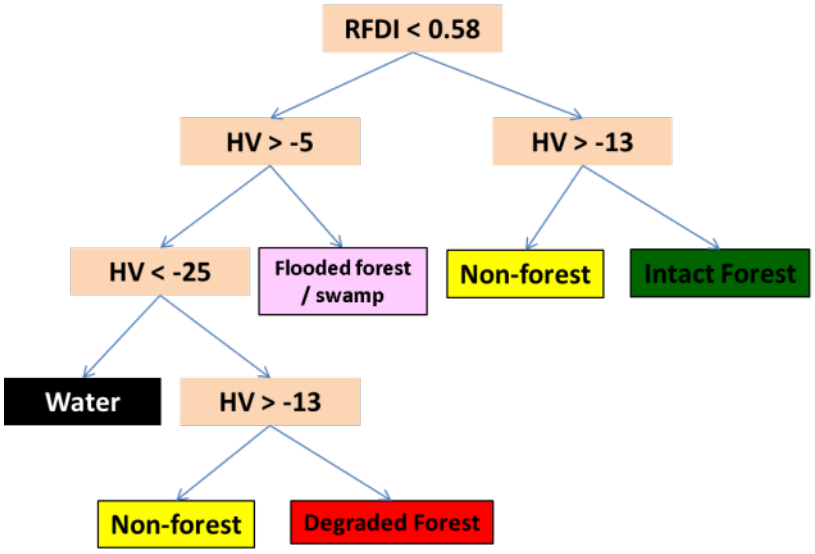
V. Radar change detection methodology

The results presented in Section IV give an accurate picture of the state of land in 2010, the last year for which we have PALSAR data. However, we do not know from this single 2010 classification the date at which the observed deforested and degraded land was cleared. We therefore used a different methodology to investigate the rates of change, which are important in setting up baseline deforestation and degradation rates.

ALOS PALSAR mosaics were provided by JAXA at a 50 m resolution for 2007 and 2010, and were georeferenced and terrain corrected to a high level of accuracy. As the same sensor and processing chain was used for both mosaics, the two images overlaid precisely. There are some issues with terrain artifacts with these layers over the very steep slopes of the Andes, but no terrain effects are apparent within the BioREDD+ clusters, which are in general in flat or moderately hilly areas.

Two existing classifications with large numbers of classes – the classification described in Section IV above and the Corine Landcover Map produced by IDEAM – were used to provide baseline information on the location of intact, degraded and flooded forest in the area. An attempt was then made to replicate these classes using the ALOS PALSAR mosaic using a consistent, replicable methodology, so there could be confidence that the same vegetation structure would be given the same class in both time periods.

In order to achieve this a Decision Tree approach was used to separate 5 classes, that could be guaranteed to produce the same results from both mosaics: intact forest, degraded forest, swamp forest and water. These were differentiated using a combination of HH and HV (same- and cross- polarized) radar backscatter and their ratioed difference, the Radar Forest Degradation Index (RFDI, Saatchi & Mitchard, in review). HV was used to separate forest from non-forest with a threshold of -13 dB, RFDI to differentiate degraded from intact forest with a threshold of 0.58, and HH was used to differentiate swamp forest from degraded forest, with swamp having HH above -5 dB. The Decision Tree is shown below:



The same Decision Tree was applied to the 2007 and 2010 PALSAR mosaics, and the resulting landcover maps compared to obtain the rates of deforestation and degradation for the project nodes and individual project areas.

Attempts were also made to classify a mosaic of JERS-1 data from 1995. Unfortunately however due to uncorrected terrain issues, the lack of cross-polarised information (JERS-1 was HH only), and calibration problems leading to seams in the mosaics, it was not possible to produce a similar map from the JERS-1 data to a sufficient degree of accuracy. Attempts were made to produce a simpler, forest/non-forest map from the same data, which could have allowed a rate of deforestation to be deduced. However, the terrain and geolocation problems made even this impossible at a sufficient degree of accuracy: verification with Landsat and other data sources suggested the majority of changes detected related to artifacts in the JERS-1 data, rather than true deforestation. We therefore were only able to produce change detection results for PALSAR data from 2007 and 2010.

V. ALOS PALSAR results – deforestation and degradation 2007-2010

The resulting maps show areas of intact forest in 2010, other natural vegetation in 2010, agriculture in 2010, and areas that suffered deforestation or degradation between 2007 and 2010. Deforestation and degradation rates were in general small but significant, and at least some degradation was found to have occurred over the period in all BIOREDD+ regions. The results are shown in Figures 1-5, the absolutely areas of deforestation and degradation given in Table 3, and deforestation and degradation rates given in Table 4.

Two types of rates are given in Table 4 – in one the area of deforestation is divided by the total area of the region to give a percentage rate of deforestation and degradation per years; in the other the area of deforestation and degradation is divided by the area of intact forest presumed to be present in 2007 (calculated by summing the area of intact forest in 2010 with the area of land deforested and degraded between 2007 and 2010). For regions with a high forest cover the second rate is more appropriate, and is what would be required under most VCS methodologies for the calculation of baseline rates; however in areas with low intact forest cover, due to the prevalence of other non-forest vegetation types, e.g. the Tumaco region, the former calculation may provide a more accurate indication of the rate of processes occurring on the ground.

Table 3 – Area deforested from 2007 - 2010

Project node	BioREDD+ area	Total area of polygon (ha)	Area intact forest 2010 (ha)	Area deforested from 2007 – 2010 (ha)	Area degraded from 2007-2010 (ha)
Uraba Darien	Apartadó Buenavista	18,837.8	12,294.4	2.0	319.0
Uraba Darien	Chicao	15,926.6	13,451.2	0.0	221.1
Uraba Darien	Chontadural Cañero	9,118.0	8,409.9	4.9	79.1
Uraba Darien	Jaikerazavi (Abibe Mutata)	35,319.2	29,691.7	150.6	1,319.5
Uraba Darien	La Madre	9,097.9	1,623.5	0.0	558.7
Uraba Darien	Los Ríos La Larga Y Tumaradó	110,161.8	8,378.0	843.8	2,784.4
Uraba Darien	Pedeguita Y Mancilla	49,612.0	5,934.0	491.2	1,101.9
Uraba Darien	Polines	2,564.1	1,627.5	58.0	165.0
Uraba Darien	Río Montaño	24,815.9	787.9	0.0	368.9
Uraba Darien	Vígia De Curvaradó Y Santa Rosa Limón	34,148.8	3,184.0	46.6	381.8
Uraba Darien	Yaberaradó (Abibe Chigorodó)	11,756.3	8,824.3	76.2	418.9
Uraba Darien	**Total**	**321,358.4**	**94,206.4**	**1,673.3**	**7,718.4**
Choco Sur	Bajo Grande	2,436.5	1,118.5	2.8	7.9
Choco Sur	Bellavista Y Unión Pitalito Río Siguiri Sua-Docampado	29,196.9	24,814.9	1.8	270.3
Choco Sur	La Costa - Concosta	69,452.4	36,763.0	270.2	500.3
Choco Sur	Mayor Del Cantón San Pablo "Acisanp"	36,639.1	32,625.5	418.5	255.4
Choco Sur	Ordo Siviru Aguaclara	2,503.0	2,454.4	0.0	0.0
Choco Sur	Pizarro	7,117.1	2,824.8	34.3	18.4
Choco Sur	Río Baudó Acaba	175,054.6	94,789.9	580.8	1,950.5
Choco Sur	Río Pepe	8,370.3	6,314.6	9.5	50.4
Choco Sur	Río Pilizá	18,320.4	11,067.0	72.2	13.4
Choco Sur	San Andrés Usaragá	12,478.6	7,288.9	30.1	5.7
Choco Sur	Santa Rosa De Ijua	7,749.3	6,806.7	6.4	5.6
Choco Sur	Sivirú	21,399.6	12,680.4	130.4	28.6
Choco Sur	**Total**	**390,717.7**	**239,548.6**	**1,557.0**	**3,106.5**
Buenaventura	Bahía Málaga -La Plata	7,894.8	6,120.6	46.2	371.3
Buenaventura	Río Cajambre	74,624.6	50,571.3	147.8	850.8
Buenaventura	Río Calima	67,191.3	45,763.2	317.9	1,463.2
Buenaventura	Río Yurumanguí	53,038.6	38,130.6	144.6	296.9
Buenaventura	**Total**	**202,749.4**	**140,585.7**	656.5	2,982.2
Tumaco	Acapa	83,165.3	19,400.8	335.6	2,990.4
Tumaco	Bajo Mira Y Frontera	47,504.2	423.8	1,345.6	1,082.1
Tumaco	**Total**	**130,669.6**	**19,824.6**	**1,681.1**	**4,072.5**

