TOTAL E&P PNG LIMITED

PAPUA LNG

Upstream Environmental Impact Statement

Volume 2: Environmental and Social Baseline

Part 7
Upstream Deforestation Baseline Report

TOTAL
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Upstream Deforestation Baseline Study Report

Papua LNG Project

Total E&P PNG Limited

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EXECUTIVE SUMMARY

Joint venture partners are currently planning the development of the Elk-Antelope gas field, which is located within Petroleum Retention License 15 (PRL-15) in the Gulf Province, Papua New Guinea. Total E&P PNG Limited (TEP PNG), a wholly owned subsidiary of TOTAL S.A (TOTAL) has the largest interest in the Elk-Antelope gas field and is the operator of the Papua LNG Project (the Project) on behalf of the other joint venture partners.

As part of the Project environmental impact statement, and environment, social and health impact assessment (EIS/ESHIA), a Deforestation Study has been commissioned. This report presents the results of the technical study conducted on deforestation as part of the EIS/ESHIA, to assess the status of deforestation prior to project development.

The analysis uses a time series of 30-meter resolution satellite images spanning 2000 to 2014 to calculate "a benchmark" land use and cover changes across the deforestation study area (DSA). Forest and non-forest classes were identified and mapped for all years using multiple satellite images, at a minimum mapping unit of 1 ha.

This information provides a historical change rate and identifies the main drivers of change over this period. The desktop analysis was supported by field work conducted in September 2016. The field verification process improved the quality of mapping by refining the classification and confirming the final condition of the areas of change.

The study area has a high forest cover (95% forested) with a low rate of change. At the start of the assessment period, year 2000 the forest area was calculated to be 438,358 ha. This is considered the benchmark value with any additional area change subtracted from this value. In 2014, some 14 years later the area of forest was calculated to be 435,220 ha – a loss of 3,139 ha. This represents a net change of approximately 0.72% (224 ha/yr) of the total area as at 2000.

Over the benchmark period the main driver of deforestation results from infrastructure developments associated with commercial timber harvesting activities (~80% of the change). The process of timber harvesting is also recorded, but this activity does not typically lead to deforestation.

To date (2016) harvesting activities are confined to the Vailala Blk 3 concession, located south of PRL-15. In addition, as part of development activities by the previous developer, the internal road access to PRL-15 was upgraded. These changes are apparent on the 2014 satellite imagery.

A smaller amount of change, 210 ha is due to subsistence agriculture and village expansion. This corresponds to an annual clearance of around 18 ha/yr.

TABLE OF CONTENTS

EXECUTIVE SUMMARY ..... **II**
TABLE OF CONTENTS ..... **III**
1. INTRODUCTION **1**
1.1 Background 1
1.2 Upstream Terrestrial Biodiversity Study Area and Deforestation Study Area 1
1.3 Technical Study Objectives 8
2. REGULATORY STANDARDS AND FRAMEWORK **9**
2.1 Papua New Guinea 9
2.2 International Standards and Guidelines 10
3. METHODS AND PROCESS **11**
3.1 Satellite Data 11
3.1.1 Processing Method 12
3.2 Land Use and Change Mapping Process 12
3.3 Accuracy Assessment of LULC Maps 13
3.4 Field Verification 15
4. RESULTS **18**
4.1.1 Field Inspection 18
4.1.2 Map Accuracy Results 20
4.2 Forest Change Analysis 21
4.3 Deforestation by Driver 22
4.4 Land Use and Land Cover of the Upstream Terrestrial Biodiversity Study Area 30
4.5 Study Limitations 30
5. CONCLUSION **32**
6. REFERENCES **33**
APPENDIX A – VEGETATION TERMINOLOGY **35**

Tables

Table 3-1: Mapped classes and sub-classes 13
Table 3-2: Distribution of biomass plots by change activity 17
Table 4-1: Accuracy matrix of the land use and change map 20
Table 4-2: DSA 2000-2014 forest and non forest area 21
Table 4-3: 2000-2014 LULC area change and rates 21
Table 4-4: Land cover and use by class for the DSA 22
Table 4-5: Deforestation by driver for the DSA 22
Table 4-6: Upstream terrestrial biodiversity study area LULC classification for 2016 30

Figures

Figure 1-1: Deforestation study area 3
Figure 1-2: DSA forest types and landuse 4
Figure 1-3: Location of forestry concessions 5
Figure 1-4: Existing infrastructure 6
Figure 1-5: The study area overview 7
Figure 3-1: Deforestation Mapping & Analysis Process 11
Figure 3-2: 2014 LULC map accuracy assessment extent 14
Figure 3-3: Field sites and aerial inspection map 16
Figure 4-1: Field verification example 18
Figure 4-2: Field photos of logging roads observed in 2000 and 2007 imagery 18
Figure 4-3: Aboveground biomass intact and harvested forest 20
Figure 4-4: LULC Maps of 2000 (a), 2007 (b) and 2014 (c) for the DSA 24
Figure 4-5: Detailed LULC maps of 2000 (a),2007 (b) and 2014 (c) for the DSA 27
Figure 4-6: LULC map for the upstream terrestrial biodiversity study area in 2016 31

Glossary and abbreviations

Term	Abbreviation/definition
Above Sea level	asl
Business as usual	BAU
Deforestation Study Area	DSA
Diameter at breast height	dbh
Food and Agriculture Organization	FAO
Forest Clearance Authority	FCA
Forest Inventory Management System	FIMS
Forest Management Agreement	FMA
Forestry	Refers to large scale commercial forestry operations incorporating harvesting (logging) activities
Geospatial Data Abstraction Library	GDAL
Global Observation on Forest and Land Cover Dynamics	GOFC-GOLD
Geospatial Modeling Environment	GME
Kyoto Protocol	KP
The Logging Code of Practice	LCOP
Light Detection and Ranging	LIDAR
Land use/land cover	LULC
Planning, Monitoring and Control Procedures	PMC
Papua New Guinea	PNG
Papua New Guinea Forest Authority	PNGFA
Reducing Emissions from Deforestation and Degradation	REDD+
Timber Authority	TA
Timber Permit	TP
United States Geological Survey	USGS

1. INTRODUCTION

1.1 Background

The following Project description is focused on the upstream components of the Papua LNG Project and aims at providing minimal but appropriate context for the baseline reports.

Joint venture partners are currently planning the development of the Elk-Antelope gas field, which is located within Petroleum Retention License 15 (PRL-15) in the Gulf Province, Papua New Guinea. Total E&P PNG Limited (TEP PNG), a wholly owned subsidiary of TOTAL has the largest interest in the Elk-Antelope gas field and is the operator of the Papua LNG Project (the Project) on behalf of the other joint venture partners.

The Elk-Antelope gas field is a significant gas discovery in Papua New Guinea consisting of a gas reservoir with several trillion cubic feet of gas reserves located approximately 120 km inland from the township of Kerema, and 340 km northwest of Port Moresby.

The Project will comprise upstream production well development and associated infrastructure at the gas field within PRL-15, construction of an upstream central processing facility (CPF) and delivery of gas and condensate via onshore and offshore export pipelines to a LNG Plant site at Caution Bay, Central Province, 20 km northwest of Port Moresby. The design life for the Project will be 25 years.

The Project area comprises the physical footprint of the various Project components and associated infrastructure as detailed below.

- Production, processing and related facilities (within PRL-15 and the export pipeline corridor):
  - Wellpads and the associated gathering system (including flowlines and trunkline).
  - CPF.
  - Logistics base and river offloading facilities, accommodation camps, airstrip, roads and bridges.
  - Quarries, communications infrastructure.
  - Initial section of the onshore export pipeline.
- Onshore pipeline (outside PRL-15):
  - Remainder of the onshore export pipeline to landfall on the Gulf coast including valve stations.
  - Temporary laydown areas and camps.
  - Quarries, communications infrastructure.
- Transport (river) corridors:
  - River transport routes — the Purari, Urika-Ivo and Wame-Varoi rivers.
- Offshore pipeline:
  - Offshore section of the export pipeline to a LNG Plant site, Caution Bay.

As part of the Project environmental impact statement, and social and health impact assessment (EIS/ESHIA), a terrestrial biodiversity baseline study has been commissioned to provide a baseline characterization of terrestrial biodiversity and conservation values present in the vicinity of the upstream Project area. This report presents the results of the technical study on deforestation conducted as part of the upstream terrestrial biodiversity baseline study to predict future deforestation based on modeling historical rates of deforestation.

1.2 Upstream Terrestrial Biodiversity Study Area and Deforestation Study Area

The upstream terrestrial biodiversity study area (hereafter ‘study area’) covers approximately 7,290 km2 of the Gulf Province lowlands (to c. 600 m above sea level (asl)). The study area is divided into five ecological zones, each of which is expected to support a distinct assemblage of terrestrial biota— the Middle Purari Hills, Southeast Hills, Delta Swamps and Plains, Mangroves, and Southeast Coast.

The study area encompasses the upstream project area of influence (upstream PAOI), the area within which the Project may potentially and measurably impact biodiversity. The terrestrial biodiversity field surveys were focused at representative sites within the upstream PAOI, hereafter referred to in this

report as survey sites. Further description of the PAOI is provided in the main Upstream ESBS report and is no longer referred to in this report.[1]

The study area is shown in Figure 1-1. The ecological zones are described in more detail in the Upstream Terrestrial Biodiversity Baseline Report.

The deforestation study area (DSA) is a subset of the upstream terrestrial biodiversity study area (Figure 1-1) and covers approximately 461,817 ha. The boundaries of the DSA were determined from a preliminary analysis of the most recent satellite imagery, forest type layers, natural features (rivers and terrain), habited areas, wildlife management areas, harvest planning layers and existing infrastructure. This approach identified that the potential extent of the area of influence of the Project on the surrounding forest is constrained principally by accessibility. Areas that have the potential for exploitation are located around existing roads. Using this assumption, a buffer area extending 20 km from all existing or identified alternative pipeline routes, including infrastructure was generated (area shown by the purple hatching in Figure 1-1). A larger DSA was not considered necessary since it is unlikely that any forest cover loss beyond the DSA will be related to the Project due to its remoteness.

The majority of the DSA (more than 96%) is covered by nine vegetation types as described in PNG's Forest Inventory Management System (FIMS). Approximately 3% of the area includes rivers and water bodies. Infrastructure developments (roads and villages) and subsistence agriculture consist of less than 1% of the area.

Hill forest (Hm & Hs) is the dominant forest type, covering approximately 56% of the area. Other forest types include Swamp forest (Fsw) at approximately 15%, alluvial forest at 12%, Swamp woodland (Wsw) at 9% and Mangrove (M) at 4%. Approximately 7% of the area is dominated by hill forest that is located in a wildlife management area. The area is sparsely populated and most of the villages are in the southern part of the study area near the coast in Orokolo Bay. The forest types and land use across the area are shown in Figure 1–2 (the vegetation terminology is defined in Appendix A). The DSA area also has two major logging concessions namely Baimuru Block 3 and Vailala Block 3 and a third, Vailala, overlaps the southeastern boundary of the DSA (Figure 1–3).

Existing infrastructure across the DSA is mostly confined to roads south of PRL-15. These roads are associated with forest harvesting activities. An access route has also been developed recently inside PRL-15 that links Herd Base to the gas exploration area. Planning maps indicated that other facilities including well pads, a central processing facility, and pipelines are being considered. Figures 1–4 and Figures 1–5 show the location of existing infrastructure and an overview of the upstream terrestrial biodiversity study area, the DSA and the study area. The map of study areas also shows the proposed offshore pipeline corridor.

[1] The boundary of the PAOI is shown in figures for context only.

