TE WHARE WĀNANGA O TE ŪPOKO O TE IKA A MĀUI

VICTORIA
UNIVERSITY OF WELLINGTON

Vanuatu Forest Change Assessment 1990-2000 using satellite data

Phase I Project Report No. 1
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Vanuatu Carbon Credits Project: Vanuatu Forests – Reducing Emissions From Deforestation

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1 Background

Deforestation accounts for 20 % - 25 % of global greenhouse gas emissions, making it the most significant source of emissions in developing countries. If these emissions are not reduced, they have the potential to undercut reductions in industrial and energy emissions. Deforestation also has significant negative impacts on soil quality, biodiversity, local livelihoods and indigenous communities. Despite the negatives impacts of deforestation, creating incentives to mitigate this source of emissions from developing countries has not been adequately addressed in either the UN Convention on Climate Change (UNFCCC) or the Kyoto Protocol.

At the same time, the need for sustainable development in Vanuatu and other developing countries has been well documented in national development planning and bilateral aid reports. This forms part of a broader international drive for sustainable development arising out of several UN initiatives: the Millennium Development Goals, the Millennium Ecosystem Assessment, Agenda 21, and the World Summit on Sustainable Development. However, creating incentives for sustainable development is difficult given the scale of short term returns from less sustainable development options.

Because the Kyoto Protocol does not address reducing emissions from deforestation in developing countries, many developing countries with forest endowments are restricted in their opportunities to benefit from emissions trading. A fair and complete post-Kyoto regime will have to expand the existing system by creating a framework that includes all land use related changes in carbon stocks, including deforestation. Developing countries act as stewards of many of the Earth's biological resources and will have to be included in an incentive framework which rewards forestry. International negotiations are currently underway (2006 and 2007) within the UNFCCC to build incentives for developing countries to reduce or avoid emissions from deforestation and forest degradation (REDD). These negotiations were initiated at COP-11 in 2005 by the Governments of PNG and Costa Rica, and the Coalition of Rainforest Nations (of which Vanuatu is a member).

2 Project objectives and framework

This project is designed to help build capacity in Vanuatu to utilize carbon markets to help fund REDD and associated sustainable development activities. In order to model and test a national mechanism for the use of carbon finance for REDD, it is necessary to undertake a detailed national forest cover area change assessment. Thus, this project provides essential components of a larger effort that tests a national mechanism/s for REDD and carbon markets for Vanuatu.

The key objective of this project is to build a historical deforestation database for Vanuatu. The experiences gained in this project are of particular importance for Vanuatu neighboring countries (i.e. South Pacific Island States). The remote sensing component (forest cover area change assessment) delivers a database to include forest cover maps and deforestation maps and associated area estimates for two time steps: 1989/90 and 2000-2003 using primarily LANDSAT TM and ETM remote sensing data for change detection. The specific outputs include:
- Pre-processed satellite data image mosaics for the different time steps
- Forest area change maps

- Forest area change statistics and rates of deforestation

The methodological approach could be directly transferred to their national circumstances. In addition, this project directly contributes to the international process (lead by GTOS/GOFC-GOLD) to coordinate and synthesize the experiences for different case studies ongoing in different parts of the world (i.e. Bolivia, Cameroon, SE-Asia, PNG). Hence, the results contribute to strategic panning for sustainable development both nationally (in Vanuatu) and internationally (through lessons/models that can be applied to other forested nations).

Copies of the report will be sent to appropriate bodies (e.g. Environment Units) in relevant Pacific Island countries with similar circumstances (e.g. PNG, Solomon Islands, Fiji, New Caledonia, and Samoa) and relevant regional agencies (South Pacific Regional Environment Programme (SPREP), Pacific Islands Applied Geoscience Commission (SOPAC), and the Asia-Pacific Forestry Commission.

Other components of the larger project (beyond the scope of this application) are/will be funded through other channels (e.g. co-funding is already secured for policy development work, and ODA funding will be sought for other in-country components of the project). These components relate specifically to testing the capacity of Vanuatu to access carbon finance for REDD activity.

3 Vanuatu

The Republic of Vanuatu (former New Hebrides) is an island nation located in the South Pacific Ocean some 1 750 km east of Australia, 500 km north-east of New Caledonia, west of Fiji and south of the Solomon Islands (Lat/Long: 17° 74S, 168° 31E). It consists of a north-south oriented chain of 13 principal islands, of which the most important are Espiritu Santo, Malakula, Éfaté, Erromango, Ambrym, Tanna and Pentecôte, and about 67 smaller islands with a total area size of 12 190 km². The north-south extension is about 650 km (Figure 1). The larger islands of the archipelago are volcanic in origin and mountainous, and there are still a number of active volcanoes. The highest mountain is Mount Tabwemanasana on Espíritu Santo with an altitude of 1 879 m.

The population is about 209 000 inhabitants which are predominantly Melanesians, with some Polynesians; but also Chinese settlers and Vietnamese laborers. Vanuatu's capital is Port-Vila located on the island of Efate. The economy is based mainly on agriculture, cattle raising, and fishing, but also with an increasing tourism sector. Vanuatu has comparatively low rate of historical deforestation.
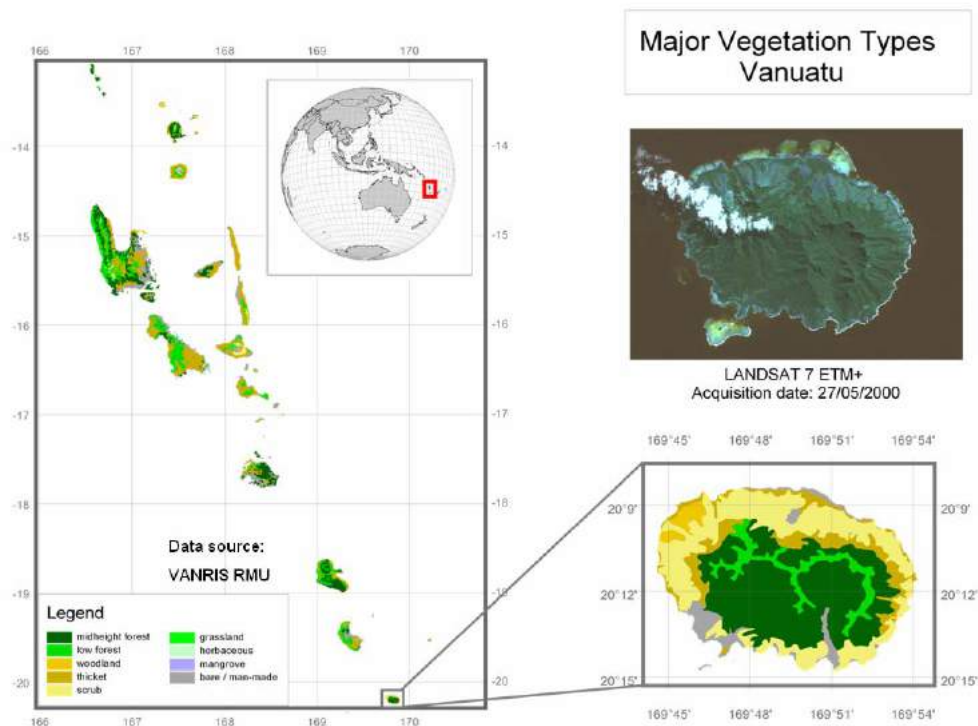
Figure 1: Location and overview map of Vanuatu.

4 Forest Area Change Assessment

A forest area change assessment is integral to an evaluation of national deforestation and forest degradation rates and a national carbon stock assessment. Multispectral and multitemporal satellite data offer the opportunity to monitor landuse/landcover conditions and dynamics in a repeated and cost-efficient manner over large areas. Despite proven capabilities in several circumstances, a critical issue for the Remote Sensing community is to evaluate the degree to which satellite observations are useful for deforestation estimates in a number of cases and conditions. For this specific project, the Vanuatu islands are of particular interest because of:

- There are no major previous satellite based land cover/forest monitoring studies
- Continuous optical observations are challenged by persistent cloud cover
- Remote island with only basic/limited satellite coverage and requirement of large amounts of initial data to cover all islands
- Topography complicating the image interpretation and mapping process (as is the case for many developing countries and their forest areas)

The remote sensing component and its processing tasks results will be further described in the following sections.

4.1 Satellite remote sensing data

The study integrated a number of satellite data following the observation model of GOFC-GOLD (De Fries et al., 2006) for monitoring tropical deforestation using primarily historical LANDSAT TM and ETM data for high-resolution change monitoring. Coverage for Vanuatu was available for the periods 1989/90 and 2000-2003 with some cloudy areas remaining. Additional data from the European SPOT sensor (1990) and ASTER (2000) have been

acquired to increase the spatial cloud free coverage and enhance the forest mapping capabilities through multiple observations.

Appendix A lists all satellite data images acquired and used as part of this project. For covering 1990 this project used 17 Landsat TM scenes + 16 SPOT scenes, and 14 Landsat ETM + 14 ASTER scenes to cover the 2000 time frame. The temporal coverage of the satellite observations may vary up to 2-3 years difference from the 1990 and 2000 dates. Such temporal differences will be considered in the deforestation rate analysis.

An additional survey of available satellite observations has emphasized additional useful satellite coverage for JERS-1 Radar for the 1990'ies period and sufficient coverage for the 2005-2007 period from ASTER and LANDSAT data. In addition there is some coverage of declassified CORONA satellite data from the early 1970ies. The list of available datasets not used in this project but useful for future efforts are shown in Appendix B.