Table 4 – Deforestation rates from 2007 - 2010

Project node	BioREDD+ area	Deforestation rate, against total area (%/yr)	Degradation against total area (%/yr)	Deforestation rate, against forest area only (%/yr)	Degradation rate, against forest area only (%/yr)
Uraba Darien	Apartadó Buenavista	0.00%	0.56%	0.01%	0.84%
Uraba Darien	Chicao	0.00%	0.46%	0.00%	0.54%
Uraba Darien	Chontadural Cañero	0.02%	0.29%	0.02%	0.31%
Uraba Darien	Jaikerazavi (Abibe Mutata)	0.14%	1.25%	0.16%	1.41%
Uraba Darien	La Madre	0.00%	2.05%	0.00%	8.53%
Uraba Darien	Los Ríos La Larga Y Tumaradó	0.26%	0.84%	2.34%	7.73%
Uraba Darien	Pedeguita Y Mancilla	0.33%	0.74%	2.18%	4.88%
Uraba Darien	Polines	0.75%	2.14%	1.05%	2.97%
Uraba Darien	Río Montaño	0.00%	0.50%	0.00%	10.63%
Uraba Darien	Vígia De Curvaradó Y Santa Rosa Limón	0.05%	0.37%	0.43%	3.52%
Uraba Darien	Yaberaradó (Abibe Chigorodó)	0.22%	1.19%	0.27%	1.50%
Uraba Darien	**Total**	**0.17%**	**0.80%**	**0.54%**	**2.48%**
Choco Sur	Bajo Grande	0.04%	0.11%	0.08%	0.23%
Choco Sur	Bellavista Y Unión Pitalito Río Siguiri Sua-Docampado	0.00%	0.31%	0.00%	0.36%
Choco Sur	La Costa - Concosta	0.13%	0.24%	0.24%	0.44%
Choco Sur	Mayor Del Cantón San Pablo "Acisanp"	0.38%	0.23%	0.42%	0.26%
Choco Sur	Ordo Siviru Aguaclara	0.00%	0.00%	0.00%	0.00%
Choco Sur	Pizarro	0.16%	0.09%	0.40%	0.21%
Choco Sur	Río Baudó Acaba	0.11%	0.37%	0.20%	0.67%
Choco Sur	Río Pepe	0.04%	0.20%	0.05%	0.26%
Choco Sur	Río Pilizá	0.13%	0.02%	0.22%	0.04%
Choco Sur	San Andrés Usaragá	0.08%	0.02%	0.14%	0.03%
Choco Sur	Santa Rosa De Ijua	0.03%	0.02%	0.03%	0.03%
Choco Sur	Sivirú	0.20%	0.04%	0.34%	0.07%
Choco Sur	**Total**	**0.13%**	**0.27%**	**0.21%**	**0.42%**
Buenaventura	Bahía Málaga -La Plata	0.19%	1.57%	0.24%	1.89%
Buenaventura	Río Cajambre	0.07%	0.38%	0.10%	0.55%
Buenaventura	Río Calima	0.16%	0.73%	0.22%	1.03%
Buenaventura	Río Yurumanguí	0.09%	0.19%	0.12%	0.26%
Buenaventura	**Total**	**0.11%**	**0.49%**	**0.15%**	**0.69%**
Tumaco	Acapa	0.13%	1.20%	0.49%	4.39%
Tumaco	Bajo Mira Y Frontera	0.94%	0.76%	15.73%	12.65%
Tumaco	**Total**	**0.43%**	**1.04%**	**2.19%**	**5.31%**

Fig. 1 Landcover for the whole Pacific Coast of Colombia, based on ALOS PALSAR data, showing intact forest cover in 2010 and overlaid with areas of deforestation and degradation from 2007-2010.