Figure 1-1: Deforestation study area

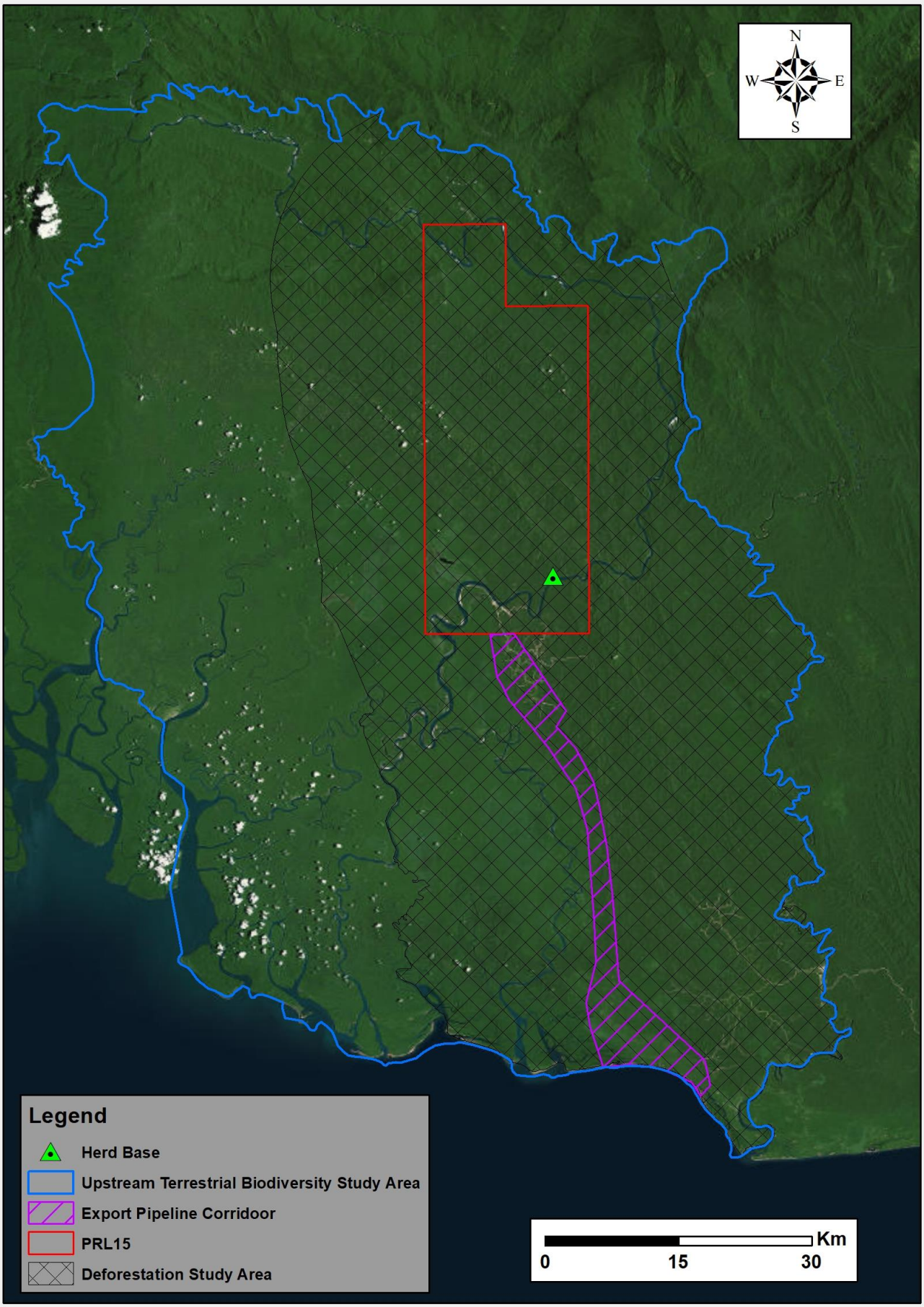


Figure 1-2: DSA forest types and landuse

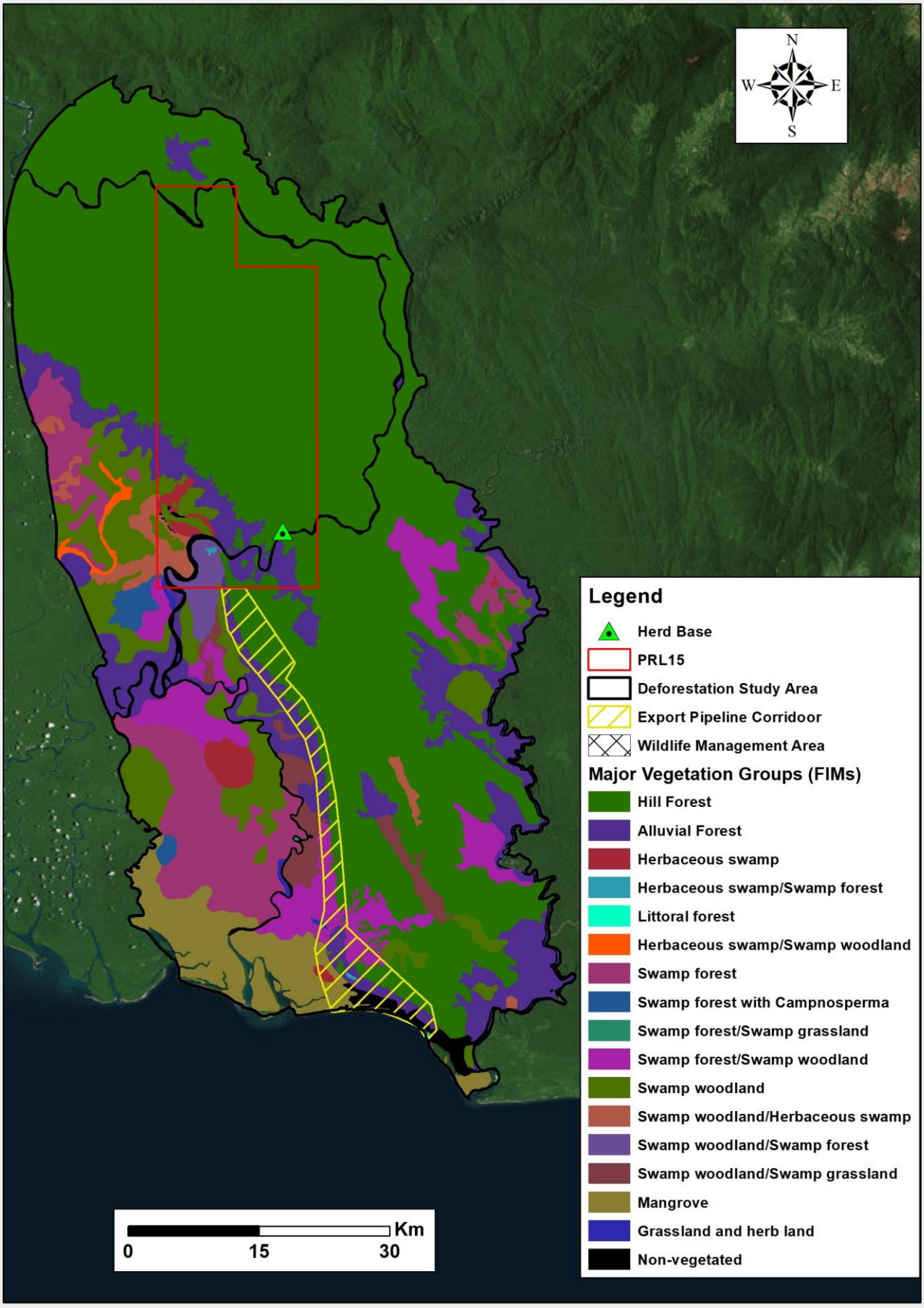


Figure 1-3: Location of forestry concessions

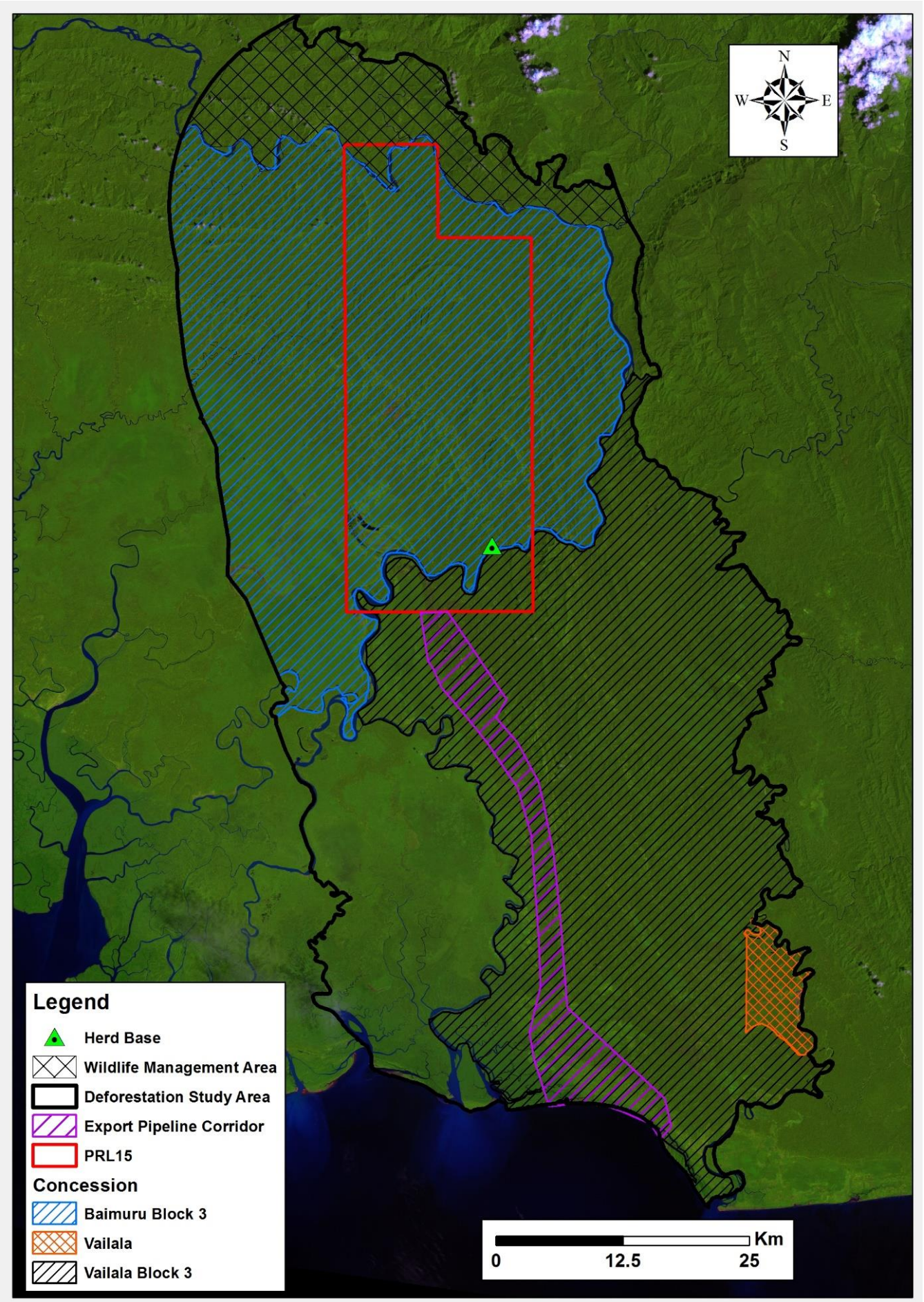


Figure 1-4: Existing infrastructure

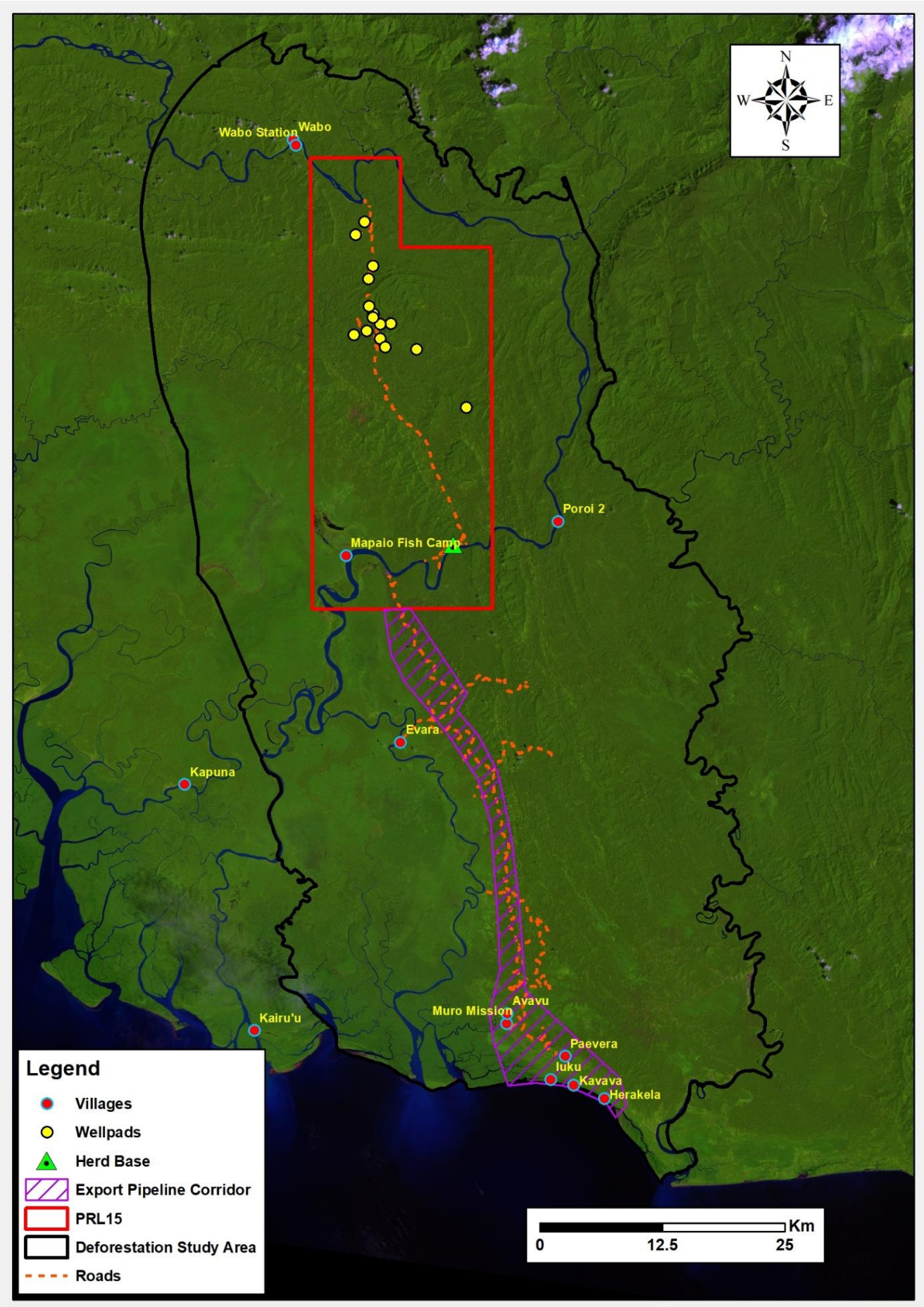
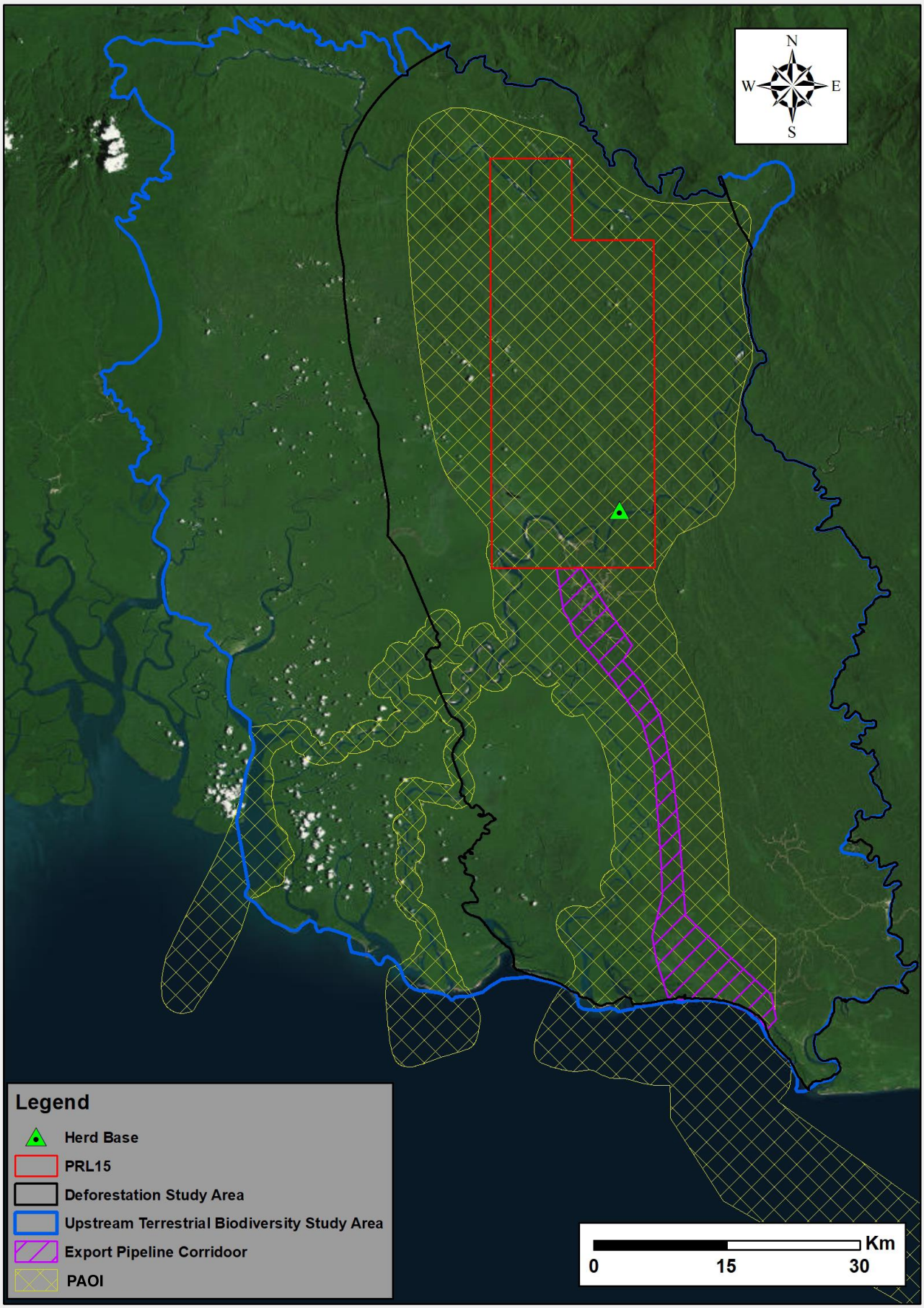


Figure 1-5: The study area overview



1.3 Technical Study Objectives

The objectives of this baseline technical study are:

1. The review of the national regulatory requirements and international standards in terms of deforestation.
2. The determination of historic levels of deforestation and forest degradation within the Project area including all forest habitats (hill forest, alluvial forest, swamp forest and mangroves) in the project area of impact and region.
3. Determining the current non-Project related deforestation activities in the Project area.

An impact assessment for the EIS/ESHIA will follow the baseline study. The objectives of which will include the following:

- The determination of the magnitude of potential deforestation and forest degradation due to the development of the Project.
- The prediction of the deforestation with and without the Project.
- The development of proposed mitigation measures to lessen the extent of environmental and social impacts due to deforestation.
- To inform and support the protection and conservation of biodiversity within the immediate Project area and the greater region in PNG, by means of reducing negative Project related impacts and enhancing positive impacts.
- The prediction of positive impacts from the Project offset strategy (if any) on deforestation issues.
- The assistance to the Project to conserve priority ecosystems, protect critical habitats and species and account for residual impacts, and
- Meeting the PNG Government and Project lenders' requirements, i.e. project financiers and the broader stakeholder community.

2. REGULATORY STANDARDS AND FRAMEWORK

2.1 Papua New Guinea

Commercial harvesting activities are covered by the Forestry Act which has been subject to four amendments (1993,1996, 2000 and 2005). This act allows landowners to assign their timber rights to the PNG government which issues permits to forest industry participants (Wilkinson, 2013). Forest harvesting is selective with trees ≥ 50 cm diameter at breast height (dbh) removed. On average, this is equivalent to an extraction rate of between 18 - 30 m^3/ha, which is about 50% of the original standing volume.

The general consensus is that harvested areas will recover gradually (1 m^3 ha^{-1} yr^{-1}) if not further degraded by fire or subsistence agriculture (Wilkinson 2013).

For non-traditional harvesting and clearance activities the Forestry Act sets out four options as described below:

1. Timber Permit granted for a Forest Management Agreement (FMA).

   Timber Permits (TP) are required for large-scale harvesting operations. The process and procedure is detailed and requires Ministerial consent. It requires and considers the following:

   – Forest inventory
   – The economic potential of the forest resources
   – Includes a tender process
   – Project agreements with government, landowners and the developer
   – Environmental permit and granting of timber permits.

   On approval, five-year and one-year development plans are submitted. Annual working plans are approved by the Papua New Guinea Forest Authority (PNGFA).

2. Timber Authority

   A Timber Authority (TA) is granted by the chairman of the Provincial Forestry Committee. Applications are made for areas that do not exceed harvest levels greater than 5,000 m^3/yr (natural and plantation forests). The harvested timber must be processed domestically. It also covers the removal of timber to create agricultural areas <50 ha and the construction of roads < 12.5 km in length.

3. Forest Clearance Authority

   A Forest Clearance Authority (FCA) may be granted by the National Forest Board to carry out any agricultural or other land use development where the amount of proposed clearance of natural forest for the project is > 50 ha in total or the road construction exceeds 12.5 km in length.

   The FCA is subject to the approval of the National Executive Council on the recommendation of the Minister and following review by the National Forest Board and relevant Provincial Forestry Management Committee.

4. License