4.2 Ancillary data

A number of additional data sources have been used to complete this project (Figure 2). The Vanuatu Resource Information System (VANRIS GIS, Bellamy 1993) was provided by the Vanuatu Forestry Department and yields spatial information on a number of important themes. The vector database includes information on national resources (resource mapping units – RMU) and vegetation type (from 1984 air photo interpretations), land use intensity and type of land use. We observed a geolocation shifts for a few island in both the RMU and VANRIS coastline data. The difference varies for neighboring islands, so there is no consistent shift. According to the Vanuatu project partner this problem is known and stems from different original cartographic data sources used to develop VANRIS. Thus, the use of the spatial data was useful but limited. For consistent coastline and digital elevation data coverage we applied the SRTM and the related water bodies product available for free http://www2.jpl.nasa.gov/srtm/cbanddataproducts.html.
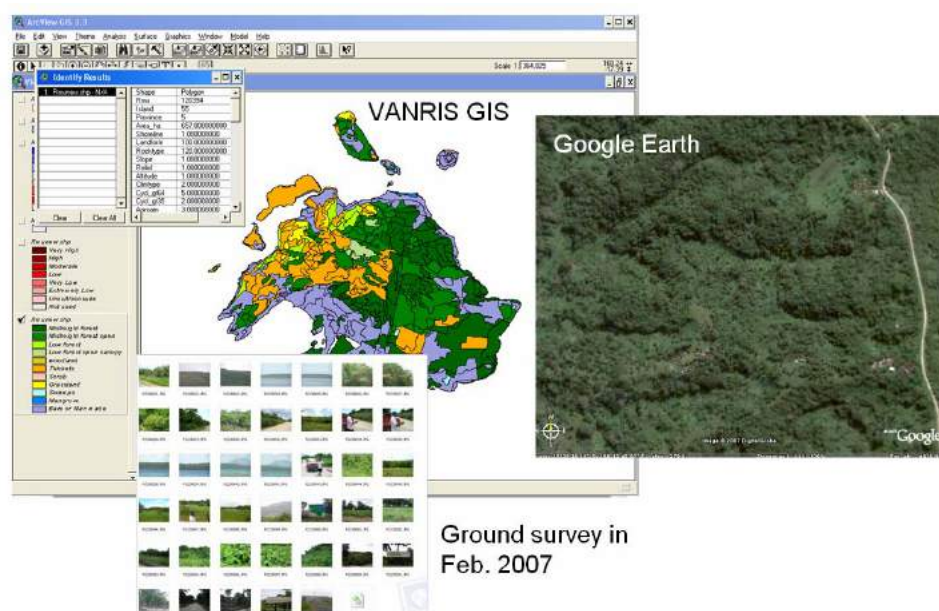

Figure 2: Overview of ancillary data sources used for this project

A field survey on major vegetation and forest types and GPS locations has been completed by the project partners in February 2007. Together with high resolution image snapshots available in Google Earth (earth.google.com), these information provided sufficient reference for the remote sensing of Vanuatu's forest and associated changes 1990-2000.

4.3. Satellite data pre-processing

The analysis of deforestation dynamics in this specific area needs to be based on high-quality and comparable satellite data. Such data can be provided by a comprehensive pre-processing including georeferencing and co-registration, mosaicing, masking and radiometric normalization of available satellite data (Figure 3). The goal of digital image preprocessing is to increase both the accuracy and the interpretability of the digital data during the image processing phase.
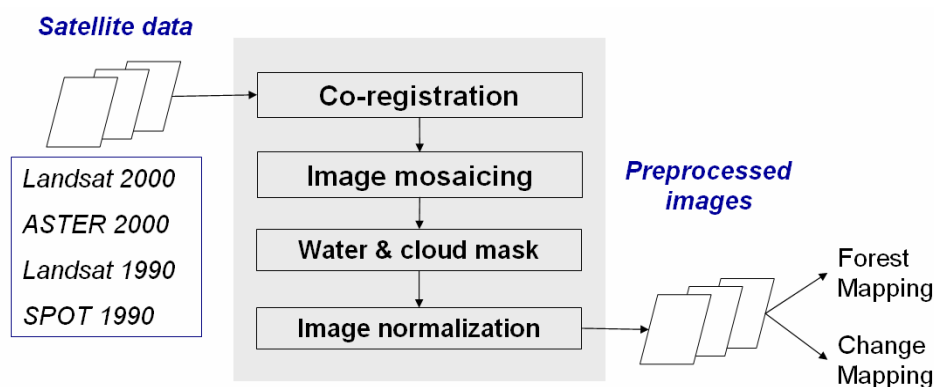
Figure 3: Workflow for the satellite preprocessing

4.3.1 Georeferencing, co-registration and image mosaics

To enable multi-temporal analyses of satellite data, it is important that the images are accurately registered, so that for any geo-located pixel, each image in the multi-temporal sequence shows the ground location and measures the same radiometric values for the same physical attributes.

For this study, the rectification was performed to a unique geodetic system (Geographic Lat/Long, ellipsoid + Datum: WGS84). The 2000 Landsat Geocover dataset provided the spatial reference for image to image registration of the other satellite data. A transformation was performed for each scene, whereas ground control points (GCP) were set visually with regard to the quality of the scene and the percentage of land coverage. Using a polynomial second order transformation and a nearest neighbor resampling, mean RMS errors less than one pixel resolution were achieved for each of the respective scene.

After geo-referencing all data they were processed to image mosaics shown in Figure 4. The image data emphasize the availability of observations. Landsat data provide the general basis and SPOT and ASTER data are used as complimentary information, mainly in persistently cloudy areas.
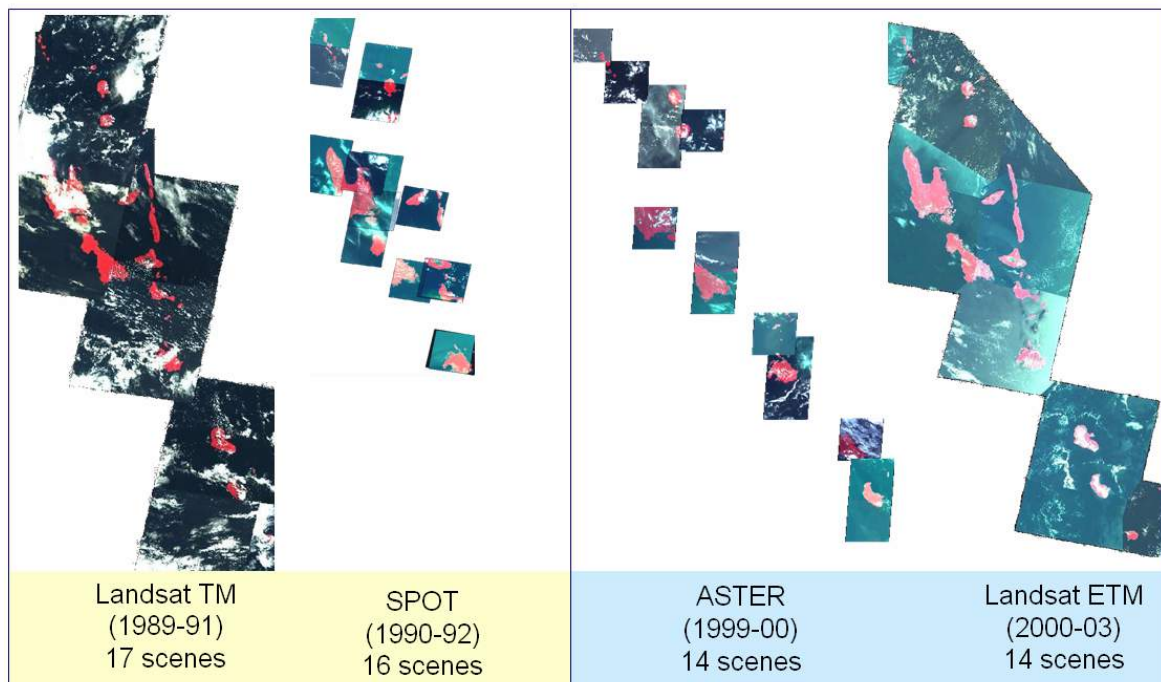
Figure 4: Image mosaics for Vanuatu derived for different times and different sensors

4.3.2 Masking and image normalization

The further processing and analysis requires clouds, cloud shadows and water bodies to be removed from the image data. First the image data were cropped using the coastline data. Landsat bands 4 and 5 thresholds (tuned for different regions) have been applied to exclude water bodies and cloud shadows. A Landsat band 1 threshold value was used to detect clouds. This approach works well for thick clouds. Thin clouds and haze were either excluded through manual editing or kept for the analysis. In particular the spectral bands with longer wavelength penetrate thin clouds and haze and can be used for the interpretations. Standard multi-temporal image normalization through histogram matching was performed to reduce radiometric image differences. Figure 5 shows an example of these processing steps. The island of Malakula is best covered by three different satellite scenes.
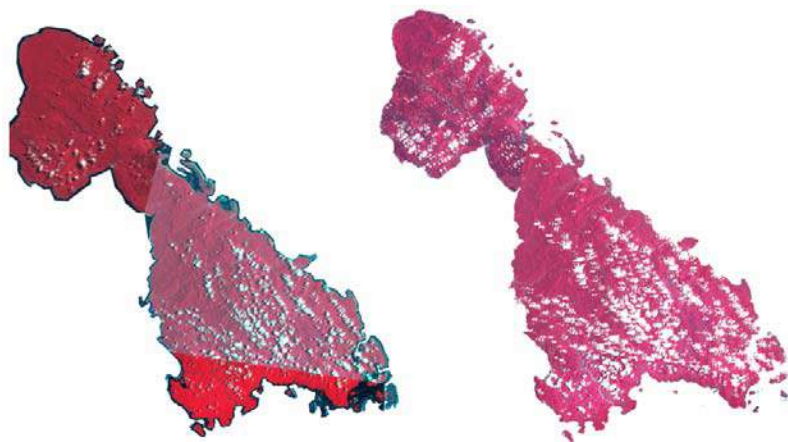
Figure 5: Example of cloud screening and image normalization for the Vanuatu island of Malakula. The image to the left shows the original data mosaic of three individual satellite