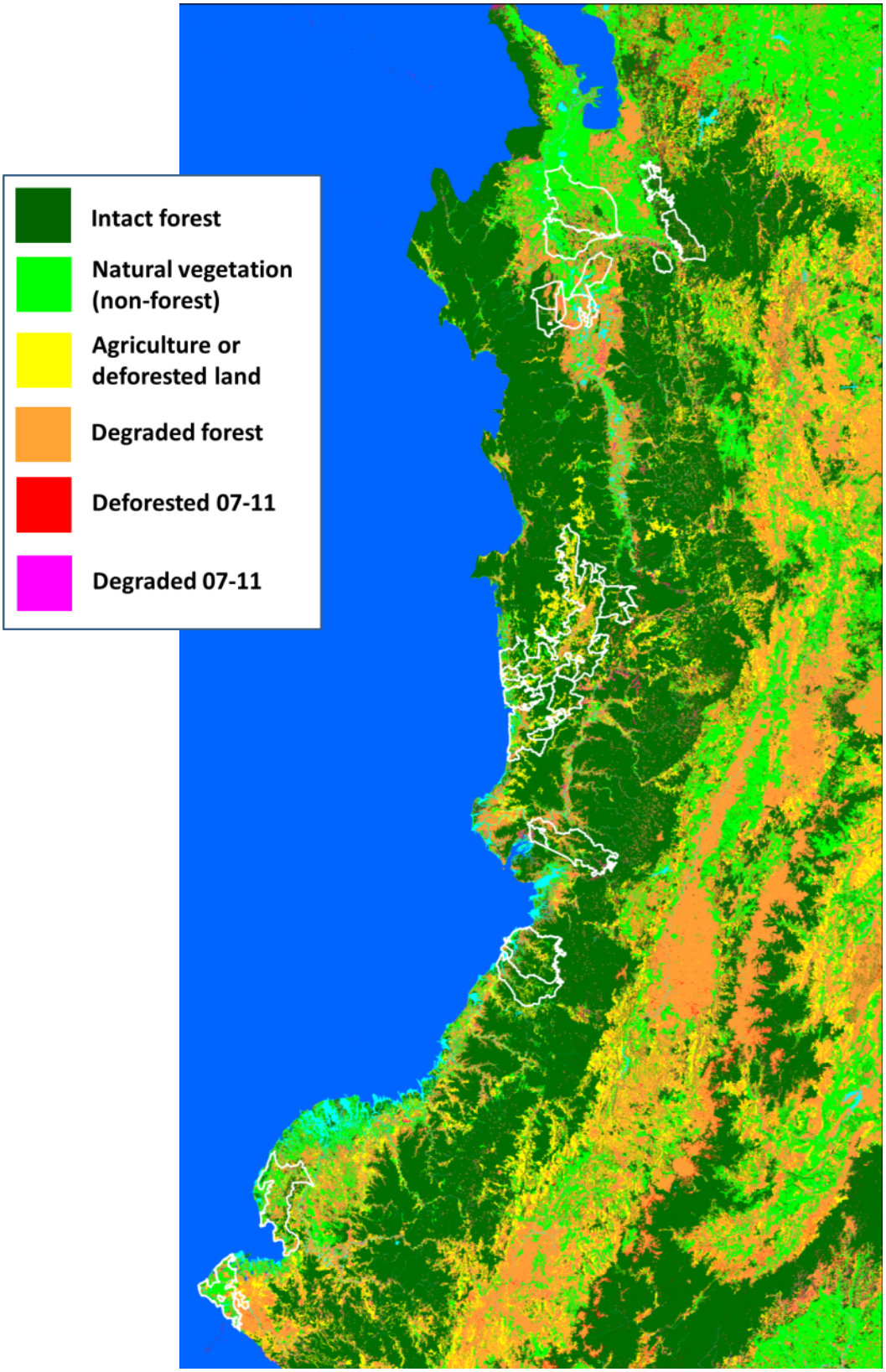


Fig. 2 Landcover for the Darién-Urabá region, based on ALOS PALSAR data, showing intact forest cover in 2010 and overlaid with areas of deforestation and degradation from 2007-2010.

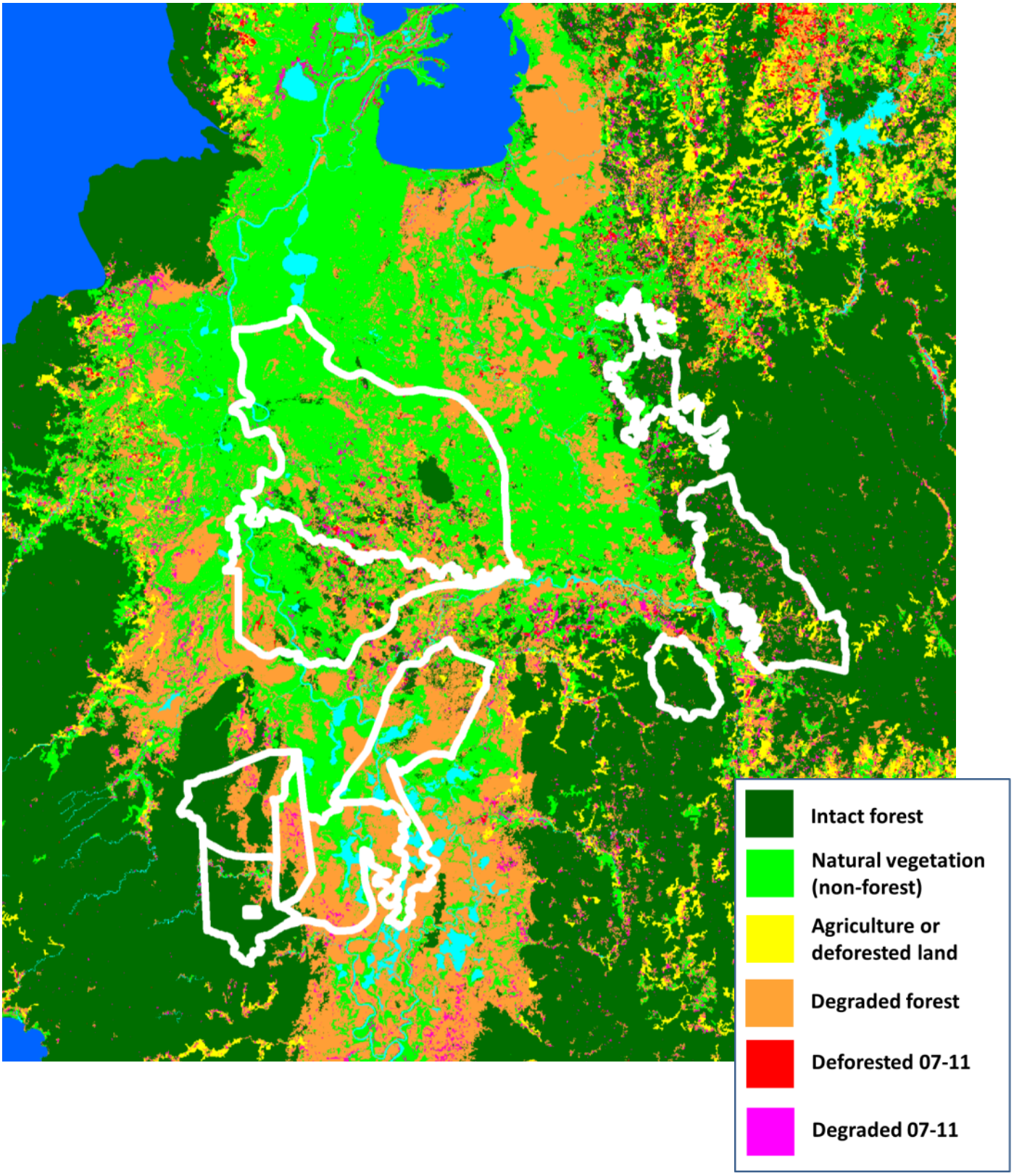


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Fig. 3 Landcover for the Choco Sur region, based on ALOS PALSAR data, showing intact forest cover in 2010 and overlaid with areas of deforestation and degradation from 2007-2010.