   Other activities not covered under the TP or TA.

   Regulation is achieved through a combination of self-regulation by forest companies and compliance and monitoring by the PNGFA. The Logging Code of Practice (1996) and Planning, Monitoring and Control Procedures (PMC) contain standards for road and track construction, felling, log landings and buffer zones surrounding watercourses. The LCOP and PMC regulations are relevant to all activities except for a FCA.

For traditional landowner harvesting and clearing activities no permits are required by landowners when forests are being cleared for traditional use. Landowners, however, are not allowed to trade in forest products unless they obtain the appropriate documentation set out in the Forestry Act (1991).

In addition to the forestry specific regulations the following acts and guidelines are applicable:

1. Environment Act 2000 – outlines the environmental and social impact assessment process and rights of customary landowners.
2. Conservation and Environmental Protection Authority (CEPA, formerly Department of Environment and Conservation (DEC)) guideline GL-Env02/2004: Guideline for Conduct of Environmental Impact Assessment & Preparation of Environmental Impact Statement (DEC, 2004) – assists developers meeting their legal obligations of the Environment Act.

The Forestry Act and associated regulations are unlikely to be applicable to the Project unless any timber is sold commercially from cleared forest. However, it is applicable to others who may be involved in the sale of harvested timber to the Project.

2.2 International Standards and Guidelines

For deforestation, a formal international framework, to which Papua New Guinea is a signatory, has been developed that allows countries to report on rates of forest change. This is known as Reducing Emissions from Deforestation and Degradation (REDD+) framework / Kyoto Protocol (KP)[2].

Under this definition forest "is a minimum area of land of 0.05–1.0 ha with tree crown cover (or equivalent stocking level) of more than 10–30 per cent with trees with the potential to reach a minimum height of 2–5 meters at maturity. A forest may consist either of closed forest formations where trees of various storeys and undergrowth cover a high proportion of the ground or open forest. Young natural stands and all plantations which have yet to reach a crown density of 10–30 per cent or tree height of 2–5 meters are included under forest, as are areas normally forming part of the forest area which are temporarily unstocked as a result of human intervention such as harvesting or natural causes, but which are expected to revert to forest[3]".

Many countries have set a minimum area of 0.5 to 1 ha for monitoring. In this study, the official definition for PNG has been applied which adopts a threshold of 1 ha. In the context of the study area, areas are only considered as deforestation if the forest cover is permanently removed, or the canopy cover falls below 10% (i.e., as occurs if forest is converted to roads, or agriculture)[4]. Forest degradation occurs when there is a continual and frequent removal of biomass. Commercial harvesting if conducted under the PNGFA guidelines is not considered as degradation as only unsustainable logging is identified as a driver of degradation (Hosonuma *et al.* 2012) unless the forest is continually degraded, or unable to regenerate. Wilkinson (2013) noted that in harvested areas that are heavily logged, or subject to a secondary impact by fire or subsistence activities, forest recovery is then less likely. Eventually these areas may transition to a deforested state.

The methods employed in this study adhere to recognized best practice as set out in the GFOI (2016) documentation. Using recognized methods forest area changes are identified and mapped at three points in time; 2000, 2007 and 2014. This information is subsequently used to analyze trends in area change and drivers.

Other relevant guidelines include:

Total E&P guideline for Environmental Monitoring and Baseline Studies: Onshore sites, GS EP ENV 111 – provides general guidelines in relation to biodiversity studies.

[2] http://unfccc.int/essential_background/convention/items/6036.php

[3] In the Forest Resource Assessment 2010 FAO defines Forest as Land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use. The area threshold falls within the range in the KP definition and the height threshold is at the upper end of the KP range.