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4.4 Forest mapping and change assessment

The mapping and data analysis process contains two individual work items. The forest mapping for the year 2000 provides the baseline data for existing forest and tree cover for Vanuatu. The change mapping 1990-2000 is a different process and employs change detection methods to identify areas of forest cover change. In the final step, both products can be combined to derive a historical forest map for 1990. In general, both mapping items were done on an island by island basis to accommodate the heterogeneity of input data and tune the supervised analysis to the specific circumstances of the major island groups.
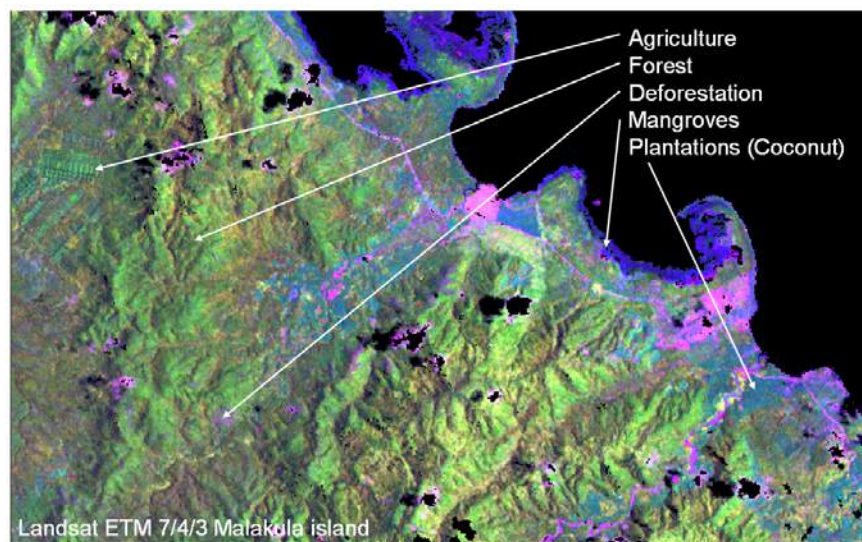
Figure 6: Satellite image for a subset of Malakula Island showing major land surface types for this part of Vanuatu.

To illustrate the information content of the satellite data, Figure 6 shows some major land surface types and their spectra characteristics. This image shows the areas missing due to clouds and still contains topographic effects that need to be considered in the analysis.

4.4.1 Deriving a forest cover map

The process of deriving the forest cover is shown in Figure 7. The approach is to classify pseudo spectral channels and label the spectral classes using the reference data into three categories defined by the amount of tree canopy cover.
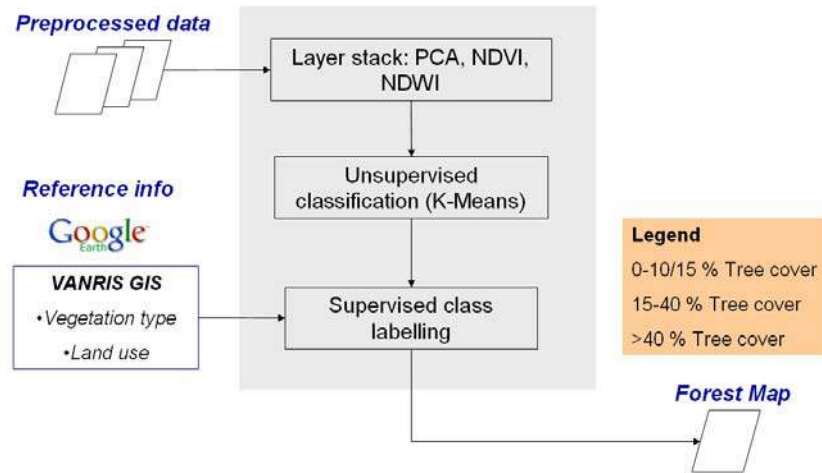
Figure 7: Workflow to derive the forest cover map for the year 2000

The use of pseudo spectral channels is required to reduce effects of different illumination conditions due to topography. It is known that image ratios and principal component analysis reduce such topographic effects while maintaining the majority of image information. The first ratio is the Normalized Difference Vegetation Index (NDVI) that is defined as the difference between the near-infrared (NIR) and the red radiation reflected by the surface, normalized by the sum of both ([NIR-RED]/[NIR+RED], Tucker, 1979). The Normalized Difference Water Index (NDWI) works in a similar manner using the NIR and short-wave infrared band (SWIR, Gao, 1996). In addition, the principal component analysis reflects the general surface illumination pattern (including topographic variations) in the first component. The subsequent principal components 2-4 have been used for the image classification (Figure 8). The minimum mapping unit applied is three Landsat pixels of 900 sqm each. Thus, the MMU can be estimated with about 0.3 ha.

Landsat ETM 5/4/3   Principal components 4/3/2   Forest cover map
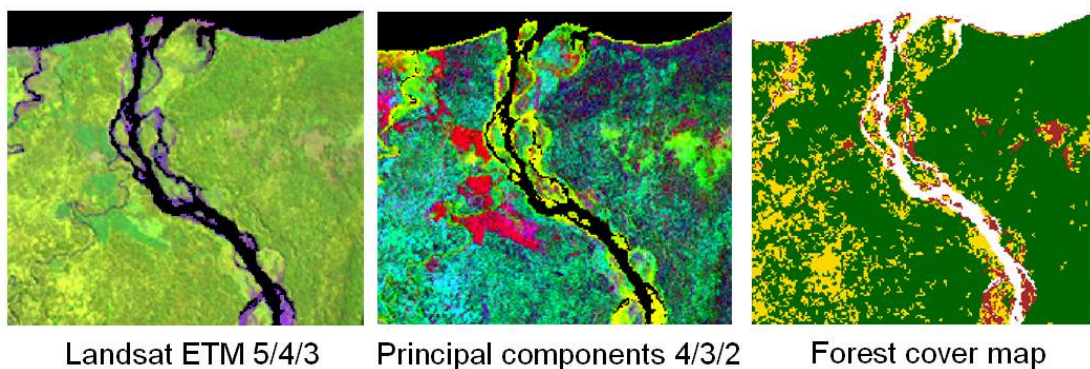
Figure 8: Example of image data to derive the forest cover map shown for a subset on the island of Santo.

4.4.2 Forest change detection

The forest change detection aimed to identify areas of significant loss in tree canopy cover and thus areas of deforestation. The technical approach is illustrated in Figure 9. The input data are the Landsat TM and SPOT data for 1990 and the Landsat ETM and ASTER data for 2000. With two datasets available for each of the two time steps, there is a maximum of four change observations for each location if all datasets are available. To derive information on what datasets are available for which location a common cloud mask is needed.
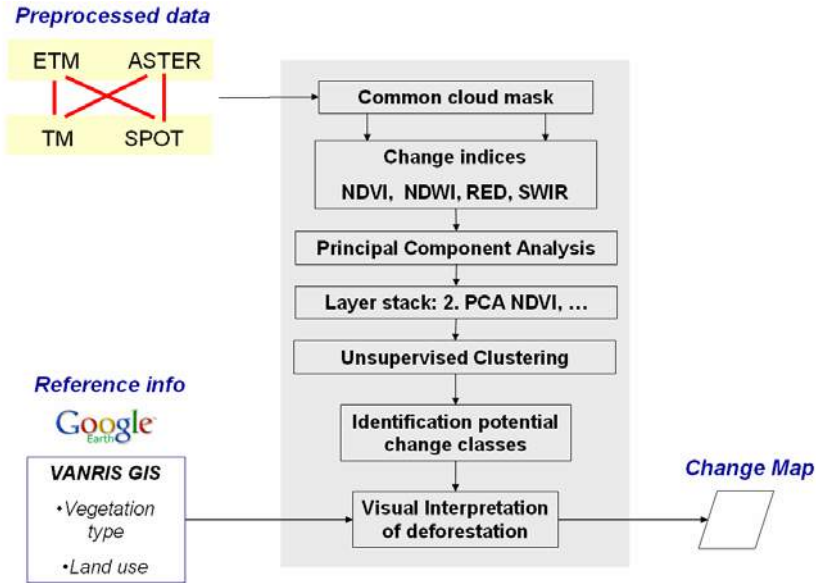
Figure 9: Workflow for deriving areas of deforestation.

The loss of tree canopy cover is highlighted in several spectral indicators including the NDVI, NDWI, the red spectra channel and the SWIR. Each of those bands are derived for the image data. To highlight the change a principal component analysis is performed between the associated change pairs, i.e. NDVI'90 and NDVI'00, NDWI'90 and NDWI'00 etc.. The first principal component contains the information that both have in common (i.e. similar NDVI fort 1990 and 2000). The second principal component highlights the areas where things have changed between the dates. This second principal component for changes in the NDVI, NDWI, the red band and the SWIR band are then jointly classified using an unsupervised clustering. The classification contains classes of potential forest loss. There maybe other influences that may be manifested in the potential change classes (i.e. phenology, radiometric image distortions and other artifacts like cloud boundaries). Thus, all identified potential change locations are visually inspected whether they indeed reflect deforestation. The change detection image interpretation process is shown for a subset area in Figure 10. All change areas including one pixel change areas (~900 sqm) have been considered in the final map product.
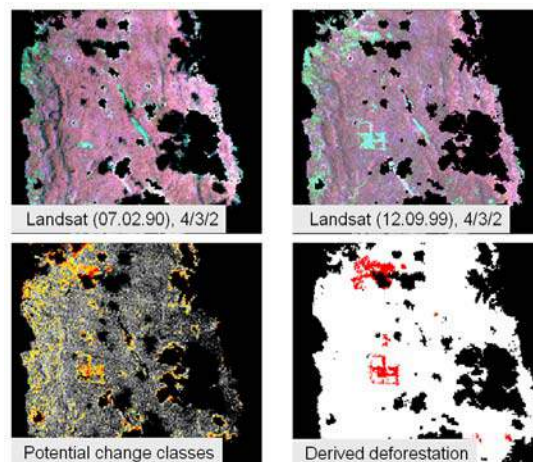
Figure 10: Example of identifying deforestation from the original satellite data, the potential change classes and the final product depicting areas of deforestation.