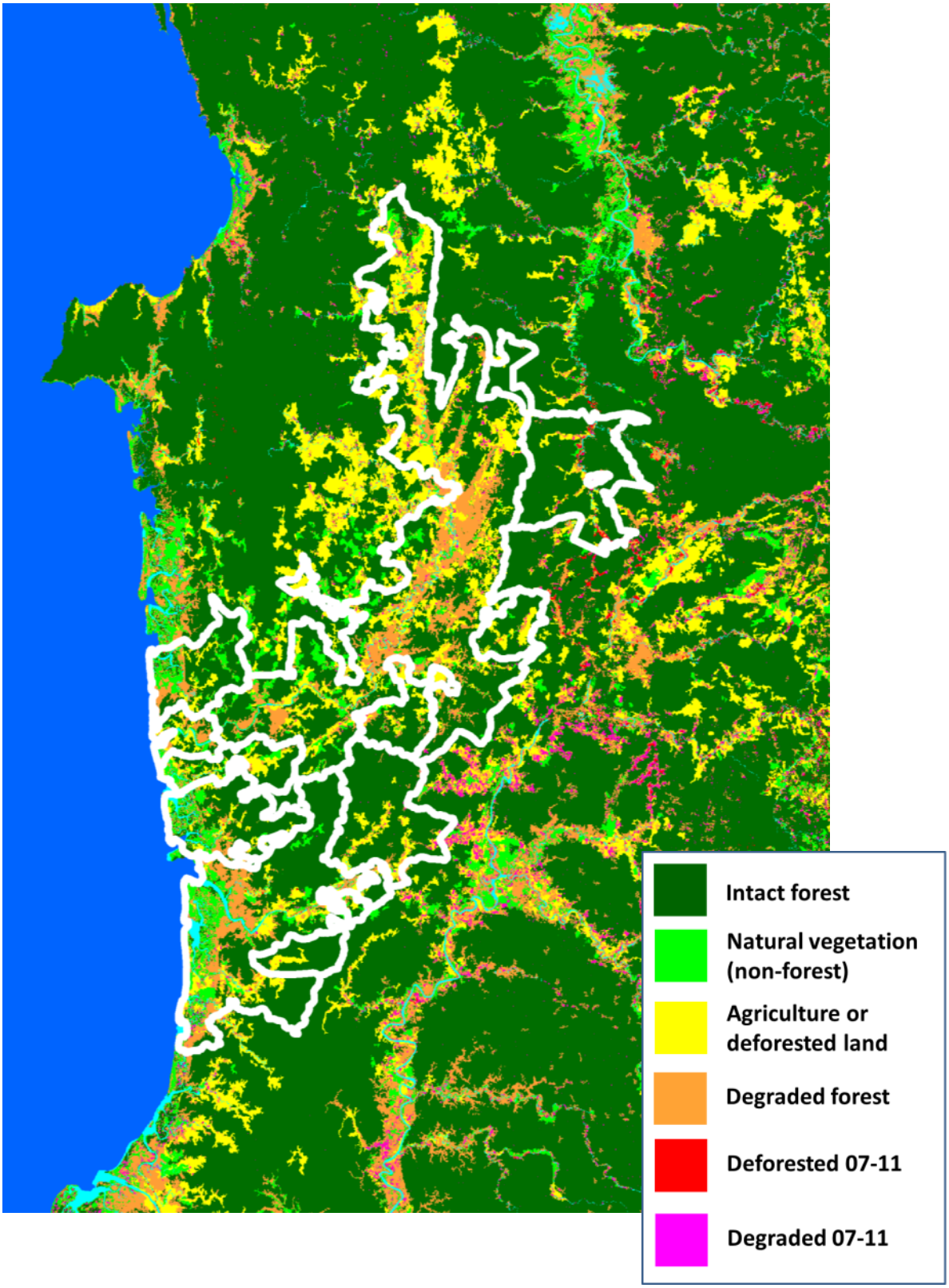


Fig 4. Landcover for the Buenaventura region, based on ALOS PALSAR data, showing intact forest cover in 2010 and overlaid with areas of deforestation and degradation from 2007-2010.

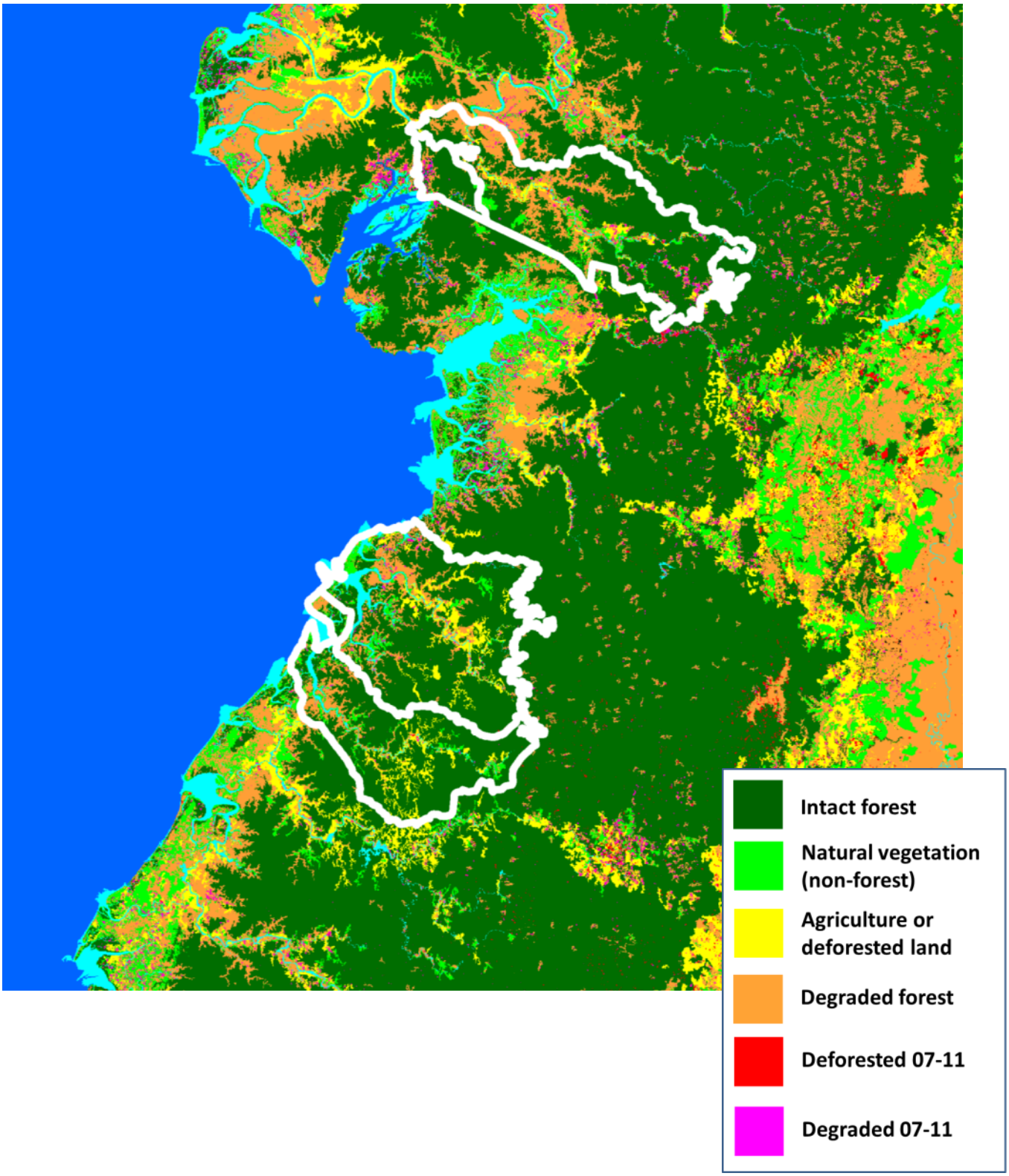
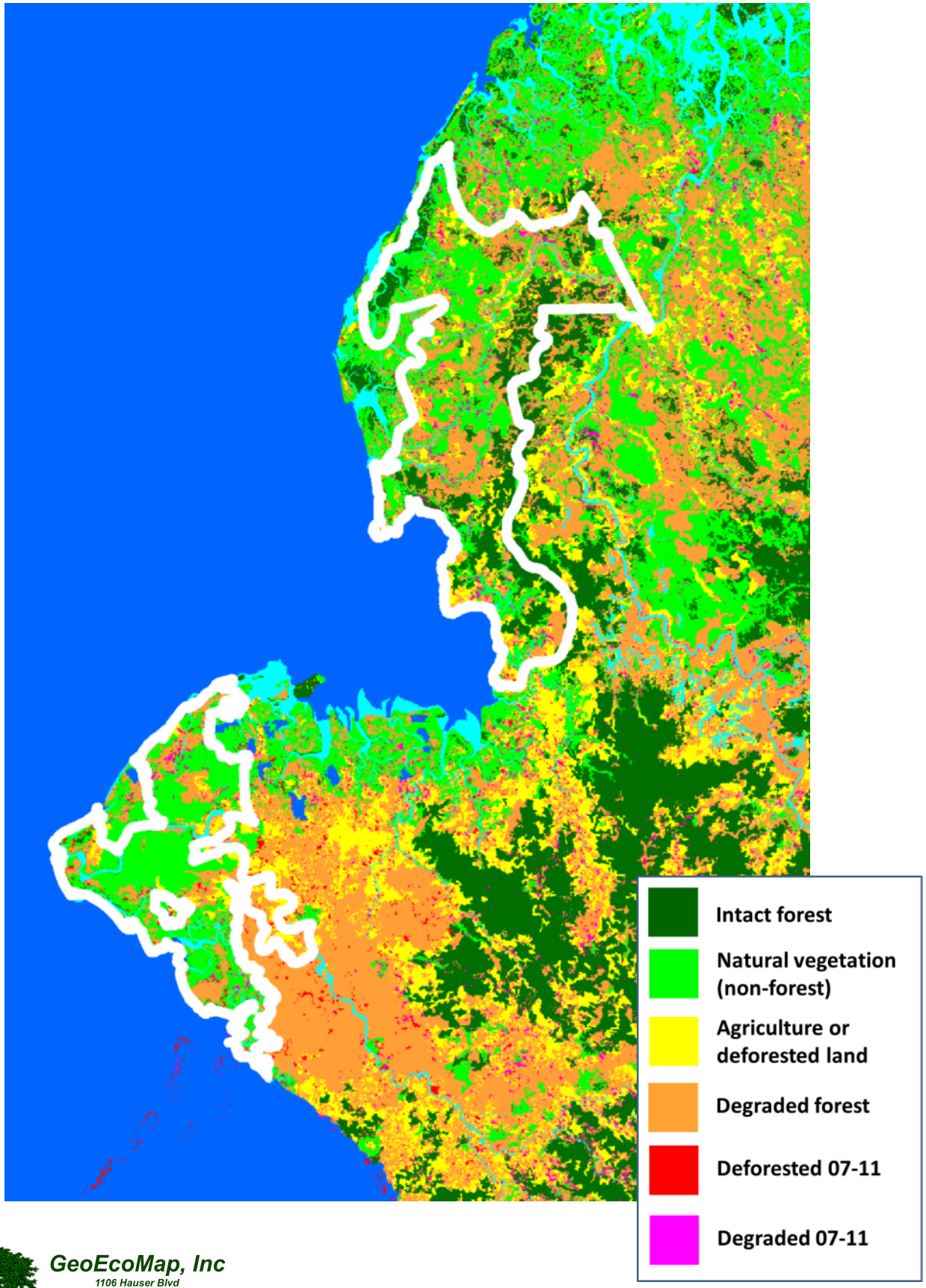