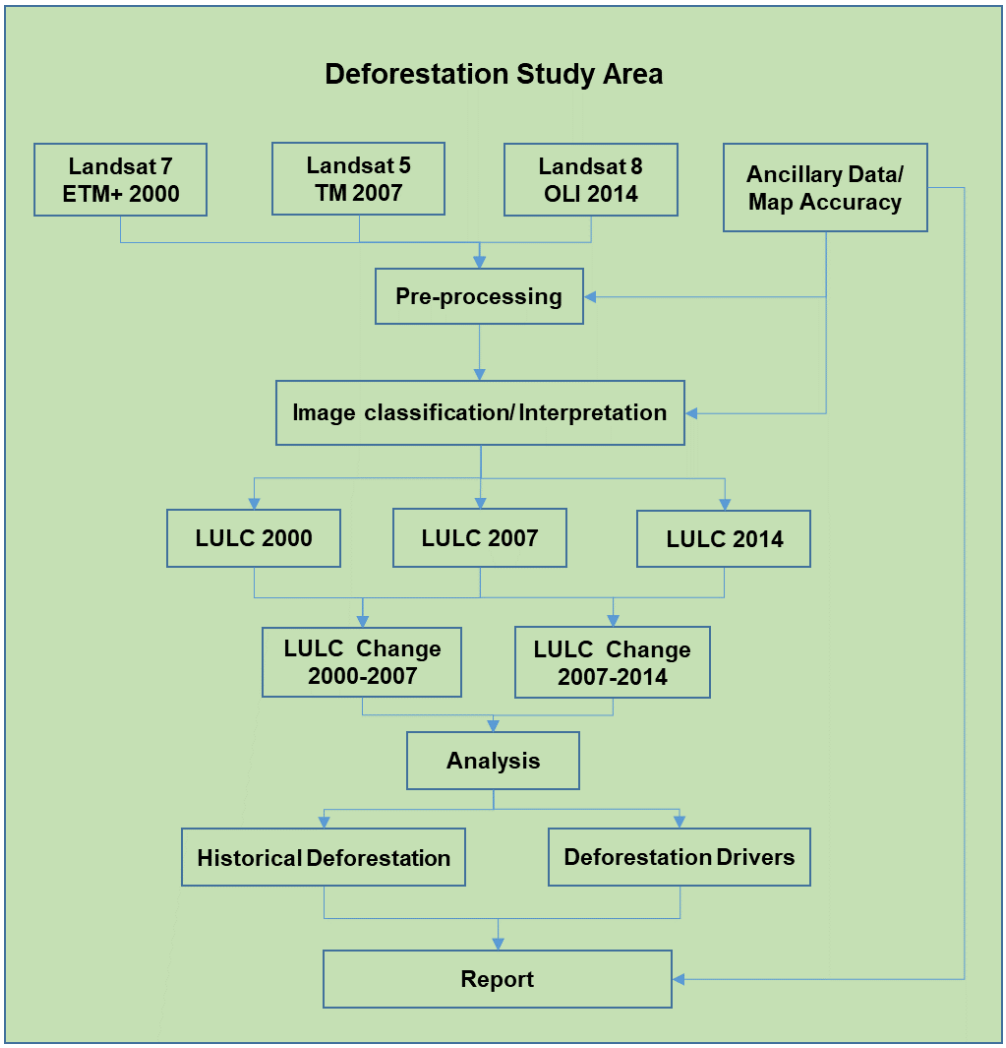
[4] http://redd.unfccc.int/submissions.html?country=PG

3. METHODS AND PROCESS

The analysis was conducted using the extent of the DSA which is based on preliminary analysis of the satellite imagery as outlined in Section 1.2. This analysis determined that the area of influence of the Project on the surrounding forest is constrained principally by accessibility.

The remaining tasks involve the identification of suitable imagery for the period 2000 to 2014 the processing of these images and classification to enable the mapping of land use and land cover (LULC) and change. The final element involves the determination of the accuracy of the thematic and change maps. The mapping and analysis process is set out in Figure 3–1.

Figure 3-1: Deforestation Mapping & Analysis Process



3.1 Satellite Data

The first aspect involves the analysis of historical deforestation and forest degradation to establish the baseline land use/land cover change rate. This information is used to create a benchmark map as at the project start date.

Medium spatial resolution 30 m Landsat 7 ETM+ imagery drawn from year 2000, Landsat 5 TM 2007 imagery and Landsat 8 OLI 2014 imagery provide complete coverage across the DSA. These images occupy the same image path (097) and row (065) and were the main dataset used to produce the LULC maps.

As no single cloud-free image covered the area, at least three scenes for each year were analyzed. These images were downloaded from United State Geological Survey (USGS). The 30 m resolution Landsat imagery is appropriate and is widely used to map land cover change including deforestation. For reference an example of one of the images analyzed is provided in Figure 1–3.

In addition, high resolution aerial imagery collected in 2014 and 2015 were assessed. The photography provides coverage across part of DSA and was used to assess the accuracy of the

Landsat-derived LULC maps. The photography coverage includes the most active area of change which is located south of PRL-15 and herd base. The 2016 LIDAR data was also used to assist with project planning however, this dataset does not cover the complete DSA, so the aerial imagery was used as the coverage met the validation requirements.

In addition to image datasets, ancillary datasets were also used to assist with the generation of the LULC change maps. These datasets including forest concession boundaries, project development layers, forest type boundaries, mapped road networks and field photos.

3.1.1 Processing Method

A typical LULC mapping approach involves pre-processing of satellite imagery, interpretation or classification of imagery and post-processing of the maps produced. Pre-processing of the imagery involves various steps to make the imagery ready for interpretation or classification. The steps taken were as follows:

- **Layer stacking:** The images acquired from USGS were received as separate files for each spectral band. A stack of multiple bands assists with the interpretation of the imagery. Therefore, stacks of all reflective bands in GeoTIFF format (band 1-5 and 7 for TM and ETM+ and band 2-7 for OLI) were created using GDAL utilities tools (http://www.gdal.org/).
- **Geometric correction:** Geometric correction is required to ensure that the multiple images across the period correctly overlay each other. All acquired imagery is standard terrain correction products which are corrected for geometric accuracy using ground control points and a digital elevation model. The accuracy however depends on the quality of ground control points and the resolution of the digital elevation model used. All images were examined for geometric consistency by overlaying each and comparing them against an independent dataset. All images were assessed as geometrically correct and with the co-registration accuracy at a sub-pixel level.
- **Radiometric correction:** The scenes were not radiometrically corrected as the change mapping outputs were visually verified.

3.2 Land Use and Change Mapping Process

A hybrid approach of automation and manual interpretation was used to classify the imagery in different LULC classes. Extraction of rivers and water bodies was carried out automatically whereas other changes were interpreted manually. Forest and non-forest classes were identified and mapped for all years using multiple image layers, using a minimum mapping unit of 1 ha.

Within the forest class, selectively logged areas for each period were mapped using the location of logging roads and landings as proxies. It is well documented that canopy disturbance caused by selective logging is not detectable using an infrequent coverage of satellite imagery, as after one growing season disturbed areas regain vegetative cover (Mitchell et al 2017).

The method concentrated on mapping harvesting as observed from each image acquisition date. Once detected, the distance of disturbance was measured using a selection of logging roads and landings. This buffer distance (500 m)[5] was then applied to each road and landing and used to estimate the area harvested. While the forest canopy has been disturbed, it is not possible to quantify the level of degradation caused by harvesting activities. The forest and non-forest classes were divided by subclasses as shown in Table 3–1.

[5] The 500m buffer was established by measuring the distance from the logging road to the extent observed on the images. Several samples were measured and this was the average distance observed.

Table 3-1: Mapped classes and sub-classes

Class	Sub-class	Description
Forest	Forest	Intact forest
	Harvested area	Selectively logged area, but still forested
Non-forest	Bare ground	Bare Ground (cleared areas)
	Non-forest	Agriculture and other non-forest land use
	Rivers	Rivers
	Roads	Roads including logging tracks
	Water Bodies/ Swamp	Other water bodies and areas of swamp

All classes extracted were merged in a single geographic layer to produce LULC map for each year. The 2000, 2007 and 2014 LULC maps were used to calculate the area of forest to non-forest change for 2000-2007 and 2007-2014 periods.

Once this mapping had been undertaken imagery from 2016 was classified to determine the most recent map classes for the entire upstream biodiversity terrestrial study area (study area) using the same process.

3.3 Accuracy Assessment of LULC Maps

The purpose of the map accuracy assessment is to determine the accuracy of the thematic and change maps. The recognized method for assessing map accuracy is to compare the mapping results against either field observations, or high-resolution imagery. This assessment is an important component as it provides a quantitative measure of the quality of the LULC mapping.

It is recognized that land cover maps derived from remotely sensed data inevitably contain error to a varying degree. Quantification of this error is an important aspect as it allows their appropriateness for a specific use to be assessed (Congalton and Green, 1998). The accuracy assessment task focused on the accuracy of the thematic LULC map produced from 2014 Landsat 8 satellite imagery. Use of appropriate validation data is a critical component of any accuracy assessment task (Herold *et al*, 2006; Powell *et al* 2004). However, it is not always easy to obtain high resolution reference data sets particularly for historical time frames (GOFC-GOLD, 2011).

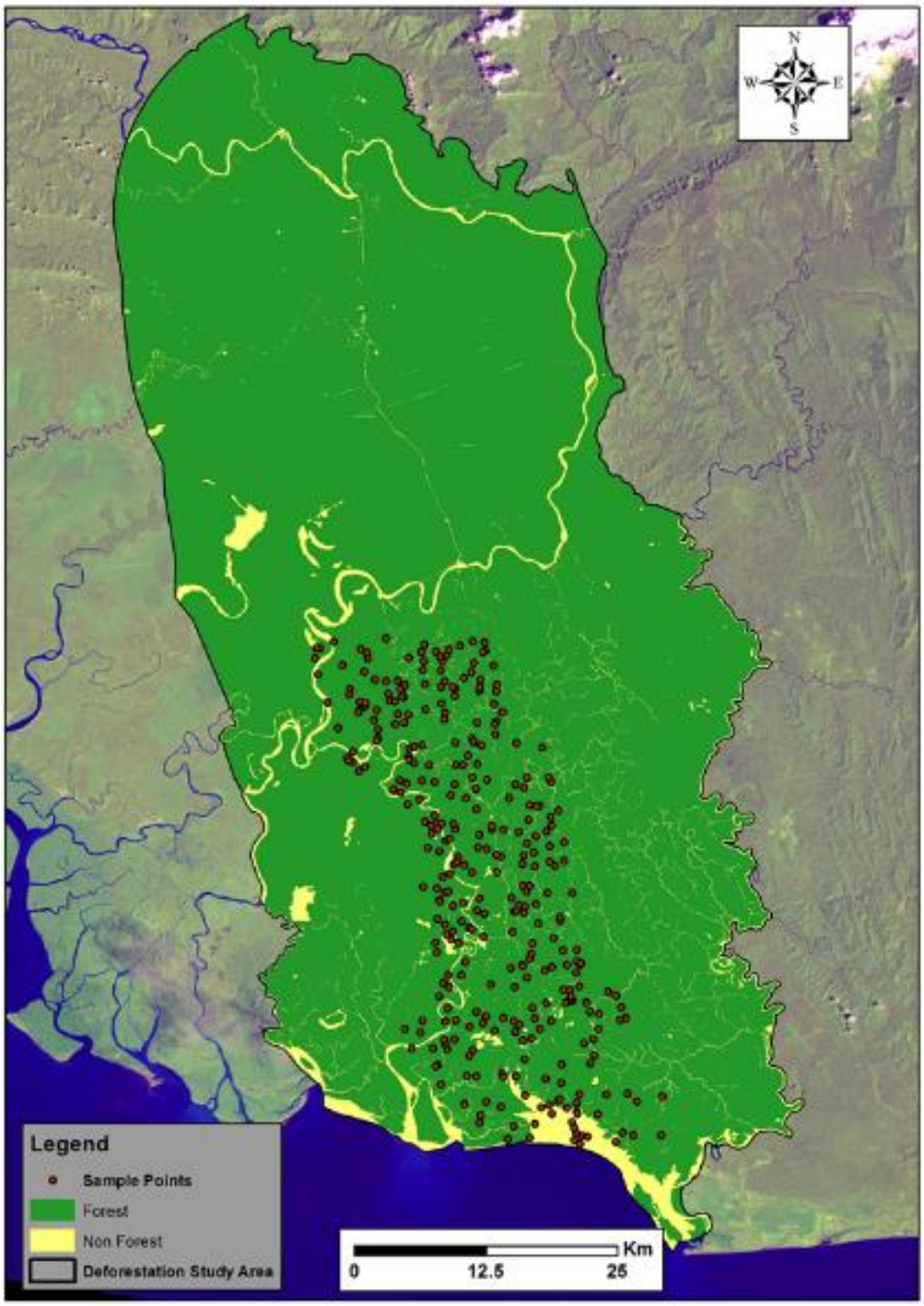
In this case, the reference dataset used for the assessment was drawn from the high-resolution aerial photography captured in 2014 which provides coverage south of PRL-15 and herd base.

The LULC was divided in to two thematic classes: Forest and non-forest and the accuracy was assessed using the following well-established process and criteria.

- Select the map classes to be assessed and identify the data to be used for validation.
- Calculate the number of sample points to be assessed.
- Select the sample points using an appropriate random, or stratified sampling design.
- Conduct the sampling.
- Interpret the aerial photography based on the minimum mapping unit used to create the LULC map.

Using the available photography, a two-phase sampling strategy was adopted that drew samples from the area shown in Figure 3–2. This area covers 84,280 ha which is approximately 18% of the DSA.