4.4.3 Deriving deforestation rates

The rate of deforestation reflects the area of forest loss within a particular period, usually per year. The frame for this study was an assessment of deforestation between 1990 and 2000 for the whole of Vanuatu. The calculation of the deforestation rate includes an average annual rate for a 10 year period. As reference period we applied 1st July 1990 – 1st July 2000 (a total of 3653 days).

The original satellite change observations had to be adjusted according to this time period since the observation dates are varying from the reference dates. In addition, there are areas of persistent clouds where no change observations could be performed. To accommodate these two factors (reference period adjustment and no data adjustment) we used a linear interpolation approach, i.e. if the mapping period was 5 % longer than the reference period we assumed 95 % of the mapped deforestation happened in the reference period. A similar approach is used for the no data adjustment with the same relative amount of deforestation being assumed in the no data region of the same island.

4.5 Forest assessment results

4.5.1 Forest cover map

The forest cover for Vanuatu is shown in Appendix C. It contains three land cover categories based on tree canopy cover density using the thresholds defined by the UN Land Cover Classification System (LCCS, Di Gregorio, 2005). The lower threshold of 15 % tree cover has to be understood as a range of 10-15 %. Basically the areas in the classes 15-40 % and 40-100 % tree cover would constitute a forest cover as defined by FAO (if land use is not considered). Figure 11 illustrates a subset of the Vanuatu forest cover map for the year 2000 for the largest island of Santo.
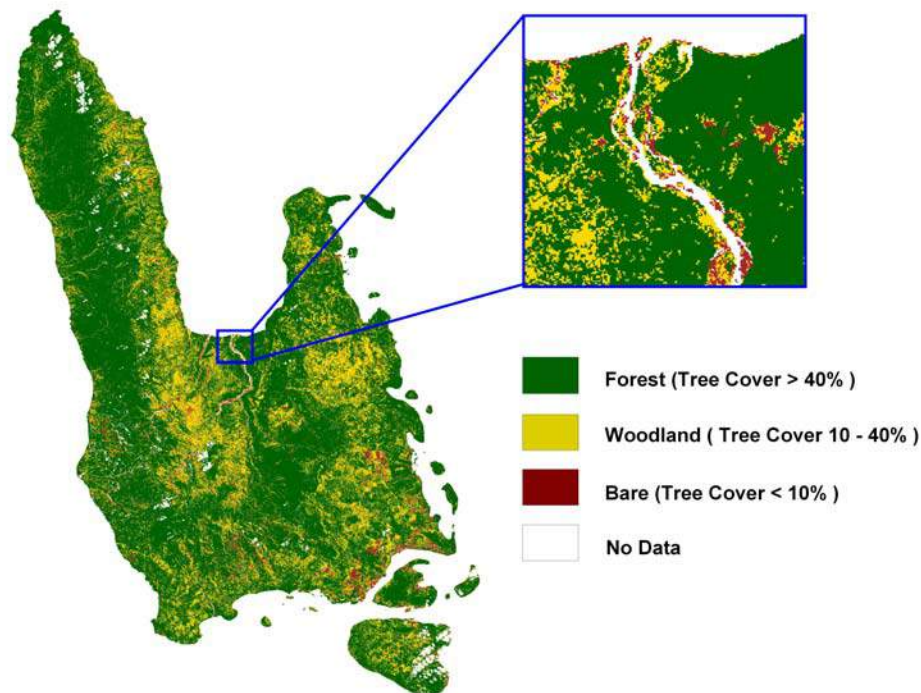
Figure 11: Subset of the Vanuatu forest cover map for 2000 derived as part of this project.

The overall distribution of the forest cover classes derived for Vanuatu (Table 1, Appendix C) emphasize the dominance of areas with tree cover larger than 40 %. Following the pure "land cover" perspective taken in this study, the area of land with more than 10-15% tree canopy cover is more than 1 million ha. It needs to be considered that these values may not be directly comparable with other existing estimates.

Table 1: Spatial distribution of different tree canopy cover categories derived from the satellite 2000 data.

Island (group)	Area according to RMU [ha]	Area >40% tree canopy cover [ha]	Area 40-15% tree canopy cover [ha]	Area >15% tree canopy cover [ha]
Torres Islands	11520	10418,2	500,7	601,1
Island Banks	75359	68949,9	5994,5	414,6
Santo	423897	316078,6	96091,8	11726,7
Maewo	30390	27058,2	3110,8	220,9
Aoba	40566	33208,7	6487,1	870,3
Pentecost	49490	42941,9	5211,8	1336,3
Malakula	206756	172330,0	28622,6	5803,4
Ambrym (incl. Liro, Lopevi)	73246	55121,9	4806,7	13317,4
Epi	53324	48962,8	4012,6	348,6
Efate	97004	67732,0	22125,1	7146,9
Erromango	88874	75599,0	10414,5	2860,5
Tanna	56668	49746,6	4297,9	2623,6
Anatom	17210	13637,8	1551,2	2021,0
TOTAL	**1224304**	**981785,5**	**193227,2**	**49291,3**
TOTAL %	**100**	**80,2**	**15,8**	**4,0**

4.5.2 Deforestation maps

The analysis of forest change revealed a variety of change pattern for different parts of Vanuatu. Figure 12 illustrates a number of such satellite change observations. The top change pair of Figure 12 shows a large scale removal of forests with parts of the cleared land being converted to agriculture. The change pair in the middle emphasizes different areas of forest clearing and logging due to number of causes. For example, the satellite images indicate the construction of new roads in the area. Such new infrastructure improves accessibility and can drive forest loss due to logging and building construction as in this case. The third case on the bottom of Figure 12 shows a forest change on a smaller, inaccessible island. There is no visible transportation infrastructure and the visible loss of forest is due small-scale changes in agriculture and plantation. The mapping procedure reflects all those different kind of forest changes.
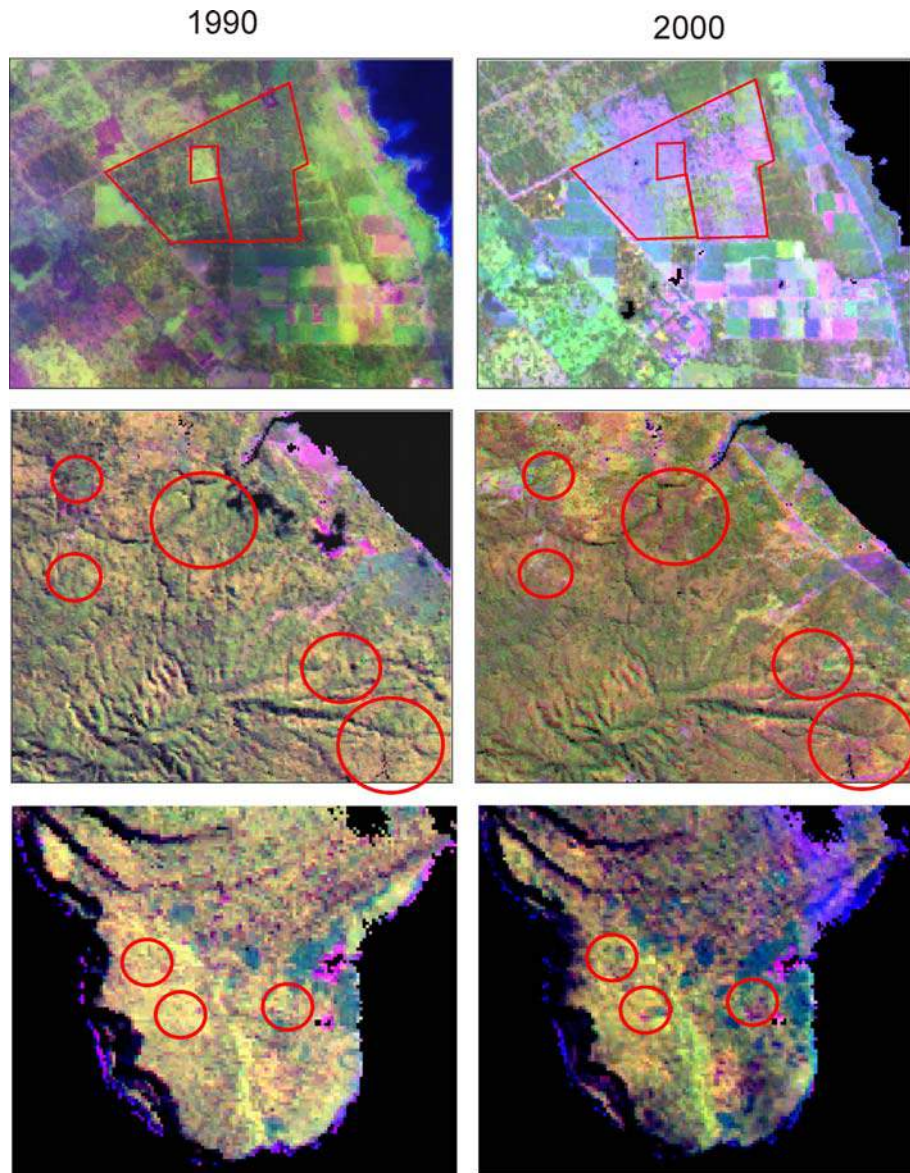
Figure 12: Examples for different types of deforestation highlighted in the satellite images as loss of tree cover. All images are from Landsat TM and ETM data and are in equal scale. Displayed is a RGB Landsat channel combination 5/4/3. The image pair on the top represents an area in South-Eastern Santo, the image pair in the middle is located on Eastern coast of Efate and the bottom pair shows and area location on the southernmost part of the Torres islands.