Fig. 5 Landcover for the Tumaco region, based on ALOS PALSAR data, showing intact forest cover in 2010 and overlaid with areas of deforestation and degradation from 2007-2010.



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VI. Landsat methodology

In total 84 scenes from Landsat 4, 5 and 7 were downloaded from the United States Geological Survey (USGS), covering the period 1984-2011. Landsat 7 scenes were only downloaded from 1999-2003, as after that point Landsat 7 developed a fault resulting in large data gaps in the resulting scenes, making them unsuitable for this type of analysis; fortunately Landsat 5 continued operating until 2012, providing continuous data.

The scenes were pre-processed to convert the raw digital number data into ground reflectance values and correct for differing atmospheric conditions. A large number of scenes were then rejected due to excessive cloud-cover or haze, and the remaining scenes combined and mosaicked to produce mosaics with the least cloud possible. Mosaics were made for the three years with the least cloud: 1986, 1999 and 2011; in order to fill in some cloudy areas however scenes from 1985, 1987 were used to supplement the 2086 mosaic, from 2000 for the 1999 mosaic, and from 2010 for the 2011 mosaic. The mosaics are still given as a single year as the vast majority of pixels come from that year and the comparisons are being made over a time-period greater than a decade. This is thought unlikely to significantly affect the change results reported here.

The mosaics were classified into 5 classes: intact high-biomass forest, secondary/degraded/lower biomass forest, non-forest, cloud, and cloud shadow. These classes were chosen based on detailed visual analysis of the imagery and comparisons to the Corine Ecosystem Map (IDEAM) and Google Earth Imagery, to decide which classes were easily and consistently distinguishable using Landsat. In particular it should be noted here that the “Degraded/Secondary forest” class in Landsat differs from the “Degraded Forest” class described above for PALSAR – as Landsat cannot penetrate the canopy fewer classes can be distinguished, and it is likely that this class in Landsat includes undisturbed but lower biomass forest, such as flooded vegetation or dwarf forests. The intact forest and non-forest classes seen by Landsat and PALSAR should be readily comparable.

The classifications were performed using a Support Vector Machine classifier, using at least fifteen training regions chosen by eye for each class. The classifications all had user accuracies in excess of 97 % when tested against the input data, which is well above the 90 % level normally used to test the acceptability of a classification to be used for a land-use change analysis (GOFC-GOLD, 2012).

Each mosaic had cloud cover over 30 % of its area, and thus normal comparisons in terms of total area, as performed for PALSAR, are not appropriate here. Instead only areas which are cloud free in pairs of mosaics can be compared. The following analyses therefore refers to two pairs of images: 1986-1999, and 1999-2011. A mask was created for any pixel that was cloud or cloud shadow in either image, in order to remove effects of haze a 2 pixel buffer was applied to this mask, and the mask was then used over both images. This provided two sets of comparison images that could be used to calculate the deforestation rate from 1986-1999, and 1999-2011.

VII. Landsat results

Despite cloud-cover limitations, the Landsat data is able to provide a long-term view of rate of deforestation.

The results are summarized in Table 5, and displayed in Figures 6-10. The raw data, including the areas of secondary and primary forest, is given in supplementary table 1.