Figure 3-2: 2014 LULC map accuracy assessment extent



In the second stage, minimum sample size was determined, and stratified random sampling was used to distribute the sample points across different LULC class proportionately to the area of each class. The minimum sample size required for assessing accuracy of any map depends on allowable error, confidence interval required and the overall accuracy of classified map itself. The following equation is based on binominal probability theory which defines the relationship between sample size, allowable error and map accuracy. These parameters are assessed to estimate the number of points required to assess the map accuracy (van Genderen and Lock, 1977; Fitzpatrick-Lins, 1981, Marsh *et al*., 1994).

$$N = \frac{z^2pq}{e^2}$$

N = Number of sample points

z = Standard normal deviation for the specified (two tail) confidence interval e.g. 1.96 for 95%

p = Expected or calculated map accuracy in percentage

q = 100 - p

e = allowable error in percentage

A recognized allowable error threshold for change mapping is 10% (Congalton, 1991). In this instance, a higher 5% threshold was set at the 95% confidence interval. As there in no a priori information of the thematic accuracy of the LULC map, an assumption of overall accuracy of the map is required. The assumption of minimum 70% accuracy was made which effectively increases the sample size. Based on this level a sample of ~323 assessment points were calculated.

The actual accuracy of the LULC map could be higher, but a conservative approach that uses a greater number of points is preferred as there is always a possibility that some points will not be suitable – due to cloud. If the map accuracy is higher than initially estimated, then the allowable error will decrease (<5% in this case).

The proportional distribution of sample size yielded 307 points for forest class alone and only 23 points for non-forest. The number of points for non-forest class was increased to 35, as more than 30 sample points are generally recommended in the literature as a minimum for each class (van Genderen and Lock, 1977). The effective sample size therefore increased to 342. The sample points for each class were then distributed randomly across the respective class using Geospatial Modelling Environment (GME) version 0.7.1.0.

To assess the accuracy, the point map generated by randomization of the sampling points for the two strata (thematic classes) were imported into the GIS and overlaid on the reference dataset.

The land cover class at each point was interpreted sequentially on high resolution reference photography and the classification recorded in the attribute table. As the minimum mapping unit used to generate the LULC is 1 ha the majority class around the sample points was also considered. Altogether 330 points were interpreted and recorded. Twelve points were not interpretable due to the presence of cloud, or cloud shadow. The reference samples were compared against the original LULC map. The total number of points in agreement and error were calculated with the data summarized to generate an accuracy matrix (Congalton, 1991).

3.4 Field Verification

The field verification process assists to refine the image classification by comparing the mapping to actual ground scenarios. The process is designed to improve the accuracy of the mapping.

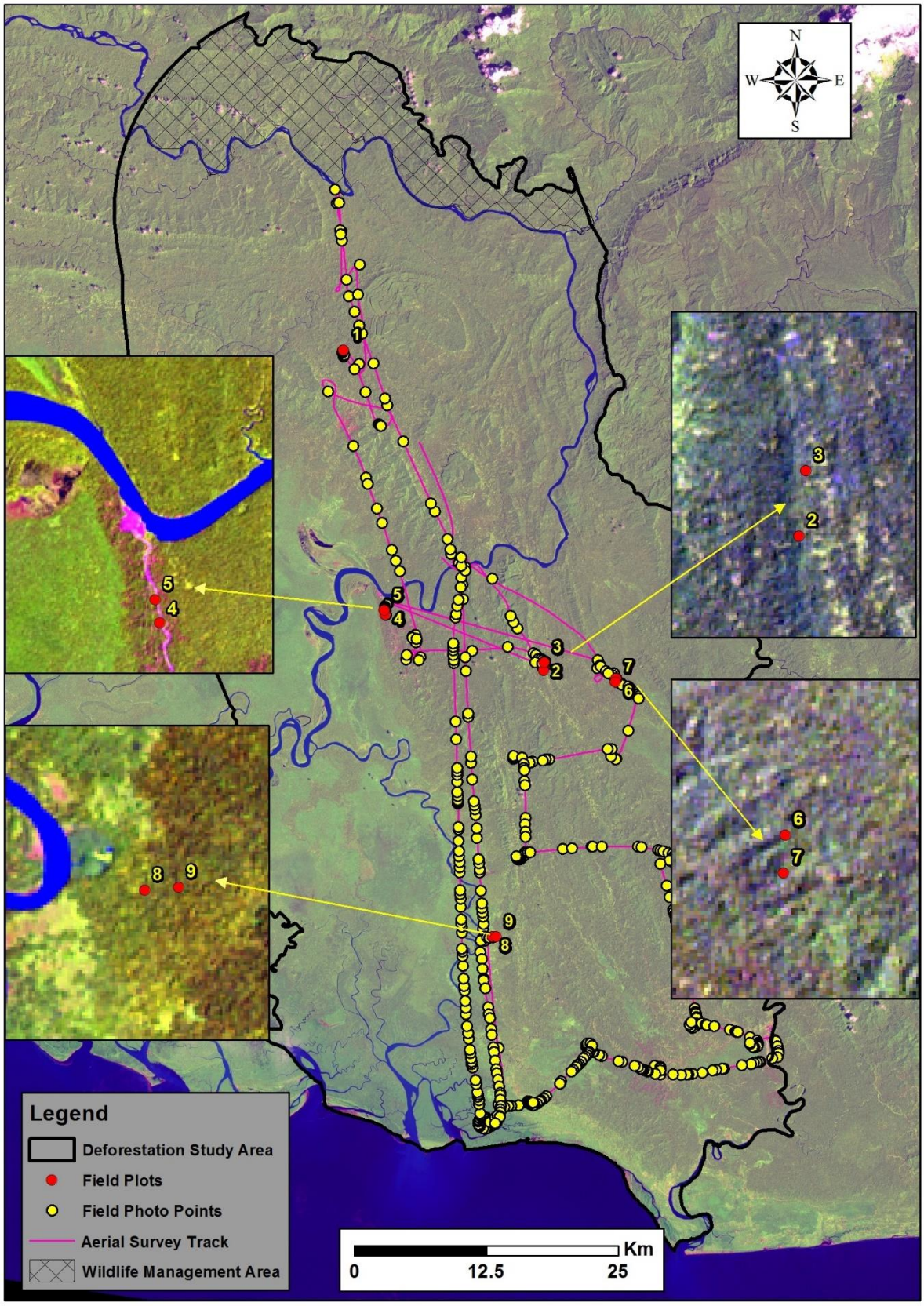
Field work was carried out in September 2016 across the DSA. The objectives of the field verification were to:

- Take field photos to assist in the assessment of the impact of harvesting, i.e., to verify and improve satellite image interpretation and to qualify areas of change.
- Check the regeneration status of logging roads constructed at different time periods.
- Biomass data collection from intact and harvested forests in different time periods to understand the nature and scale of harvesting.

To achieve these objectives, an aerial reconnaissance of the area was conducted. Approximately 500 reference photos were captured as well as locating landing sites required to establish field plots.

Figure 3–3 shows the aerial inspection route and the location of field sites.

Figure 3-3: Field sites and aerial inspection map



Nine field plots were established and biomass measurements made at each. At each, concentric circular plots of 6 m, 14 m and 20 m were established. The smallest plot was used to measure all trees and saplings greater than 2 cm diameter, the medium size to measure greater than 25 cm diameter trees and the largest to record trees greater than 50 cm diameter. Table 3–2 provides a summary of the field plots.

Table 3-2: Distribution of biomass plots by change activity

Plot No	Activity Type	Forest Type	Remarks
1	Intact Forest	Hill forest (Hm)	Undisturbed forest
2	2007 Harvested Area	Hill forest (Hm)	Inspected 2007logging road
3	2007 Harvested Area	Hill forest (Hm)	Inspected 2007 logging road
4	2000 Harvested Area	Hill forest (Hm)	Inspected 2000 logging road
5	2000 Harvested Area	Hill forest (Hm)	Inspected 2000 logging road
6	2014 Harvested Area	Hill forest (Hm)	Inspected 2014 logging road
7	2014 Harvested Area	Hill forest (Hm)	Inspected 2014 logging road
8	2007 Harvested Area	Swamp forest/Swamp woodland (Fsw/Wsw)	Inspected 2007 logging road
9	2007 Harvested Area	Swamp forest/Swamp woodland (Fsw/Wsw)	Inspected 2007 logging road

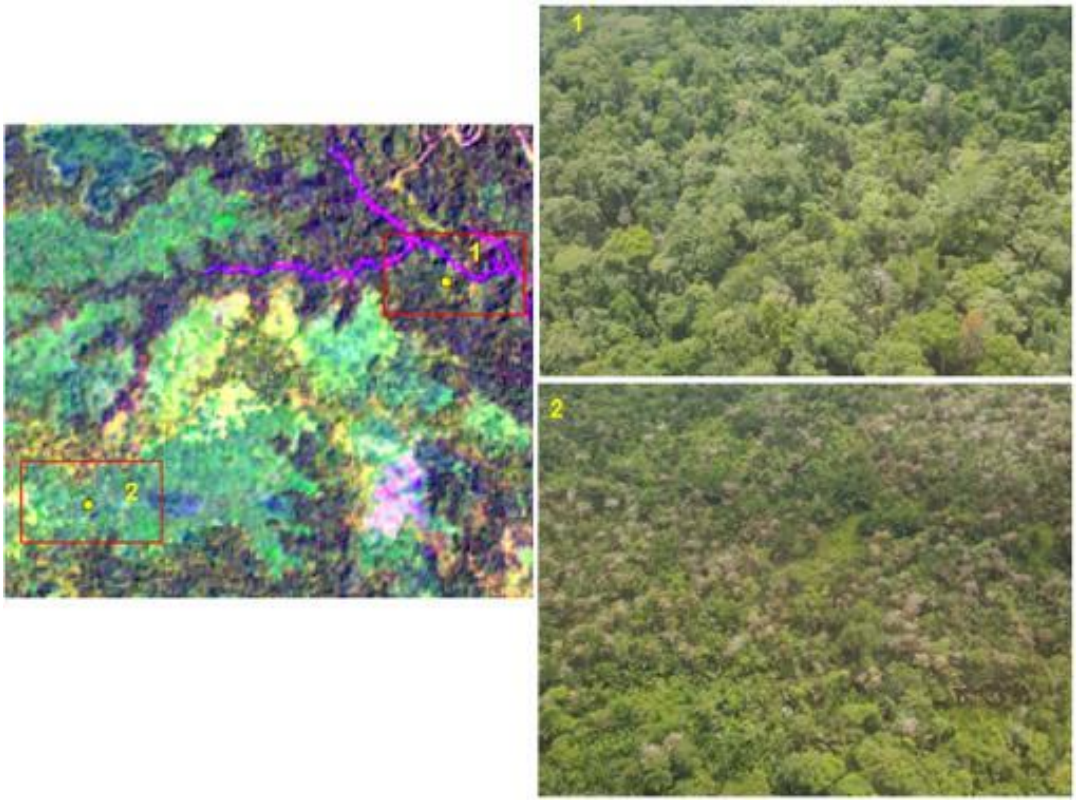
More plots were measured in the 2007 harvest areas, as this period accounted for most of the harvesting. The data provides some insight into the level of biomass lost during harvesting, and time required for biomass recovery. The biomass data collection exercise also provided an opportunity to check regeneration status of the logging roads for the change period.

4. RESULTS

4.1.1 Field Inspection

The aerial inspection and photos were used to verify and improve the LULC maps. On the satellite image, different vegetation types can be identified using a combination of their spectral signature (greenness, or brightness), canopy texture and surrounding forest cover patterns. Figure 4-1 provides an example. Area 1 was inspected to confirm the forest type (Hill forest (Hm)) and Area 2 was inspected to confirm that the area is a natural forest type rather than the result of any change process. Photos corresponding to the LULC areas are included.

Figure 4-1: Field verification example



Both aerial survey and field observations confirmed that no regeneration of woody vegetation occurs on roads constructed post 2000. This means that logging roads will likely remain deforested.