One essential consideration was to deal with data availability. Although data from a number of satellites have been used there are still remaining areas of persistent cloud cover. Such areas with no information from either 1990 or 2000 available were excluded from the change mapping process. Figure 13 represents the spatial distribution of the availability of image change pairs for all Vanuatu islands. The areas shown in yellow reflect an availability of 1 change pair, hence one satellite observation for 1990 and one for 2000. The areas in red are covered with four change observations. All datasets Landsat'90, SPOT'90, Landsat'00 and ASTER'00 have been available for these locations.
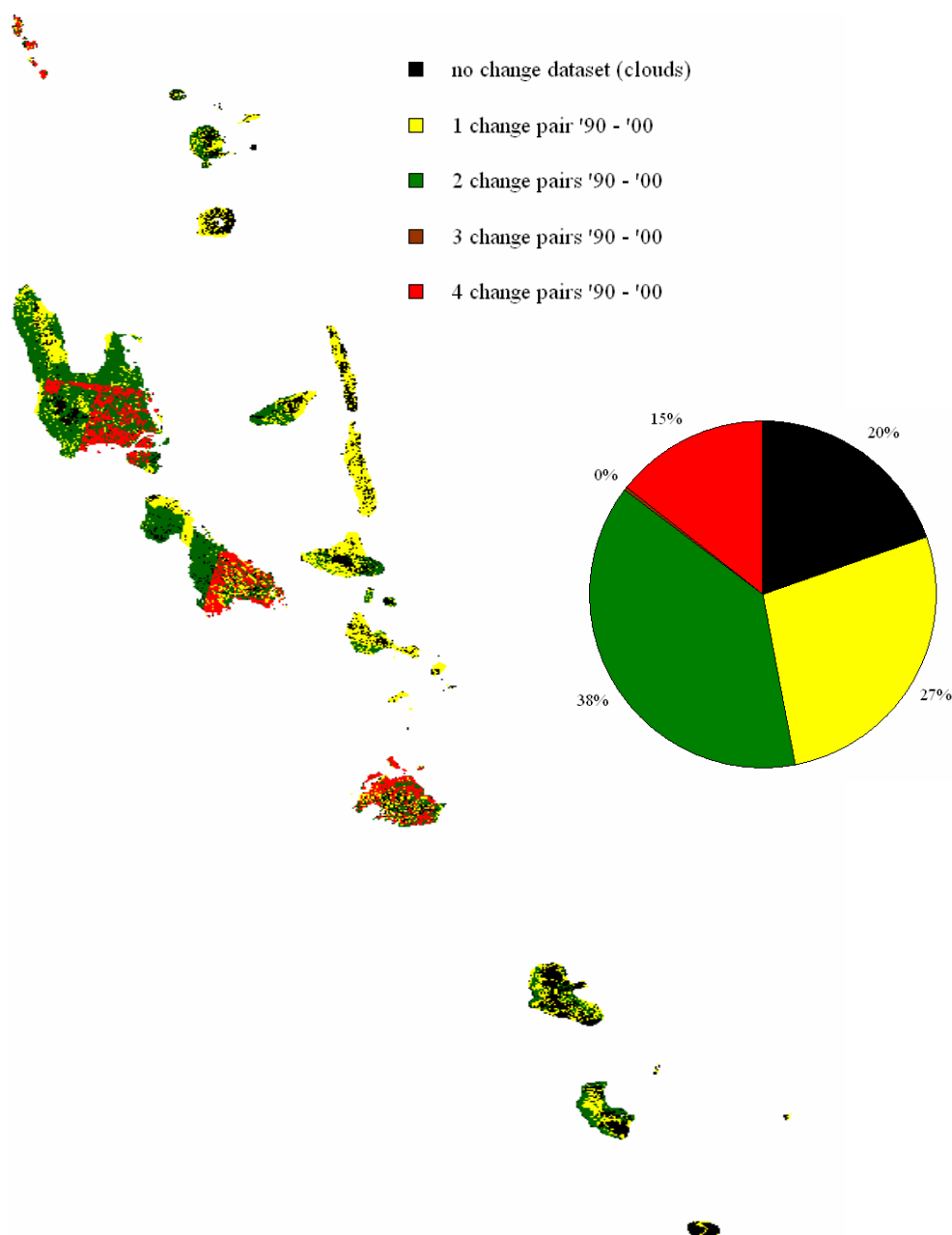
Figure 13: Availability of satellite data change observations pairs with the different colors corresponding to number of change observations for each location. The pie chart describes the area proportions for each case.

The pie chart in Figure 13 shows the relative distribution of change observation availability. About 80 % of the Vanuatu land area could be included in the change detection. Nearly 55 % of the land area is covered by 2 or more change observations. Basically, the more change observations are available the more confidence there is in the observed change. The main islands including Santo, Malakula and Efate are well covered by the satellite observations.
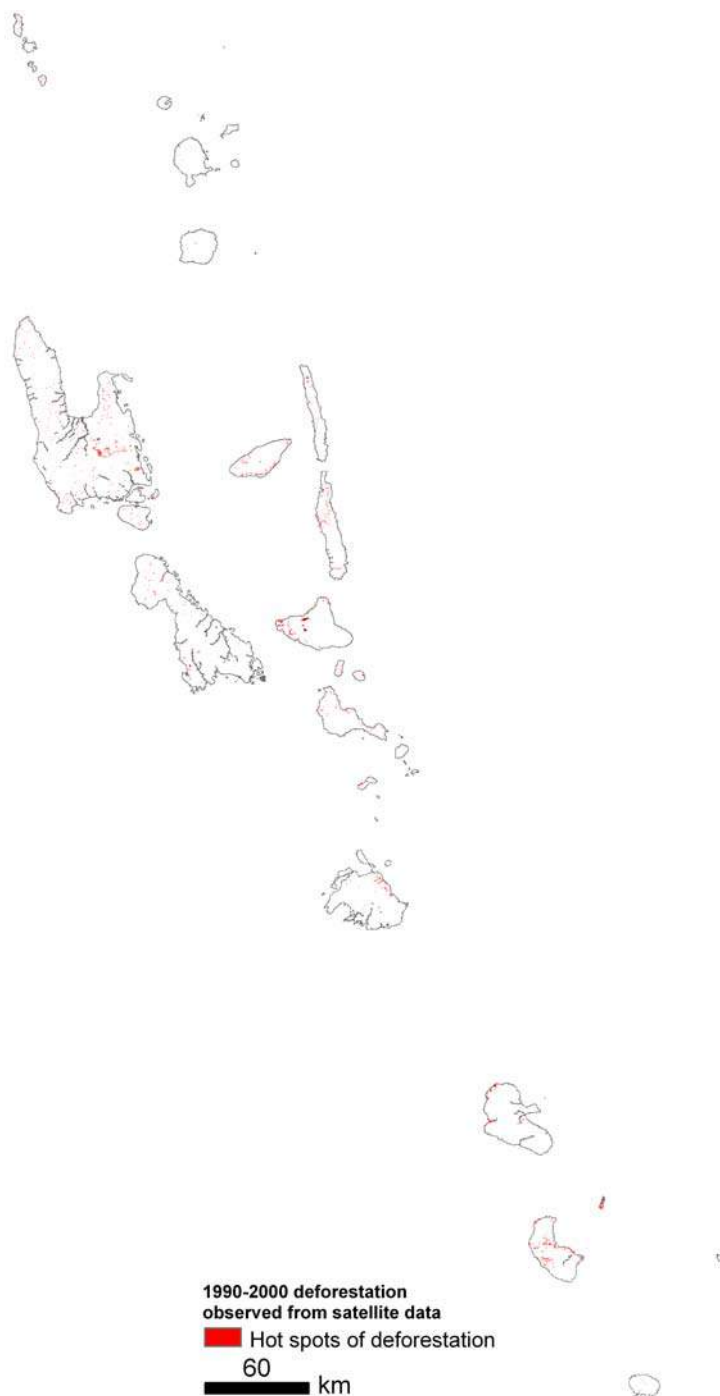
Figure 14: Map of Vanuatu showing areas of major deforestation observed from the satellite data 1990-2000.

The deforestation maps for all individual islands and island groups are presented in Appendix D. They show the detailed deforestation patches observed and emphasize different patterns and processes of deforestation. To get an idea for main areas of deforestation, a map of main locations of the deforestation has been derived (Figure 14).

4.5.3 Deforestation statistics

The rates of deforestation were calculated from the satellite observed forest area change adjusted to accommodate the reference time period (1st July 1990- 1st July 2000) and the areas

with no data. The final and adjusted areas and area rates of deforestation are presented in Table 2. The gross deforestation for all islands of Vanuatu between 1990 and 2000 is estimated with 4677,6 ha. More than 1/5 of the total forest loss was observed on the island of Santo. The spatial distribution of the numbers shown in Table 2 emphasizes Santo and Tanna as the Vanuatu areas with most gross deforestation (Figure 15).