Table 5 – rates of deforestation from the Landsat analysis

Project node	BioREDD+ area	% of imagery cloud free in 1986 and 1999	Deforestation rate, 1986 to 1999	% of imagery cloud free in 1999 and 2011	Deforestation rate, 1999 to 2011
Uraba Darien	Apartadó Buenavista	*24.8%*	0.32%	*22.8%*	0.08%
Uraba Darien	Chicao	*8.7%*	0.43%	*9.7%*	0.01%
Uraba Darien	Chontadural Cañero	*0.0%*	n/a	*33.4%*	0.14%
Uraba Darien	Jaikerazavi (Abibe Mutata)	*0.3%*	0.23%	*26.7%*	0.20%
Uraba Darien	La Madre	*17.5%*	0.42%	*7.5%*	0.16%
Uraba Darien	Los Ríos La Larga Y Tumaradó	*16.7%*	0.56%	*22.7%*	2.80%
Uraba Darien	Pedeguita Y Mancilla	*10.7%*	0.52%	*22.4%*	1.97%
Uraba Darien	Polines	*13.6%*	0.14%	*20.1%*	0.12%
Uraba Darien	Río Montaño	*11.6%*	0.55%	*7.4%*	1.82%
Uraba Darien	Vígia De Curvaradó Y Santa Rosa Limón	*23.3%*	0.29%	*22.0%*	1.16%
Uraba Darien	Yaberaradó (Abibe Chigorodó)	*21.8%*	0.19%	*23.3%*	0.30%
Uraba Darien	**Total**	***14.1%***	**0.45%**	***21.1%***	**1.59%**
Choco Sur	Bajo Grande	*5.5%*	0.08%	*81.9%*	0.06%
Choco Sur	Bellavista Y Unión Pitalito Río Siguiri Sua-Docampado	*12.3%*	0.14%	*61.2%*	0.06%
Choco Sur	La Costa - Concosta	*29.5%*	0.14%	*74.6%*	0.13%
Choco Sur	Mayor Del Cantón San Pablo "Acisanp"	*21.2%*	0.58%	*30.9%*	0.19%
Choco Sur	Ordo Siviru Aguaclara	*24.3%*	0.02%	*89.5%*	0.02%
Choco Sur	Pizarro	*35.0%*	0.08%	*74.1%*	0.07%
Choco Sur	Río Baudó Acaba	*23.8%*	0.14%	*52.4%*	0.12%
Choco Sur	Río Pepe	*29.7%*	0.11%	*31.7%*	0.14%
Choco Sur	Río Pilizá	*26.1%*	0.14%	*57.5%*	0.05%
Choco Sur	San Andrés Usaragá	*34.2%*	0.08%	*89.1%*	0.06%
Choco Sur	Santa Rosa De Ijua	*40.9%*	0.15%	*83.8%*	0.02%
Choco Sur	Sivirú	*27.4%*	0.07%	*78.9%*	0.18%
Choco Sur	**Total**	***24.9%***	**0.16%**	***58.9%***	**0.12%**
Buenaventura	Bahía Málaga -La Plata	*66.5%*	0.07%	*91.1%*	0.05%
Buenaventura	Río Cajambre	*48.1%*	0.03%	*67.3%*	0.22%
Buenaventura	Río Calima	*79.9%*	0.04%	*32.1%*	0.36%
Buenaventura	Río Yurumanguí	*53.0%*	0.07%	*72.0%*	0.04%
Buenaventura	**Total**	***60.6%***	**0.05%**	***57.8%***	**0.18%**
Tumaco	Acapa	*22.7%*	0.14%	*30.5%*	0.11%
Tumaco	Bajo Mira Y Frontera	*38.0%*	0.52%	*31.8%*	0.71%
Tumaco	**Total**	***28.2%***	**0.32%**	***31.0%***	**0.33%**

Fig. 6 Landcover change in (a) 1986-1999 and (b) 1999-2011 over the Pacific coast of Colombia, based on Landsat data.

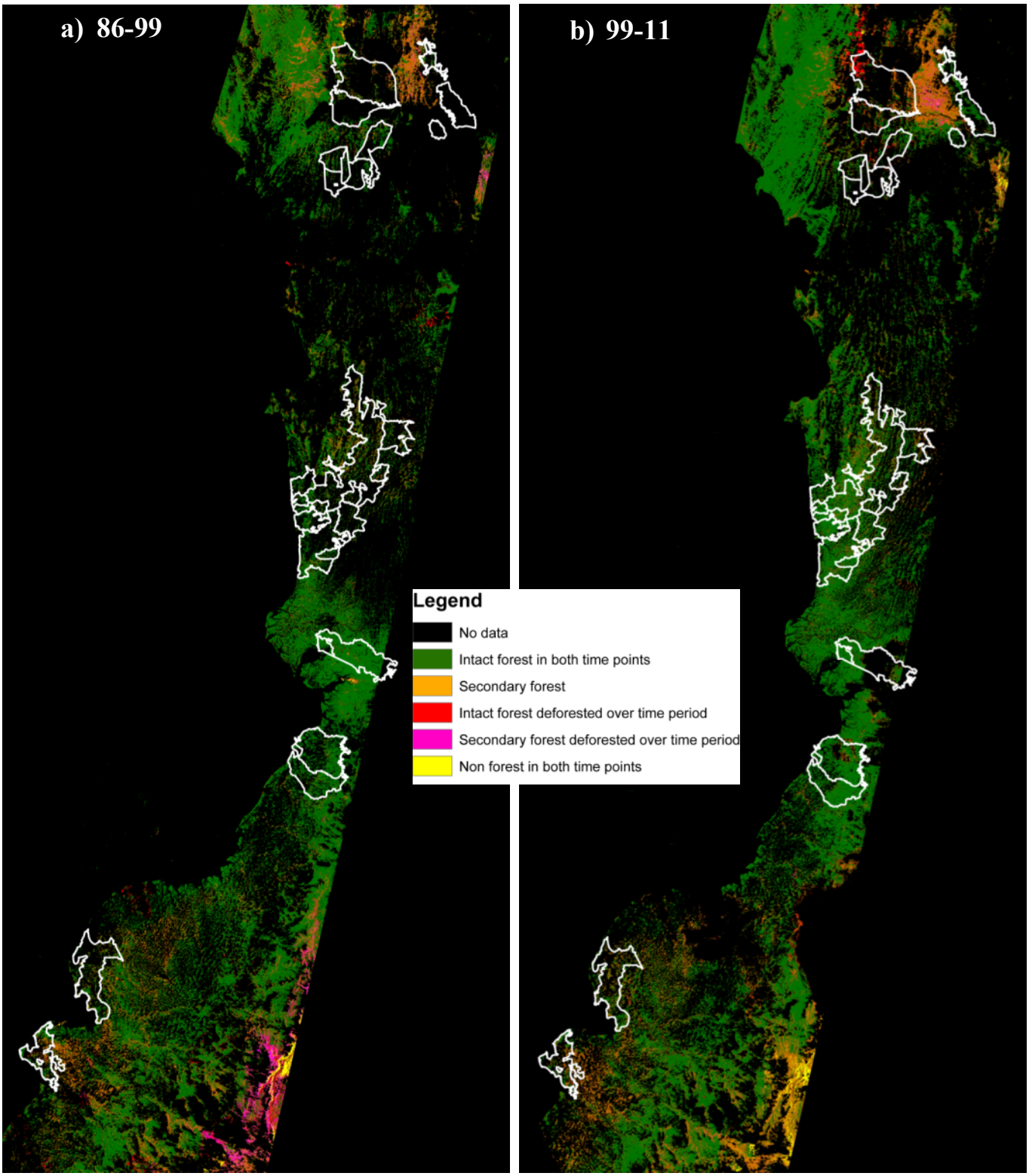
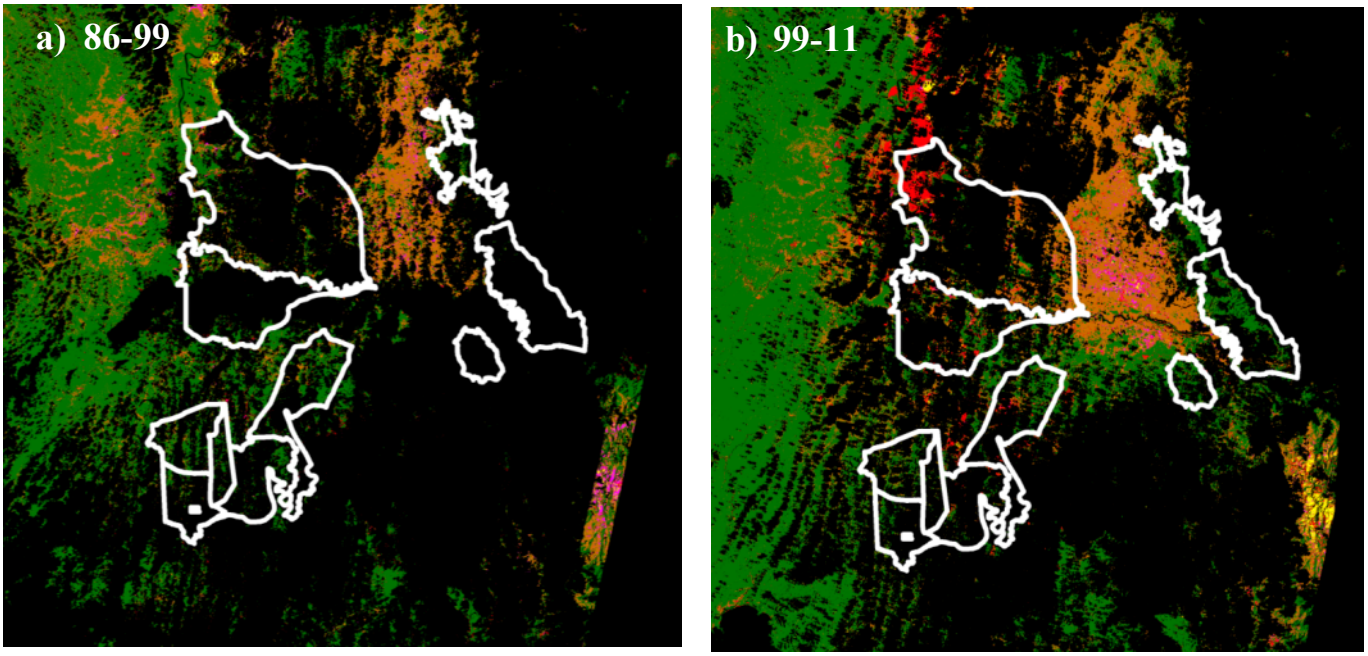