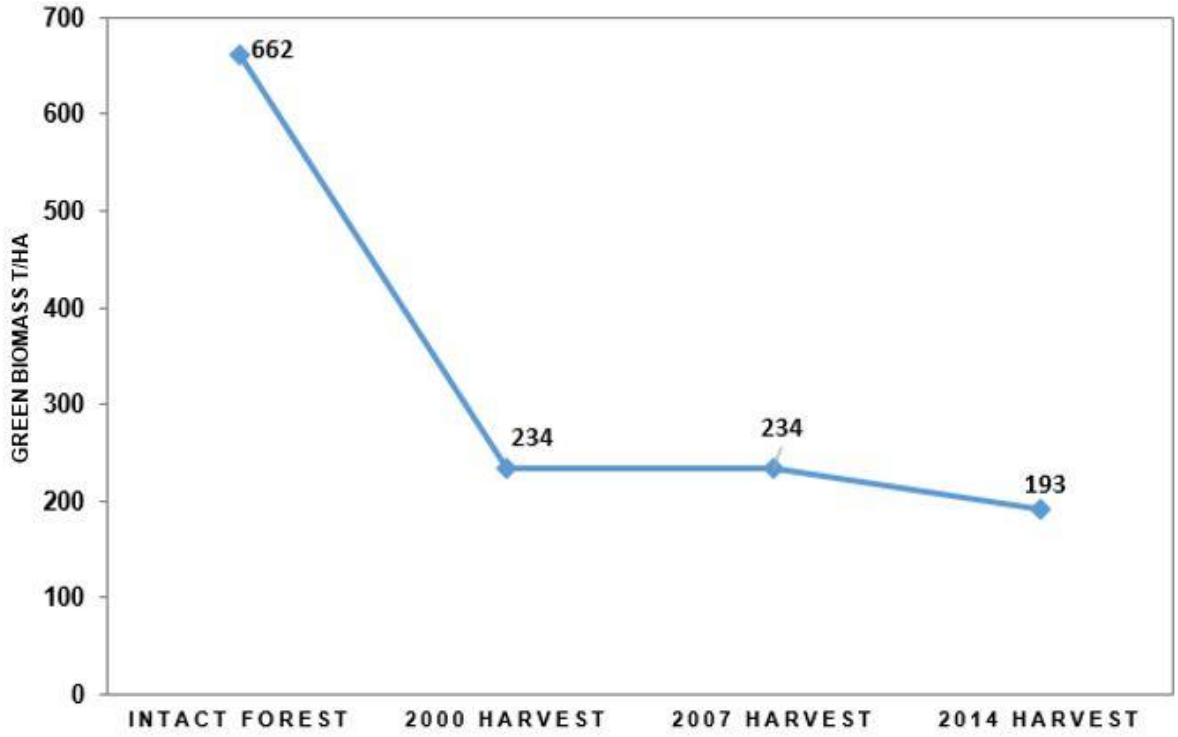
Figure 4-2: Field photos of logging roads observed in 2000 and 2007 imagery

The above ground biomass was calculated using the biomass equation published in Chave et al. 2005. The above ground biomass is calculated from tree diameter and a default wood density value. Figure 4-3 shows the quantity of above ground biomass per ha based on the field plot measurements. Though the number of plots was too few to draw sound statistical inference, it provides an indication of the impact of existing logging practices. The above-ground green biomass for intact forest was 662 t/ha and ranged from 193 to 234 t/ha for harvested areas. Our estimate of unlogged area appears to be higher compared to the estimation reported by Bryan, et al (2010) which was 358 t/ha (SD = 108t/ha, n = 22).

In logged areas, the measurements were similar to their estimate of 98 to 286 t/ha with the overall average being 161 t/ ha (SD = 47t/ha, n = 35).

These estimates indicate that the existing harvesting practices result in the loss of almost 55 -70 % of the biomass.

Figure 4-3: Aboveground biomass intact and harvested forest



4.1.2 Map Accuracy Results

The thematic accuracy of the 2014 LULC map is provided in Table 4-1. The overall accuracy of the map is high and about 98%. Both omission and commission errors[6] for the forest class were 1% and 2%, respectively.

A 5% commission error and 15% omission error were observed for non-forest class. However, the overall accuracy is high, with the mean omission and commission error +/- 10% for all classes. This result means that the map accuracy was well within accepted standards. It is assumed that a similar accuracy exists for the 2000 and 2007 LULC maps and the LULC change map as they were produced using the similar approach.

Table 4-1: Accuracy matrix of the land use and change map

Map Class	Reference Class (2014 Aerial Photography)		Total	User's Accuracy	Commission Error
	Forest	Non-forest			
Forest	**287**	6	293	98%	2%
Non-Forest	2	**35**	37	95%	5%
Total	**289**	**41**	**330**		
Producer's Accuracy	99%	85%			
Omission Error	1%	15%			
Overall Accuracy				**97.6%**	

[6] Errors of *commission* result when mapped areas are incorrectly mapped to another class. Errors of *omission* occur when areas that should have been identified as belonging to a particular class are missed.

4.2 Forest Change Analysis

The analysis showed that in 2000 the forest cover across the DSA was 95%. This has gradually decreased over time, but not at a constant rate. Table 4-2 shows the area of forest and non-forest for each assessment year. The forest area figure also includes harvesting activities as the definition applied considers these areas to be forested. At the start of the assessment period, year 2000 the forest area was calculated to be 438,359 ha. This is considered the benchmark value with any additional area change considered relevant. In 2014, some 14 years later the area of forest was calculated to be 435,220 ha. The main driver of change is identified as commercial timber harvesting.

Table 4-2: DSA 2000-2014 forest and non forest area

Year	Land Cover		
	Forest	Non-forest	Total Area
	Area (ha)		
2000	438,359	23,458	461,817
2007	436,397	25,420	461,817
2014	435,220	26,597	461,817

Calculating Change Rates

The rate of annual change calculation is based on the subtraction of the starting forest area less the end of period forest area, less any afforestation (Table 4-3). For example, the rate of change in the first period (2000-2007) uses the starting 2000 forest area of 438,359 ha and subtracts the 2007 forest area of 436,397 ha to give a change value of 2,152 ha. The net change is calculated by deducting any areas of non-forest that regenerate back to forest, in this case 190 ha.

Overall the net deforestation for the 2000-2007 period was 1,962 ha which is low and represents a net change of approximately 0.45% of the total forest area as at 2000.

Between the 2007-2014 period the change rate slowed with 1,117 ha of forest converted to non-forest. No forest regeneration was observed across this period. Overall between 2000-2014, the net deforestation was 3,139 ha which represents a net change of approximately 0.72% (224 ha/yr) of the total area as at 2000.

Table 4-3: 2000-2014 LULC area change and rates

Period	Changed Area (ha)			Net Period Change (%)	Annual Change Rate (%)
	Forest to non-forest	Non-forest to forest	Net Period Change		
2000-2007	2,152	190	1,962	0.45	0.06
2007-2014	1,177	0	1,177	0.27	0.04
2000-2014	3,329	190	3,139	0.72	0.05

The area of each class and sub-class by period and the corresponding change for each period is presented in Table 4-4. The first half of the table shows the LULC areas by class for the three time periods. The area of forest also includes areas of harvest as technically no land conversion has occurred. Non-forest areas include naturally occurring features such as grassland, wetlands and rivers, and man-made features such as roads and harvest decks.

The second half of the table shows the change for each period. The largest change observed is the area harvested each year. The harvest area is calculated by applying buffers to logging roads and landings which means it is not possible to ascribe an accuracy value to the area harvested. It is understood that the harvesting process is regulated and managed by the Papua New Guinea Forest Authority (PNGFA)[7]. In this context, harvesting is considered to be a managed process that reduces biomass but it does not result in deforestation.

Across all change periods harvesting roads are the major cause of deforestation. In the period 2000-2007, out of the total deforested area (2,152 ha), road construction contributed 2,009 ha (93%) of the change. The remaining areas include log landings, clearings and small areas related to project

[7] The Forestry Act 1991 places the responsibility of conservation and management of forests under the Ministry of Forests through the PNGFA.

infrastructure (33 ha). Afforestation accounts for 190 ha leaving a net change of 1,962 ha for the period.

The situation is similar in the second period (2007-2014) with roads contributing 874 ha (74%) of the total deforested area of 1,177 ha with the remainder caused by the construction of log landings and other clearance activities. Of this total, petroleum sector activities represent 96 ha (8.2%) of the change.

Table 4-4: Land cover and use by class for the DSA

Land Cover Class**	Sub classes	Land Use and Cover			Change by Period		
		2000	2007	2014	2000-2007	2007-2014	2000-2014
		Area (ha)					
Forest	Total Forest	438,359	436,397	435,220	1,962	1,177	3,139
	Forest	419,114	362,288	344,458			
	Harvested area*	19,245	74,109	90,762	54,865	16,653	71,517
Non-forest	Non-forest	8,966	8,802	8,959	-165	157	-8
	River	11,737	11,737	11,737	0	0	0
	Water Bodies/Swamp	1,908	1,908	1,908	0	0	0
	Bare ground (log landings and other clearance activities)	138	255	401	117	146	263
	Road development	709	2,719	3,593	2,009	874	2,883
	Total Area (ha)	461,817	461,817	461,817			

* Harvested forest areas as estimated using a road and landing buffering approach

** Note when added actual areas will differ by +/-1 ha due to rounding

4.3 Deforestation by Driver

During the mapping process the driver of the forest change was also recorded. Drivers were identified from the imagery based on expert knowledge and other associated indicators such as location, shape and size of the deforestation area, and proximity to the roads, rivers and villages.

Both anthropogenic and non-anthropogenic drivers were identified and recorded. Table 4-5 summarizes the deforested area by drivers for both periods. As already indicated commercial harvesting is the major driver for both periods and contributed 96% of total deforestation in period one and 78% in period two, although the area of deforestation declines.

Table 4-5: Deforestation by driver for the DSA

Deforestation Drivers**	2000-2007		2007-2014	
	Area (ha)	(%)	Area (ha)	(%)
Logging roads and associated infrastructure	2,066	96.0%	908	78.1%
Anthropogenic (Subsistence agriculture)	42	1.9%	167	13.2%
Petroleum sector activities	33	1.5%	96	8.2%
Landslides	12	0.5%	6	0.5%
Total	2,153	100.0%	1,177	100.0%

** Note when added actual areas will differ by +/-1 ha due to rounding

The findings are similar to previous studies which also identified logging as a dominant driver of forest cover change (Babon, 2011; Shearman and Bryan, 2011), reflecting the presence of large scale logging concessions across relatively accessible lowland forest.

Anthropogenic factors, which includes villages and agricultural land expansion is the second largest driver of change. However, the area changes are very small, with an area of 42 ha cleared in period one (2000-2007) and 167 ha in period two (2007-2014). The relatively small area presumably reflects the low population of the DSA, other than along the coast where there is a concentration of villages. Anthropogenic factors mainly impacted forest along the Purari River, its tributaries and in coastal areas, presumably reflecting the importance of these areas for settlements and food gardens

Figure 4-4 and Figure 4-5 show time series maps for 2000, 2007 and 2014. The first series are aggregated to two classes; forest and non-forest maps. The maps show the progression of change

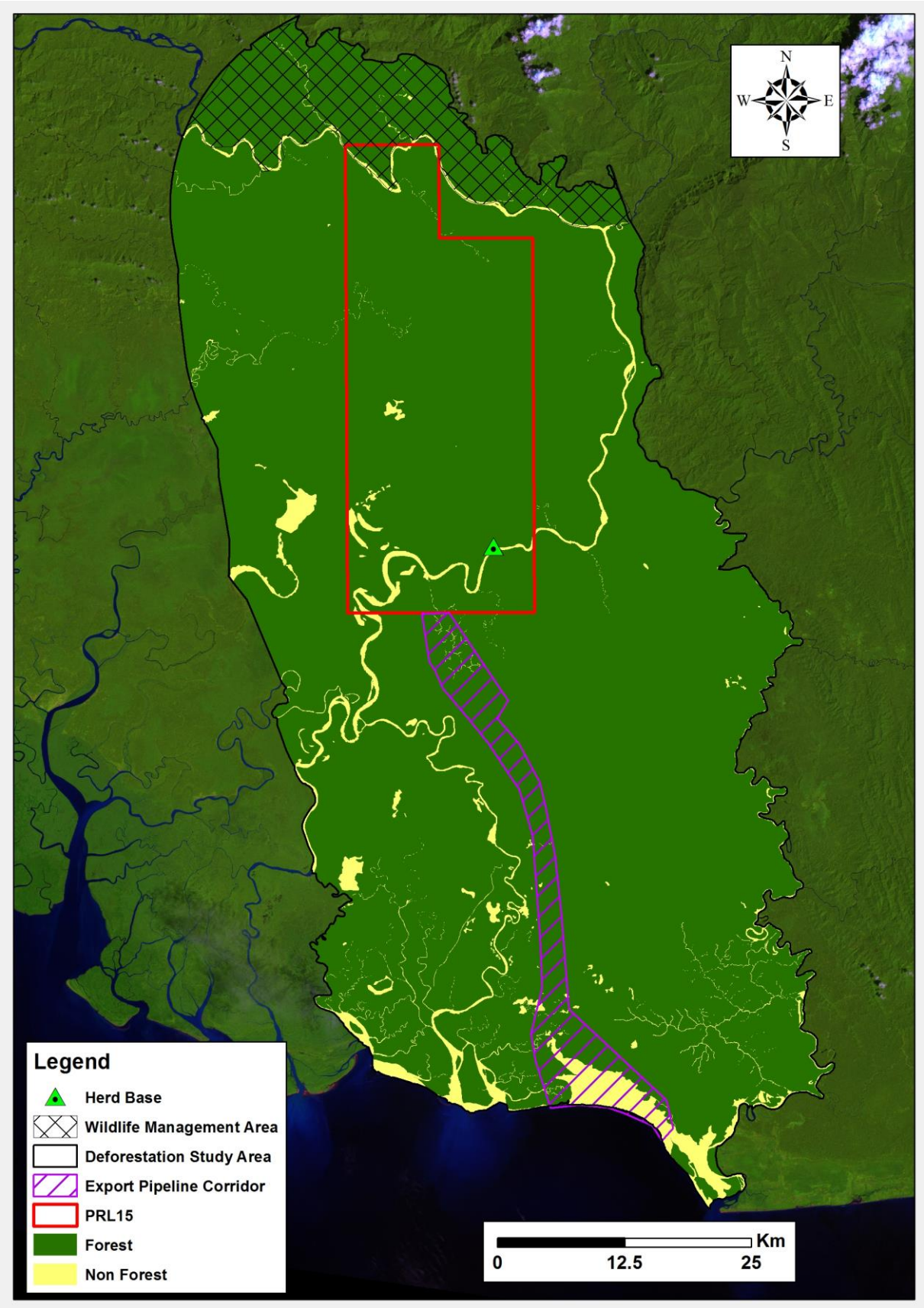
over the fourteen-year period with road construction confined to the Vailala Blk 3 concession, located south of PRL-15 and herd base.