**Forest loss
1990-2000 in ha**

	0 - 200
	201 - 400
	401 - 600
	601 - 800
	>801

60
km
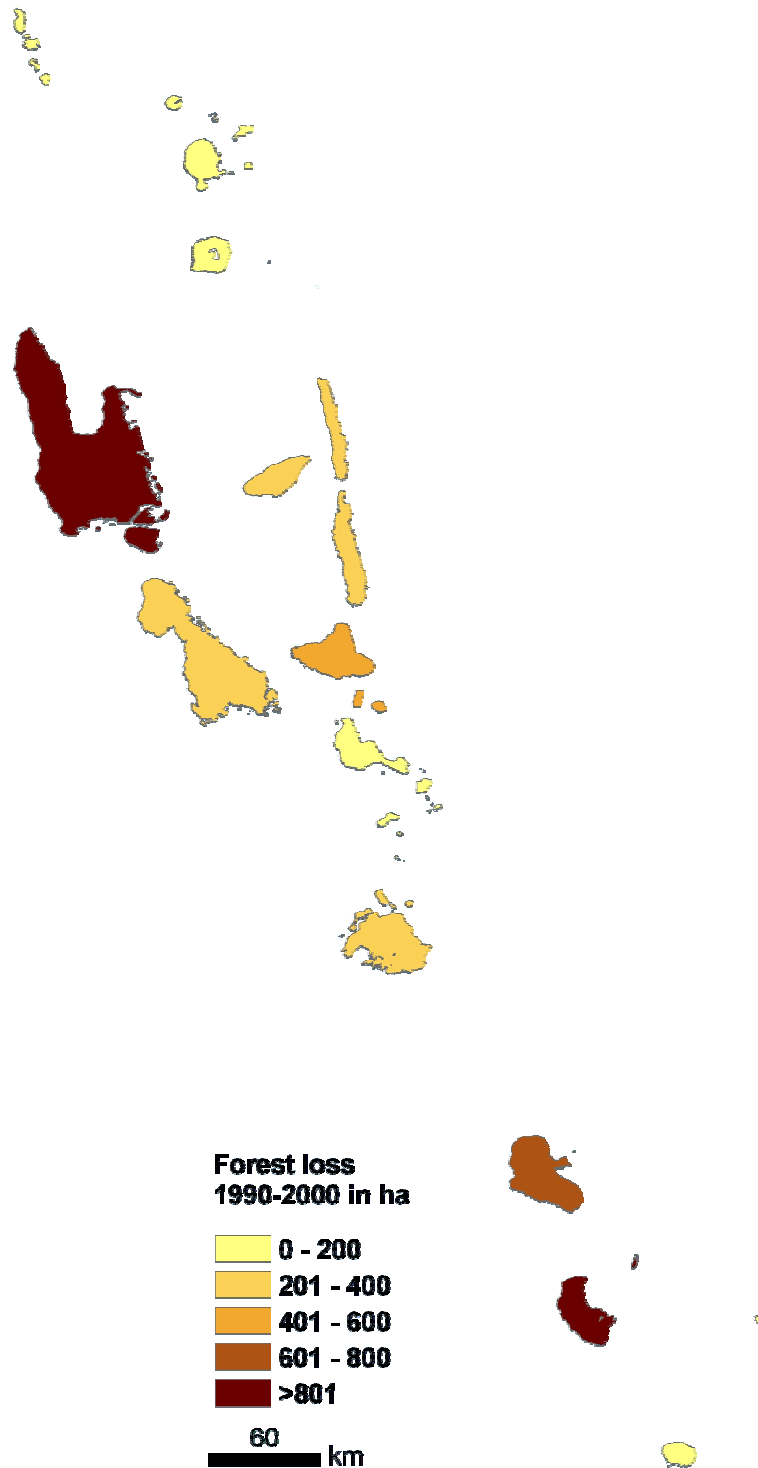
Figure 15: Loss of forest area 1990-2000 observed from the satellite data for different island of Vanuatu.

Table 2: Final area and area rates of gross deforestation for different islands and islands groups of Vanuatu shown with the total area and proportion of missing satellite change observations.

Island (group)	Area according to RMU [ha]	Proportion of missing change data	Loss of forest 1990-2000 [ha]	Loss of forest [ha/a]
Torres Islands	11520	9,8	45,8	4,6
Isles Banks	75359	45,0	56,8	5,7
Santo	423897	4,5	1114,4	111,4
Maewo	30390	43,3	217,0	21,7
Aoba	40566	22,3	210,4	21,0
Pentecost	49490	23,1	249,0	24,9
Malakula	206756	9,0	293,4	29,3
Ambrym (incl. Liro, Lopevi)	73246	27,7	447,4	44,7
Epi	53324	23,8	190,3	19,0
Efate	97004	12,7	302,5	30,3
Erromango	88874	51,5	666,0	66,6
Tanna	56668	36,7	811,6	81,2
Anatom	17210	80,7	73,0	7,3
Total	**1224304**		**4677,6**	**467,8**

5. Project Management

5.1 Timeline

The project was running for duration of three months (January- March 2007). The different tasks have been completed following the outline made in the proposal:

	January	February	March
Satellite data ordering	■		
Satellite data pre-processing	■	■	
Forest and forest change mapping		■	■
Deriving deforestation rates			■
Reporting and documentation			■

All tasks were successfully completed within the time frame anticipated.

5.2 Budget and payments

This report describes the methods and results of the remote sensing component of this project. An additional report on the ICMSD model has been submitted separately.

The overall budget proposed for the project was basically used as advocated in the proposal with some minor changes:

Expenditure Category	J	F	M	A	M	J	J	A	S	O	N	D	Total Cost(£)
Forest area change assessment													
Salary (incl. overheads)	■	■	■										45.684,15
Subcontract	■	■	■										16.159,35
Hardware + Software	■	■	■										6.574,84
Data sets	■	■	■										5.365,66
ICMSD Model													
Travel / accom	■	■	■										1,100
Salary (inclusive of NZ tax)	■	■	■										5,116
TOTAL													80,000

The salary for the remote sensing component includes 2 full time remote sensing technicians and 2 full time graduate students for 3 months including university overheads (20 %). A subcontract (for a local remote sensing company) was needed given the short time frame of the project to ensure operational geometric (mosaicing) and radiometric pre-processing of the Landsat data within the first 1.5 months of the project. Some hardware (incl. server, two remote sensing workstations etc.) was already available for the project. Equipment for two additional image interpretation workstations and hard disc space was needed at the start of the project. The remote sensing contractor provided the one license of the remote sensing image processing and analysis software (ERDAS Imagine/ENVI IDL). However, the number of people involved required an upgrade of existing licenses for the two additional workstations. Most of the Landsat satellite data were available free of charge. Due to persistent cloud cover,

some additional Landsat or similar data had to be bought from data providers like NASA, and USGS.

The payment procedure for the remote sensing component involved an installment to acquire the data and get the resources in place to start the project. The second and larger payment is due after the project has been successfully completed.

Forest area change assessment*	1. Payment* (start of project)	2.Payment (after product delivery)	Total*
Salary (incl. overheads)	--	45.684,15	45.684,15
Subcontract	10.000	6.159,35	16.159,35
Hardware + Software	6.485*	--	6.574,84*
Data sets	5.144	221,66	5,365,66
Total (remote sensing)	21.629	52.065,10	73.784
ICMSD Model		6.216	6.216
Overall			80.000

* Small difference between first payment and total amount may arise from currency exchange variations

6. Conclusions and recommendations

International negotiations are currently underway (2006 and 2007) within the UNFCCC to build incentives for developing countries to reduce or avoid emissions from deforestation and forest degradation (REDD). In that context, the project was designed to build capacity in Vanuatu to utilize carbon markets to help fund REDD and associated sustainable development activities. The project aimed to provide one essential requirement i.e. the development of a historical deforestation database using historical satellite observations. Applying such an approach to Vanuatu requires consideration of particular challenges:

- There are no major previous satellite based land cover/forest monitoring studies
- Continuous optical satellite observations are challenged by persistent cloud cover
- Remote island with only basic/limited satellite coverage and requirement of large amounts of initial data to cover all islands
- Topography complicating the image interpretation and mapping process

Despite such difficulties, the project results have proven the suitability of satellite-based assessment of forest cover change in the context of REDD. The detailed achievements of the project, accomplished in a 3 month time period, include:

- The processing and analysis of 61 individual satellite images with the cost for satellite being only a small fraction (<10 %) of the overall project budget.
- Development of the Vanuatu historical deforestation database version 1 from a wall-to-wall forest cover and forest change assessment including all islands of Vanuatu with the results being complimentary to the existing Vanuatu Resource Information System (VANRIS).
- Derivation of a spatially explicit forest cover map accompanied by targeted field visits.
- Monitoring of forest cover change for 1990 and 2000 to quantify the rates of deforestation, and spatial identification of deforestation hot spots and major processes causing loss of forest.

The results have shown that an area of more than 4600 ha has been deforested. In an international context, such a rate of forest loss is comparatively low but there are distinctly different patterns for the different parts of Vanuatu. The different processes relate to industrial logging, changes in plantations and agricultural pattern, and subsistence timber extraction. Developments of policies and carbon crediting options have to consider these different processes at work.

The development of version 1 of the Vanuatu deforestation database provides the first and essential step to further evolve the basis for Vanuatu's participation in any REDD carbon crediting system. There are a number of next steps to have to be pursued to further progress in this arena:

- Extend remote sensing survey 2006 to develop the Vanuatu historical deforestation database version 2. Such a step can be accomplished in rather short time and limited funding with the resources and experiences developed as part of this project.
- A detailed study of identified deforestation hot spots help to further understand the processes and future threats for the loss of forest.
- A thorough carbon emissions assessment will have to integrate previous forest inventory information, remote sensing-based estimates, and additional field work to quantify the carbon emissions from deforestation. The IPCC technical guidelines provide the methodological framework.

- With the database evolving (version 3 and 4), different options for policies and sustainable development implementation will have to be defined and explored. Perhaps, this database together with existing VANRIS system will allow for a number of joint benefits relating to international reporting obligations (FAO-FRA, UNCBD) and helps to build a thorough environmental accounting system that can be maintained by a country like Vanuatu.