Fig. 7 Landcover change in (a) 1986-1999 and (b) 1999-2011 in the Darién-Urabá region, based on Landsat data.



Legend

- No data
- Intact forest in both time points
- Secondary forest
- Intact forest deforested over time period
- Secondary forest deforested over time period
- Non forest in both time points

Fig. 8 Landcover change in (a) 1986-1999 and (b) 1999-2011 in the Choco Sur and Buenaventura regions, based on Landsat data.

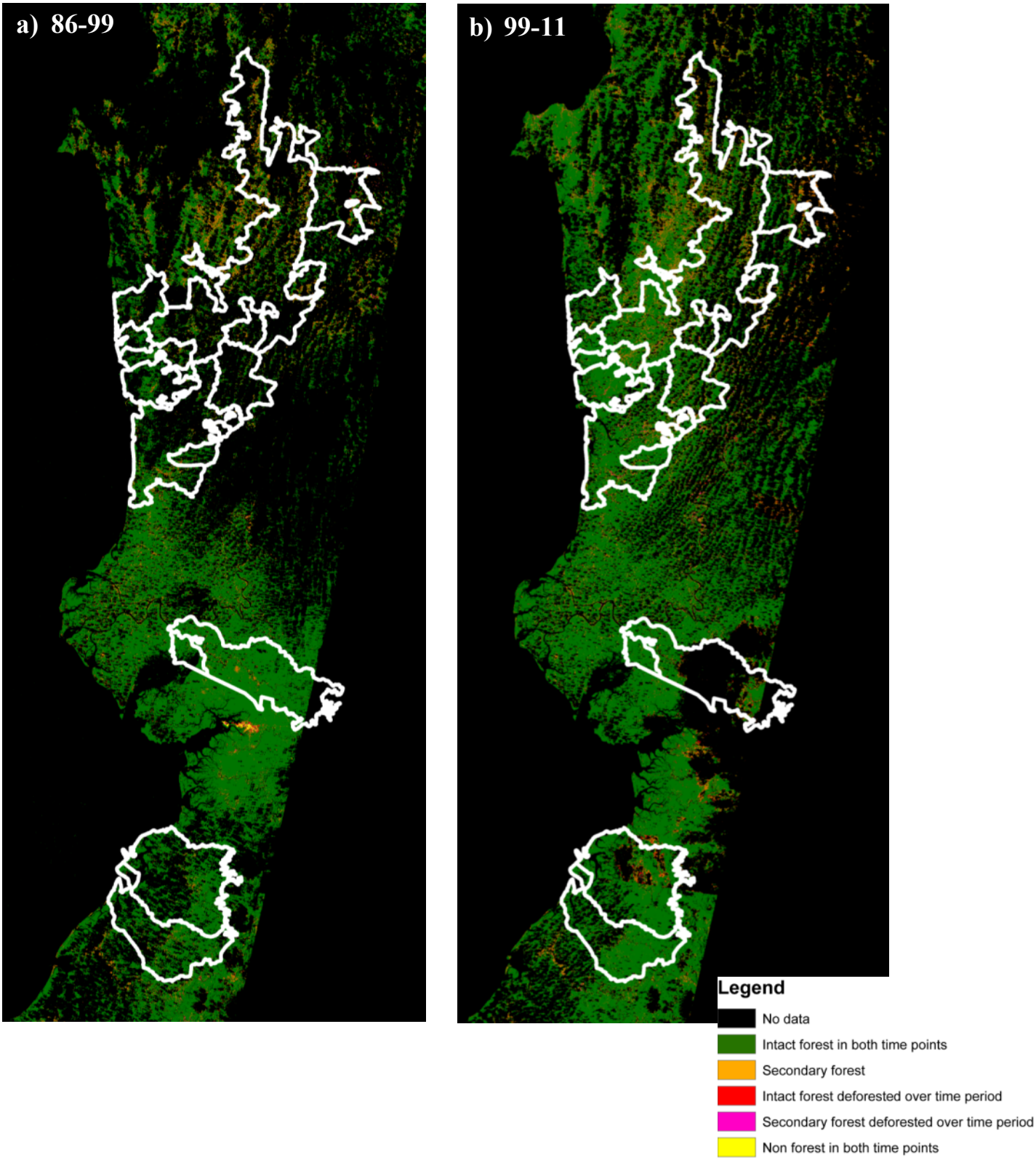
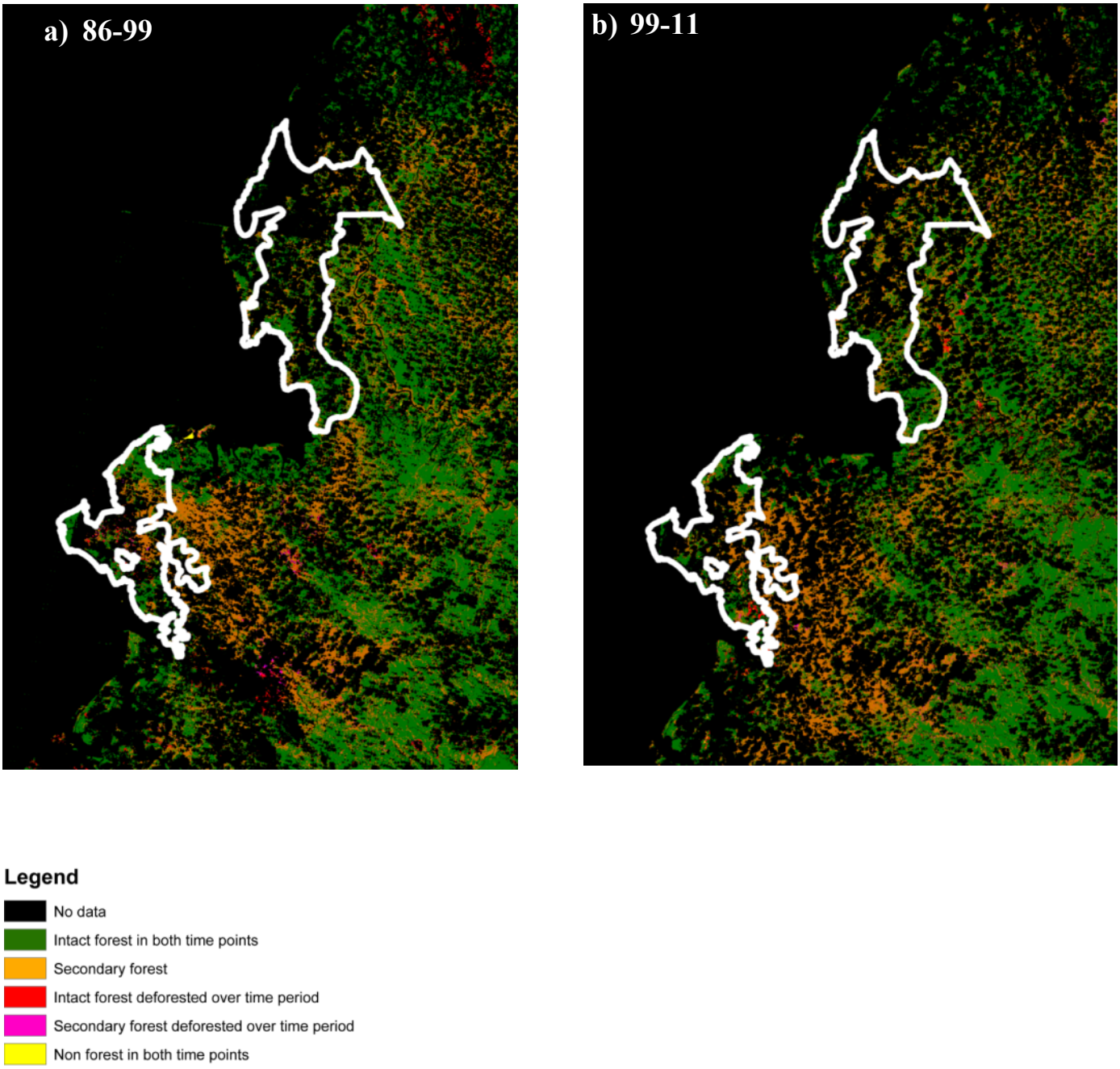