The second series of maps (Figure 4-5) includes forest harvesting activities and other land cover sub-classes. Harvesting activities are clustered around the road network, and also start in the south and move northwards over time. The harvesting stops at the Purari River. For the time duration assessed, harvesting has not commenced in the Baimuru Blk 3 concession. The only disturbance north of the herd base and located inside the PRL is due to road construction activities undertaken by the previous project developer. This road is identified on the 2014 LULC map.

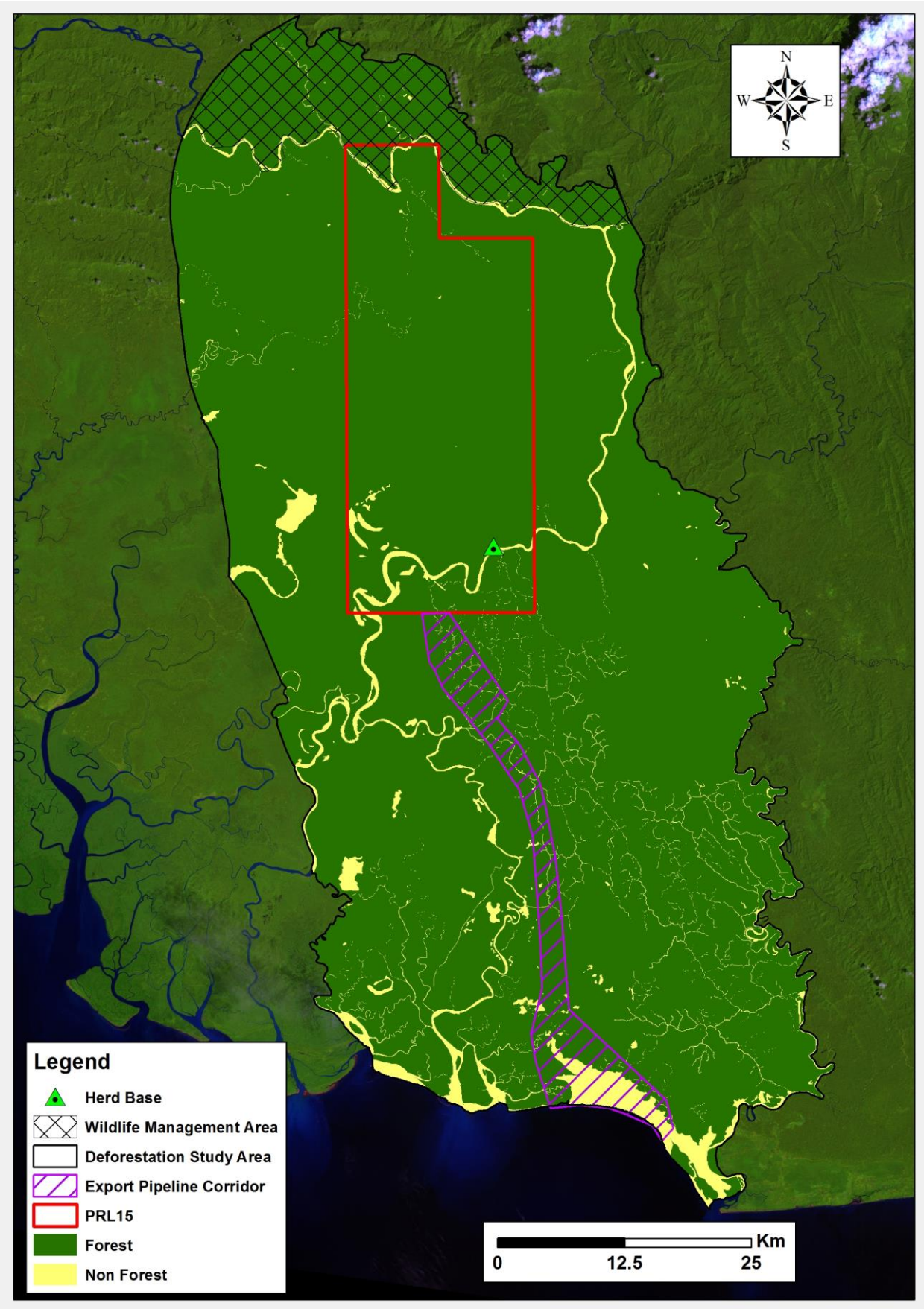
Further analysis of the March 2016 Landsat image shows that road development post 2014 shows a similar trend to the annual rate of road expansion of 200 ha/year.

Figure 4-4: LULC Maps of 2000 (a), 2007 (b) and 2014 (c) for the DSA

2000 Forest and Non-forest LULC Map (a)



2007 Forest and Non-forest LULC Map (b)



2014 Forest and Non-forest LULC Map (c)

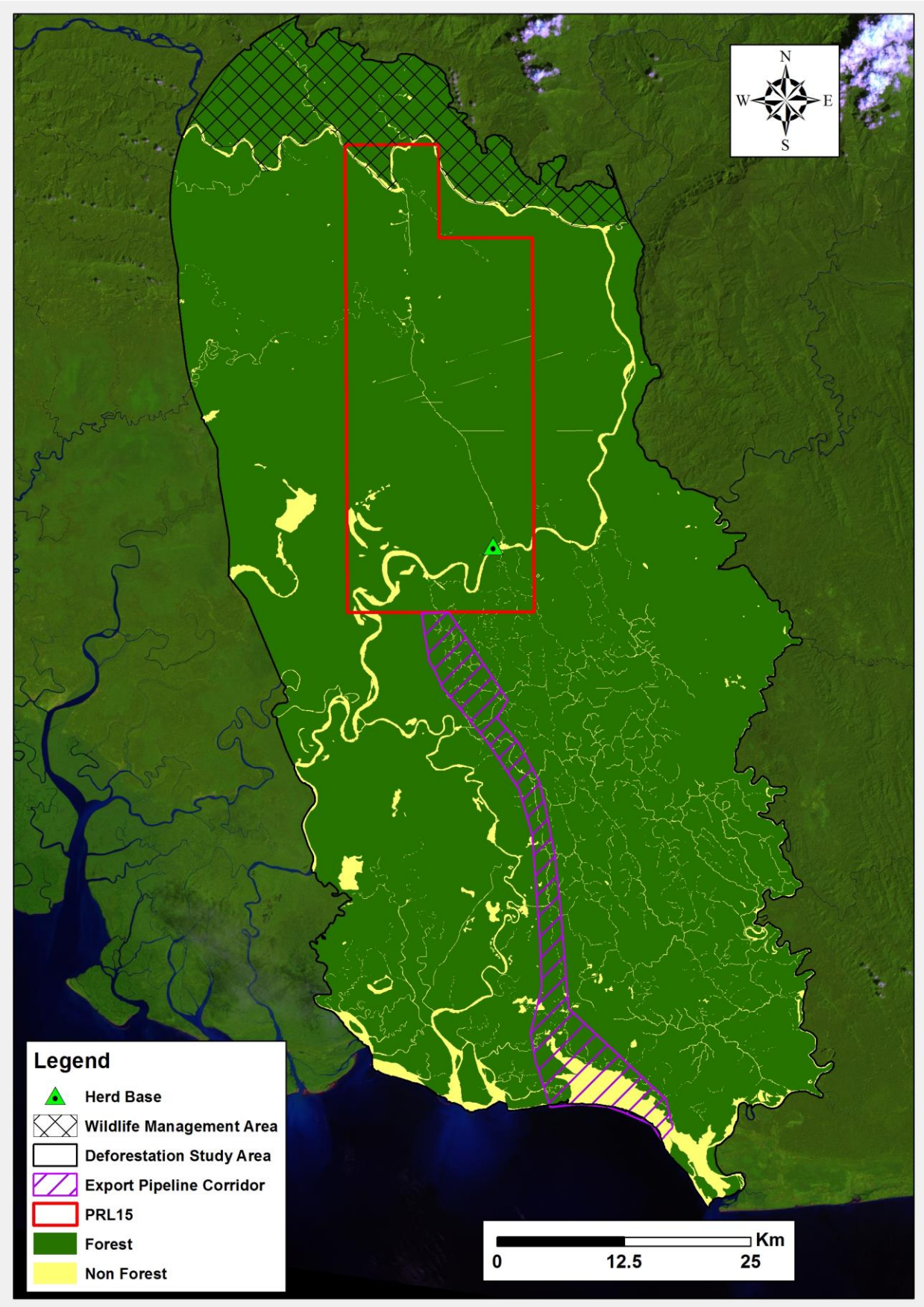
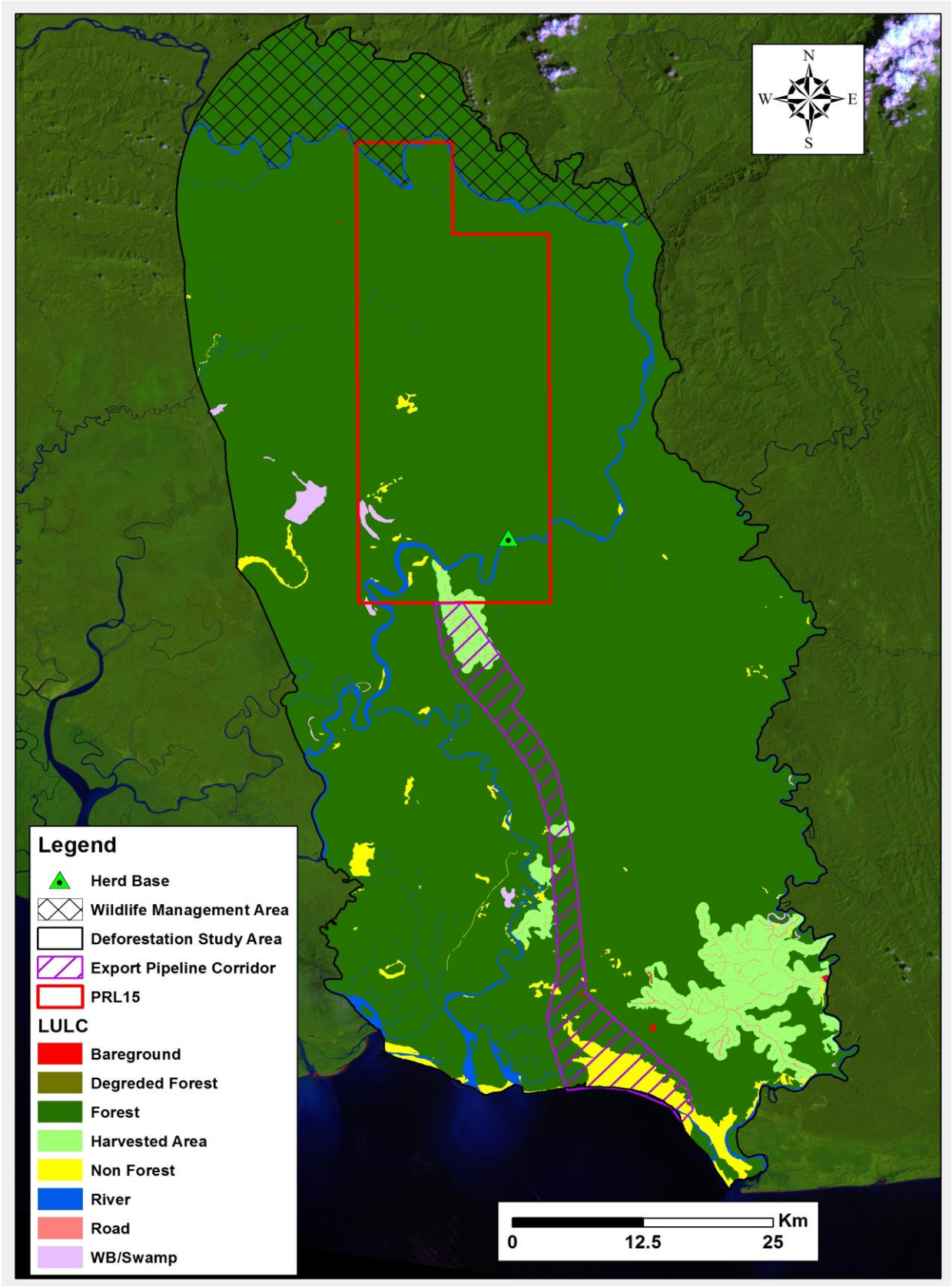
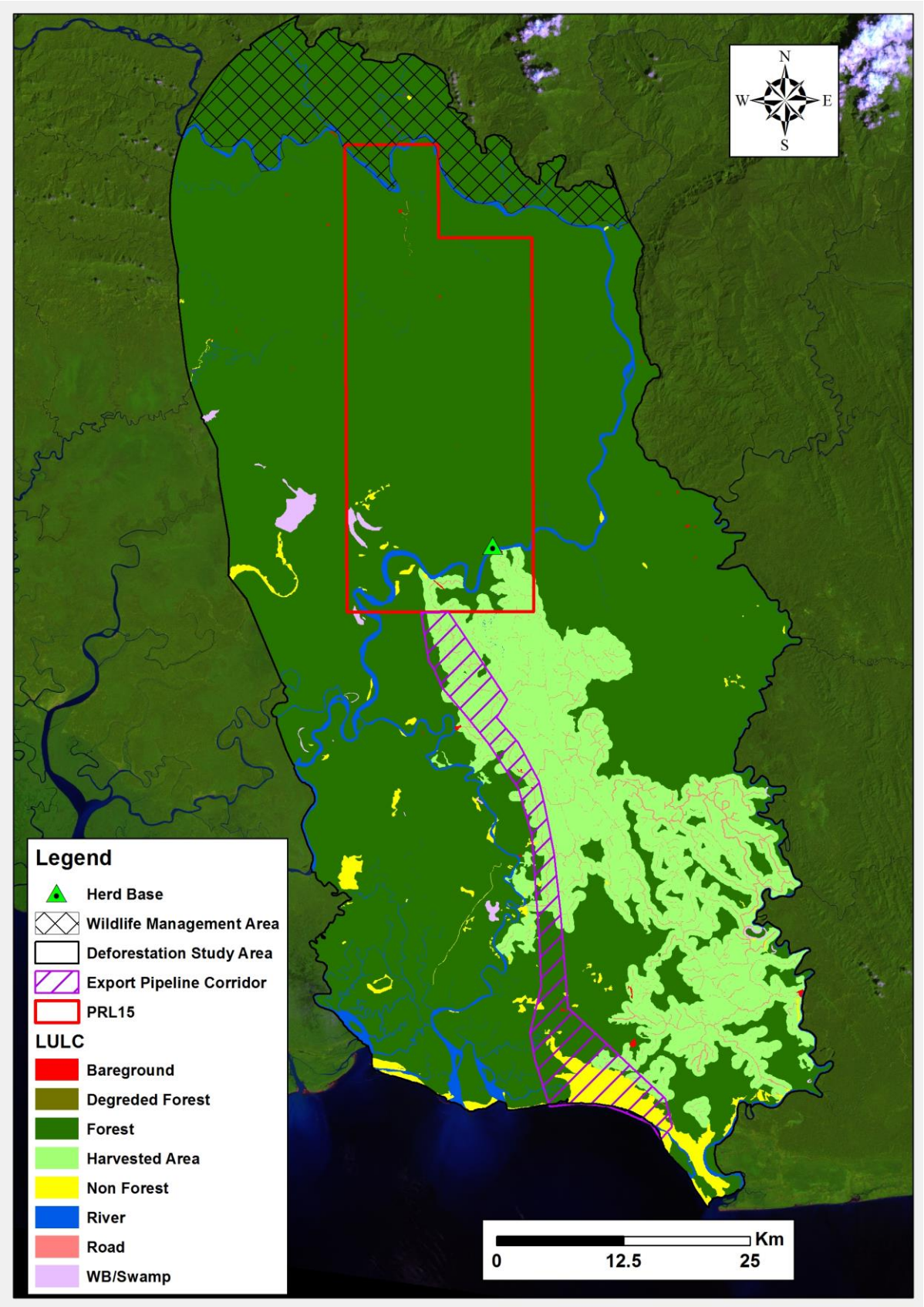