The technical approach used and proven in this Vanuatu case study could be directly transferred to other national circumstances in the south pacific region and beyond. Since major deforestation problems tend to be of international origin and involve regional impacts, the project will certainly aim to extend beyond the boundaries of Vanuatu.

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Appendix A: Overview of satellite data used for this project

ID	path	row	Acquisition date
Landsat TM 4, L1G product (time step 1989/90)			
ID: 4083069009016410	83	69	13.06.1990
ID: 4082069009014110	82	69	21.05.1990
ID: 4082070008909010	82	70	31.03.1989
ID: 4082070008910610	82	70	16.04.1989
ID: 4082071008910610	82	71	16.04.1989
ID: 5082071009024510	82	71	02.09.1990
ID: 4081069009003810	81	69	07.02.1990
ID: 4081070009003810	81	70	07.02.1990
ID: 4081071009016610	81	71	15.06.1990
ID: 4081071009015010	81	71	30.05.1990
ID: 4081071009003810	81	71	07.02.1990
ID: 4081072009008610	81	72	27.03.1990
ID: 4081072009016610	81	72	15.06.1990
ID: 4080073009012710	80	73	07.05.1990
ID: 4080073009009510	80	73	05.04.1990
ID: 4080074009009510	80	74	05.04.1990
ID: 4079074009004010	79	74	09.02.1990
Landsat ETM+, L1G product (time step 1999/2003)			
ID: 7083069000008050	83	69	20.03.2000
ID: 7082069000015350	82	69	01.06.2000
ID: 7082070000015350	82	70	01.06.2000
ID: 7082070000109151	82	70	01.04.2001
ID: 7082071000109151	82	71	01.04.2001
ID: 7082071000110750	82	71	17.04.2001
ID: 7081070009925550	81	70	12.09.1999
ID: 7081071000304250	81	71	11.02.2003
ID: 7081071009925550	81	71	12.09.1999
ID: 7081072009931950	81	72	15.11.1999
ID: 7080073000300350	80	73	03.01.2003
ID: 7080073009924851	80	73	05.09.1999
ID: 7080074000002750	80	74	27.01.2000
ID: 7079074000014850	79	74	27.05.2000
SPOT (time step 1990/92)			
24103769006292316432X0	410	376	29.06.1990
24103779004172320232X0	410	377	17.04.1990
24113799206112306391X5	411	379	11.06.1992
24113809206112306481X0	411	380	11.06.1992
24123779007092324422X0	412	377	09.07.1990
24123789007092324502X0	412	378	09.07.1990
24123809107242317382X0	412	380	24.07.1991
24123809206112306462X0	412	380	11.06.1992
24123819107242317472X0	412	381	24.07.1991
24133819201272322071X0	413	381	27.01.1992

2414381921009225951IX0	414	381	09.10.1992
2414383920128230304IX0	414	383	28.01.1992
2415383900726225834 2X0	415	383	26.07.1990
2415383920128230303 2X0	415	383	28.01.1992
2416385920305225130IX0	416	385	05.03.1992
2416385920902231147IX0	416	385	02.09.1992
ASTER L1 B products (time step 2000/03)			
AST_L1A.003:2003797257			09.08.2001
AST_L1A.003:2003797259			09.08.2001
AST_L1A.003:2004355574			07.09.2000
AST_L1A.003:2007112670			31.05.2002
AST_L1A.003:2007685131			26.07.2000
AST_L1A.003:2007783650			06.04.2002
AST_L1A.003:2008670539			06.10.2002
AST_L1A.003:2008670540			06.10.2002
AST_L1A.003:2010333125			07.09.2000
AST_L1A.003:2010922522			01.01.2003
AST_L1A.003:2010922536			01.01.2003
AST_L1A.003:2010922563			01.01.2003
AST_L1A.003:2018709643			12.09.2000
AST_L1A.003:2019778227			19.04.2001

Appendix B: Overview of additional satellite data identified as part of the data survey and potentially useful for follow up activities

JERS 1 SAR imagery:

Path	Row	ID	Observation Date
648	332	ID: J1SAR19940706M08087707648332	06.07.1994
649	329	ID: J1SAR19930902M08057007649329	02.09.1993
649	330	ID: J1SAR19930902M08057007649330	02.09.1993
650	327	ID: J1SAR19930903M08057108650327	03.09.1993
650	328	ID: J1SAR19930903M08057108650328	03.09.1993
650	329	ID: J1SAR19930903M08057108650329	03.09.1993
650	330	ID: J1SAR19930903M08057108650330	03.09.1993
651	327	ID: J1SAR19941118M08101207651327	18.11.1994
651	328	ID: J1SAR19940822M08092406651328	22.08.1994
		ID: J1SAR19941118M08101207651328	18.11.1994
652	325	ID: J1SAR19960909M08167309652325	09.09.1996
652	326	ID: J1SAR19960909M08167309652326	09.09.1996
652	327	ID: J1SAR19941006M08096907652327	06.10.1994
		ID: J1SAR19960909M08167309652327	09.09.1996
652	328	ID: J1SAR19941006M08096907652328	06.10.1994
		ID: J1SAR19960909M08167309652328	09.09.1996
653	323	ID: J1SAR19951107M08136610653323	07.11.1995
653	324	ID: J1SAR19951107M08136610653324	07.11.1995
653	325	ID: J1SAR19951107M08136610653325	07.11.1995
653	326	ID: J1SAR19951107M08136610653326	07.11.1995
653	327	ID: J1SAR19940711M08088202653327	11.07.1994
		ID: J1SAR19941120M08101409653327	20.11.1994
		ID: J1SAR19951107M08136610653327	07.11.1995

ASTER data after 2002:

Path	Row	ID	Aquisition	Comments
83	69	ID: AST_L1A.003:2018929190	Date: 2003/11/24	cloudfree
		ID: AST_L1A.003:2018929179	Date: 2003/11/24	cloudfree
82	69	ID: AST_L1A.003:2034582625	Date: 2006/6/9	cloudfree
		ID: AST_L1A.003:2032195286	Date: 2005/12/8	cloudfree
		ID: AST_L1A.003:2033906634	Date: 2006/4/15	small cloud
82	70	ID: AST_L1A.003:2032195287	Date: 2005/12/8	cloudfree
		ID: AST_L1A.003:2021772331	Date: 2004/3/8	clouds
		ID: AST_L1A.003:2033906635	Date: 2006/4/15	clouds Vanua
		ID: AST_L1A.003:2033906638	Date: 2006/4/15	small clouds
82	71	ID: AST_L1A.003:2030778668	Date: 2005/9/3	
		ID: AST_L1A.003:2010922544	Date: 2003/1/1	

		ID: AST_L1A.003:2010922563	Date: 2003/1/1	
		ID: AST_L1A.003:2034582630	Date: 2006/6/9	
		ID: AST_L1A.003:2034582632	Date: 2006/6/9	
81	71	ID: AST_L1A.003:2031164854	Date: 2005/10/5	
		ID: AST_L1A.003:2033990443	Date: 2006/4/24	
		ID: AST_L1A.003:2035118293	Date: 2006/7/13	
		ID: AST_L1A.003:2031164855	Date: 2005/10/5	
		ID: AST_L1A.003:2030422062	Date: 2005/8/11	clouds
81	71	ID: AST_L1A.003:2032386377	Date: 2005/12/24	cloudfree
		ID: AST_L1A.003:2034685253	Date: 2006/6/18	
		ID: AST_L1A.003:2027925218	Date: 2005/2/16	
		ID: AST_L1A.003:2030652712	Date: 2005/8/27	
81	71	ID: AST_L1A.003:2029999512	Date: 2005/7/10	
81	71	ID: AST_L1A.003:2033915422	Date: 2006/4/17	
		ID: AST_L1A.003:2022691668	Date: 2004/4/18	cloudfree
81	72	ID: AST_L1A.003:2033150336	Date: 2006/2/19	
		ID: AST_L1A.003:2022018784	Date: 2004/3/17	
		ID: AST_L1A.003:2027925217	Date: 2005/2/16	
81	72	ID: AST_L1A.003:2033915425	Date: 2006/4/17	clouds
		ID: AST_L1A.003:2019778227	Date: 2001/4/19	clouds
		ID: AST_L1A.003:2027474717	Date: 2005/1/15	cloouds
		ID: AST_L1A.003:2019778225	Date: 2001/4/19	
80	73	ID: AST_L1A.003:2027815749	Date: 2005/2/9	clouds
		ID: AST_L1A.003:2021340598	Date: 2004/2/23	clouds
80	73	ID: AST_L1A.003:2023497879	Date: 2004/5/13	
		ID: AST_L1A.003:2023497878	Date: 2004/5/13	
		ID: AST_L1A.003:2031096664	Date: 2005/9/30	
80	74	ID: AST_L1A.003:2034455781	Date: 2006/5/28	

Declassified Corona Satellite Imagery:

Entity ID	Acquisition Date	Mission No.	Ops	Frame No.	Segment Count
DZB1206-500049L001001	1973/07/24	1206-5	00049	1	1
DZB1206-500049L002001	1973/07/24	1206-5	00049	2	1
DZB1206-500049L003001	1973/07/24	1206-5	00049	3	1
DZB1206-500049L004001	1973/07/24	1206-5	00049	4	1
DZB1206-500049L005001	1973/07/24	1206-5	00049	5	1
DZB1206-500049L006001	1973/07/24	1206-5	00049	6	1
DZB1206-500049L007001	1973/07/24	1206-5	00049	7	1

EO-1 Advanced Land Imager (ALI):

| Entity ID	Acquisition Date
EO1A0810712002327110PZ_LGS_01	2002/11/23
EO1A0800732003003110PZ_LGS_01	2003/01/03
EO1A0820702003065110PZ_LGS_01	2003/03/06
EO1A0800732003099110PX_AGS_01	2003/04/09