Fig. 9 Landcover change in (a) 1986-1999 and (b) 1999-2011 in the Tumaco region, based on Landsat data.



VIII. Sources of Uncertainty

Image classification is the key methodology used in detecting changes of the forest cover associated with deforestation and degradation in the study area. All classification approaches are based on the state of the art methodologies and have internal tests for accuracy and precision. In the process of detecting changes, we eliminated all potential changes that may have either large errors and low confidence intervals. The key source of error in our analysis is due to the extensive cloud cover along the Pacific coast of Colombia. However, as results reported based on the rate of change and aggregated over each project site, we expect the overall estimates are representative of the changes of forest cover in the region. Any potential bias may be due to the underestimation of the forest cover change primarily due to clouds partially blocking the area of forests changed in the past. However, in general there are several sources of uncertainty in the products that can be readily improved by acquiring new data sets. These include:

1. Cloud cover in Landsat time series data. The clouds will block the classification of a percentage of forest cover and the average percentage of change may be an underestimation in areas that has a large cloud cover. However, as the rate has been calculated over areas that are cloud free and not over the entire project areas, the average percentage of change is relatively representative of the BioREDD project polygons.
2. The overall land cover classification as part of the deliverable 6 provides the most up-to-date estimate of forest cover for the region. Land cover is based on the radar imagery and therefore has no impact of cloud cover. Although, there are errors regarding the classification accuracy of radar imagery, the overall area of deforested and degraded for BioREDD regions up to the year 2010 has no specific bias and when aggregated with Landsat time series analysis will allow us to have a more realistic estimate of deforested area and rate of change.
3. Deforestation in the region is often small scale and does not include large areas of clear cutting. Most areas used for pasture and crops along the coast are small in size and may only include few Landsat size pixels. Most of these changes are along rivers that are often mixed with naturally low vegetated areas along the rivers. Deforestation along the roads are also small and do not cover large areas and although detectable by Landsat and to some extent by radar imagery, there maybe errors associated with quantifying the extent of deforestation. There are some chances of mixing the deforested areas with degraded regions. We may improve the area and rate of deforestation checking the availability of high-resolution imagery over the study

area. If the project allows, we may purchase some RapidEye or WorldView sample imagery to enhance the resolution and accuracy of the products.

4. There are several sources of errors in accurately separating the degraded and secondary forests or areas under tree plantations. In general, we are not able at this point to accurately separate the areas of forest degradation from secondary forests or any potential tree plantations in Landsat imagery. This is primarily due to the spectral confusion for separating the land use classes and lack of multi-temporal cloud free data to classify the forests from temporal changes. We expect to improve these errors after the field observations and future acquisitions of cloud free satellite data.
5. Other sources of errors in land cover classification and change detections may be due to the effect of topography, pixel size, and unknown vegetation covers along the coast that may cause confusion between natural low density vegetation and deforested or degraded areas.

IX. Conclusions

From a combination of both analyses, it is clear that there is a significant level of deforestation occurring in all four BioREDD+ clusters. There is significant variation in this rate of deforestation between regions, but in general it ranges between about 0.1 % and 2 % per year, depending on the area and method compared. The PALSAR rate is the most trustworthy, as the analysis was not impacted by cloud cover, and swamp vegetation could be more reliably excluded from degraded or deforested land. However, for the long view the Landsat data provides a reasonable estimate of trends. The Landsat analysis suggests that the rate of deforestation has increased over the two periods compared, that is to say that in the majority of the region the rate detected in 1999 and2011 was higher than that between 1986 and 1999.

The rate of creation of new degraded forest ("degradation rate") could be estimated from the ALOS PALSAR data for 2007-2010; this is in general higher than the deforestation rate. However, it should be stressed that this underestimates the impact of degradation, for two reasons:

1) PALSAR will not see the initial stages of degradation, involving the removal of a few trees, thus this represents the rate of detectable degradation, involving relatively severe removal of biomass

2) A degradation rate only includes the area of land that was intact forest in time 1, and is degraded by time 2. However, biomass will continue to be lost from existing degraded forest.

The area of degraded land from the 2010 classification, a little higher than the degradation rate, should be used in addition to the degradation rate to assess the degradation baseline. A more accurate estimation of the degradation rate will be possible following further analyses: the LiDAR campaign will give a snapshot of the true extent of degraded forest and its biomass stocks at different levels of degradation. To address problem (2) at this time point, it should be assumed given the known land-use history of this region that there will be an ongoing net reduction in biomass in the total area of degraded forests reported in the PALSAR analysis – though some of this forest will be regrowing, the net change is likely to be negative.