EO1A0820702003161110PX_AGS_01	2003/06/10
EO1A0790732003204110PZ_PF1_01	2003/07/23
EO1A0810712003218110PZ_SGS_01	2003/08/06
EO1A0800732003227110PY_PF1_01	2003/08/15
EO1A0800732003259110PW_LGS_01	2003/09/16
EO1A0820702003257110PY_SGS_01	2003/09/14
EO1A0790742003268110PZ_SGS_01	2003/09/25
EO1A0800732003323110PY_AGS_01	2003/11/19
EO1A0810712003330110PY_AGS_01	2003/11/26
EO1A0810712003339110KZ_AGS_01	2003/12/05
EO1A0790742003348110PZ_AGS_01	2003/12/14
EO1A0820702004004110PY_SGS_01	2004/01/04
EO1A0800732004006110PY_SGS_01	2004/01/06
EO1A0790742004031110PZ_SGS_01	2004/01/31
EO1A0810712004045110PY_AGS_01	2004/02/14
EO1A0790742004047110PZ_SGS_01	2004/02/16
EO1A0820702004052110PZ_AGS_01	2004/02/21
EO1A0820712004068110PZ_AGS_01	2004/03/08
EO1A0800732004070110PY_AGS_01	2004/03/10
EO1A0820712004084110PY_AGS_01	2004/03/24
EO1A0820702004100110PX_SGS_01	2004/04/09
EO1A0800732004134110PZ_AGS_01	2004/05/13
EO1A0820702004244110PY_LGS_01	2004/08/31
EO1A0800732005040110PZ_SGS_01	2005/02/09
EO1A0820702005054110PY_LGS_01	2005/02/23
EO1A0800732005120110PZ_PF1_01	2005/04/30
EO1A0810712005309110KF_WPS_01	2005/11/05
EO1A0810712005335110KF_AGS_01	2005/12/01
EO1A0810712005342110KF_AGS_01	2005/12/08
EO1A0820702005347110KF_WPS_01	2005/12/13
EO1A0800732005349110KF_WPS_01	2005/12/15
EO1A0810712005359110KF_PF1_01	2005/12/25
EO1A0810712005364110KF_SGS_01	2005/12/30
EO1A0810712006006110KF_WPS_01	2006/01/06
EO1A0810712006023110KF_AGS_01	2006/01/23
EO1A0810712006028110KF_PF1_01	2006/01/28

Landsat- 7 ETM (SLVC-OFF) after May 2003

Latitude	Longitude	Acquisition date
Latitude: 40.3631	Longitude: -84.0824	27.05.2004
Latitude: 40.3631	Longitude: -84.0824	14.02.2003
Latitude: 40.3631	Longitude: -84.0824	13.05.2006
Latitude: 40.3631	Longitude: -84.0824	13.05.2005
Latitude: 40.3631	Longitude: -84.0824	09.05.2006
Latitude: 40.3631	Longitude: -84.0824	17.04.2004

Latitude: 40.3631	Longitude: -84.0824	22.01.2007
Latitude: 40.3631	Longitude: -84.0824	13.02.2006
Latitude: 40.3631	Longitude: -84.0824	21.05.2004
Latitude: 40.3631	Longitude: -84.0824	15.04.2006
Latitude: 40.3631	Longitude: -84.0824	09.01.2006
Latitude: 40.3631	Longitude: -84.0824	08.12.2005
Latitude: 40.3631	Longitude: -84.0824	21.02.2007
Latitude: 40.3631	Longitude: -84.0824	03.02.2006
Latitude: 40.3631	Longitude: -84.0824	18.04.2004
Latitude: 40.3631	Longitude: -84.0824	26.05.2006
Latitude: 40.3631	Longitude: -84.0824	08.04.2006
Latitude: 40.3631	Longitude: -84.0824	18.04.2004
Latitude: 40.3631	Longitude: -84.0824	11.01.2006

Appendix C: Forest cover map
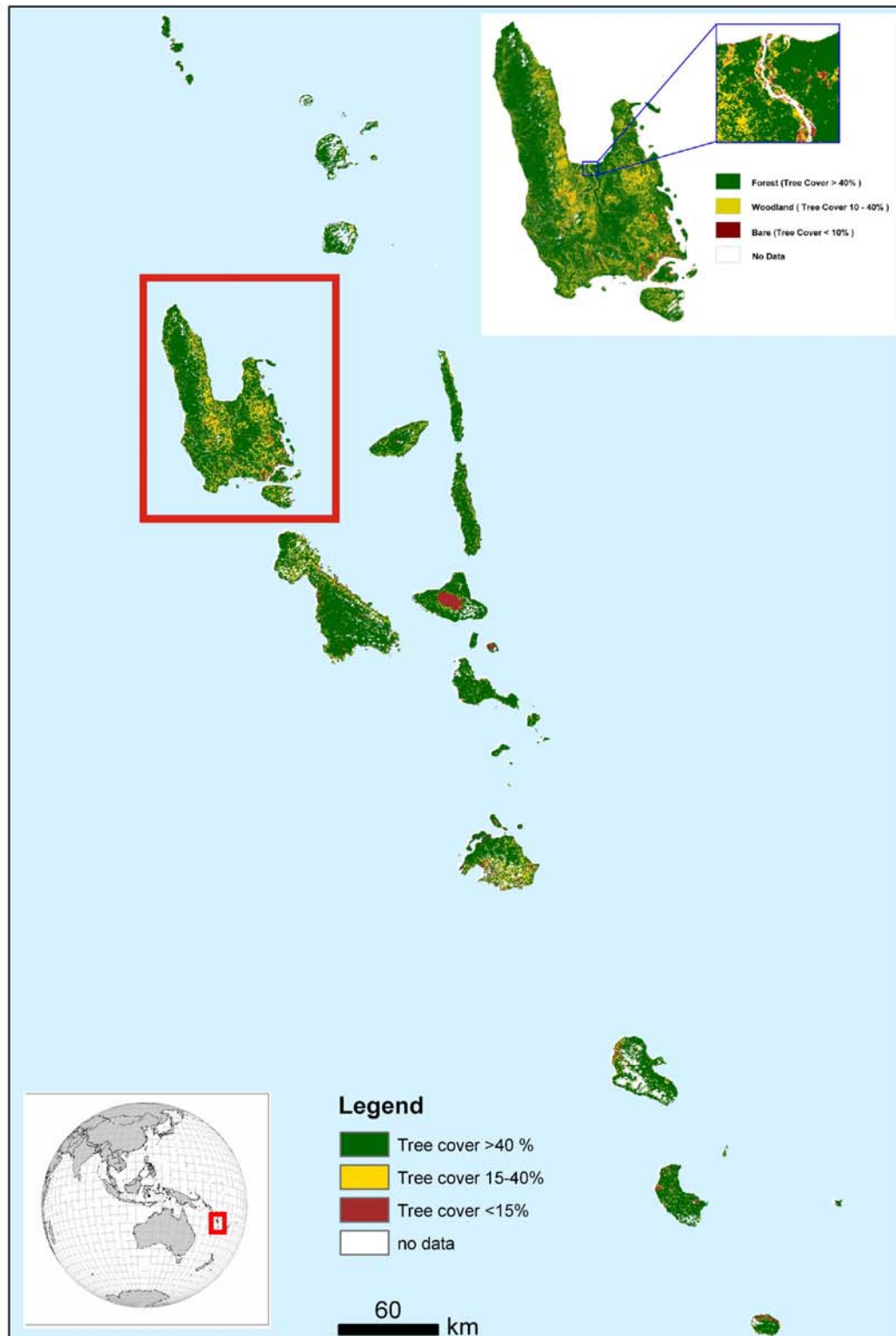
Appendix D: Deforestation maps for different islands and island groups

Legend

1990-2000 deforestation observed from satellite data

■ Loss of forest
□ No forest change
■ No change data
— Roads

5.920 ▬ m

Ambrym

Paama

Lopevi

Epi

Futuna

Legend

**1990-2000 deforestation
observed from satellite data**

Loss of forest
No forest change
No change data
— Roads

7.200
m

Anatom

Efaté

Legend

**1990-2000 deforestation
observed from satellite data**

Loss of forest
No forest change
No change data
— Roads

5.725
■■■ m

Legend

**1990-2000 deforestation
observed from satellite data**

- 🟥 Loss of forest
- ⬜ No forest change
- ⬛ No change data
- — Roads

6.460 ___ m

Epi

Shepherd Islands

Erromango

Legend

**1990-2000 deforestation
observed from satellite data**

- Loss of forest
- No forest change
- No change data
- Roads

5.075
m

Îles Banks

Ureparapara

Vanua Lava

Mota Lava

Legend

1990-2000 deforestation observed from satellite data

■ Loss of forest

□ No forest change

▨ No change data

— Roads

7.500 m

Santa Maria

Legend

1990-2000 deforestation
observed from satellite data

■ Loss of forest
□ No forest change
▨ No change data
— Roads

6.570
▬▬▬▬ m

Maewo

Ambae

Pentecost

Malakula

Legend

1990-2000 deforestation
observed from satellite data

- Loss of forest
- No forest change
- No change data
- Roads

10.090 ▬▬▬ m

Pentecost

Legend

1990-2000 deforestation observed from satellite data

■ Loss of forest
□ No forest change
■ No change data
— Roads

5.025
━━━━━ m

Santo

Legend

1990-2000 deforestation observed from satellite data

- Loss of forest
- No forest change
- No change data
- Roads

10.030
m

Malo

Aniwa

Tanna

Legend

**1990-2000 deforestation
observed from satellite data**

Loss of forest
No forest change
No change data
—— Roads

4.860
■■■■■■ m

Torres Islands

Hui

Legend

**1990-2000 deforestation
observed from satellite data**

- Loss of forest
- No forest change
- No change data
- Roads

3.470
m

Tegua

Loh

Toga