Figure 4-5: Detailed LULC maps of 2000 (a),2007 (b) and 2014 (c) for the DSA

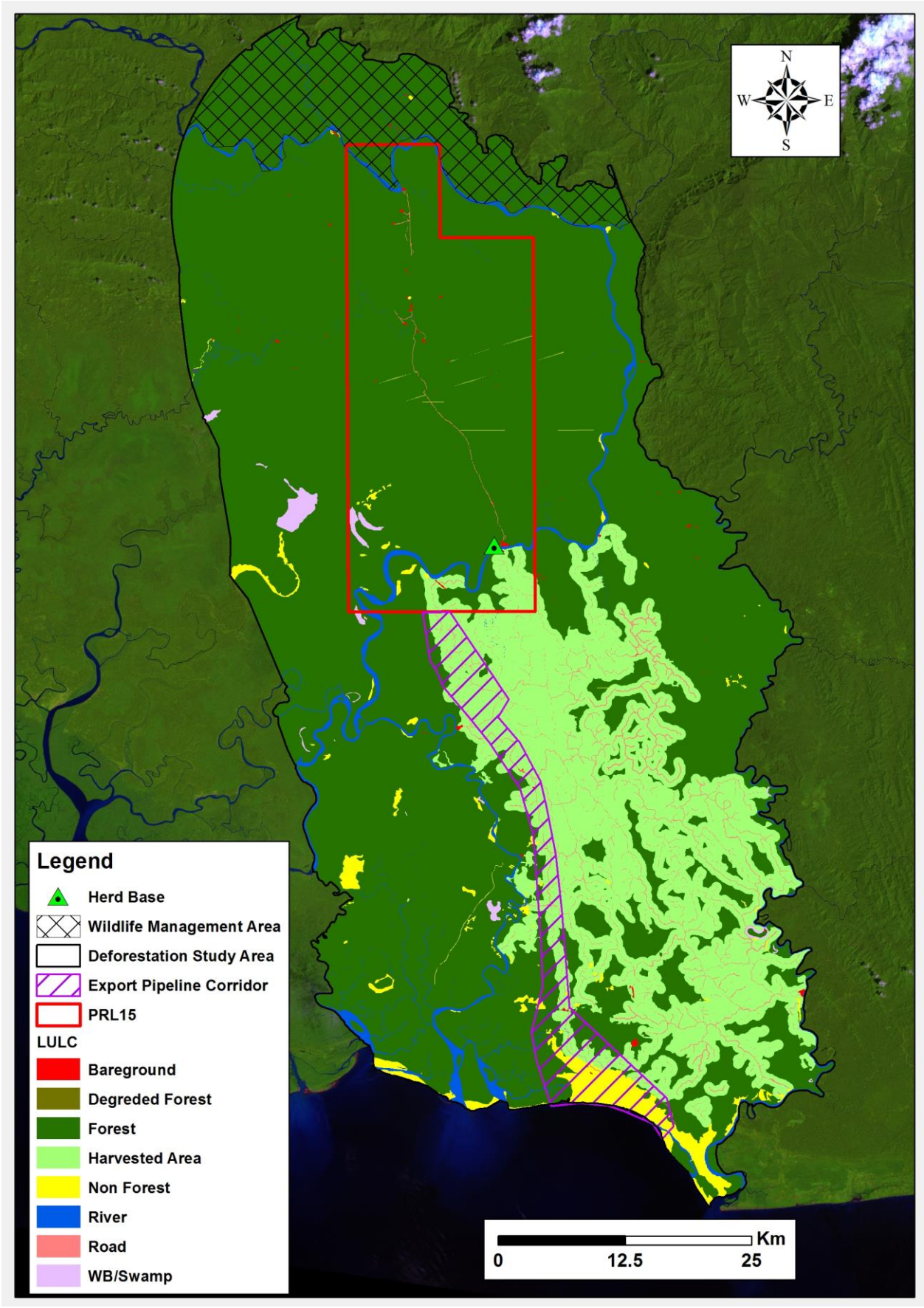
2000 Detailed LULC Map (a)



2007 Detailed LULC Map (b)



2014 Detailed LULC Map (c)



4.4 Land Use and Land Cover of the Upstream Terrestrial Biodiversity Study Area

The LULC for the upstream terrestrial biodiversity study area is provided in Figure 4-6 which shows the classification for 2016. The majority of the area (94%) is covered by forest and only 6% is occupied by the various non-forest classes such as rivers, swamp and infrastructure (Table 4-6: Upstream terrestrial biodiversity study area LULC classification for 2016). An estimated 15% of forest area (99,595 ha) or 13.6% of total area was harvested after 2000.

Table 4-6: Upstream terrestrial biodiversity study area LULC classification for 2016

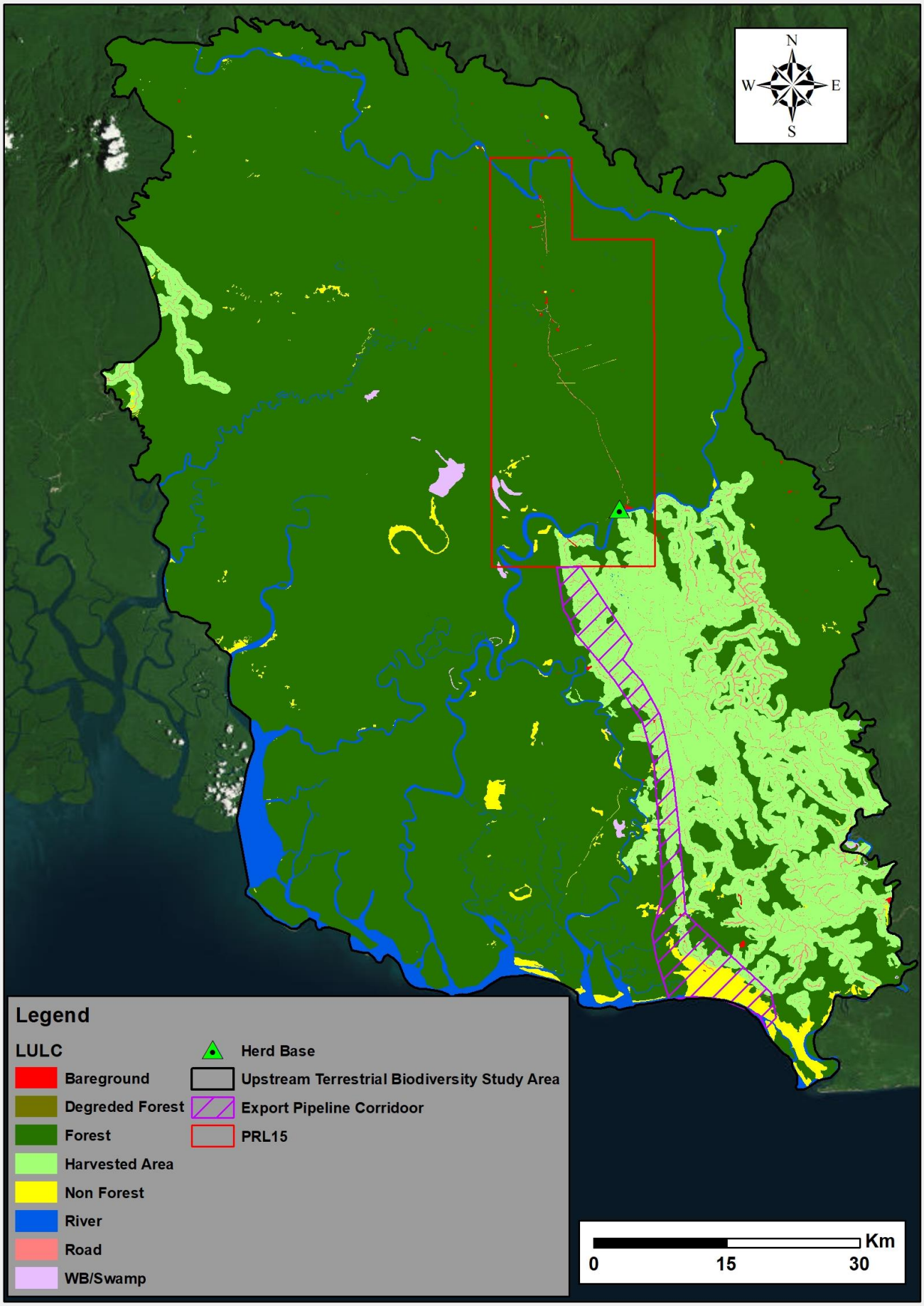
Land use / cover	LULC	Area (ha)	%
Forest	Forest	585,793	80.0
	Harvested area	99,595	13.6
Sub-total Forest		685,388	**93.8**
Non-forest	Bare ground	411	0.1
	Non-forest	9,943	1.4
	River	28,755	3.9
	Road	4,012	0.5
	WB/Swamp	1,908	0.3
Non-forest		45,029	**6.2**
Total Area		730,417	100

4.5 Study Limitations

The study was subject to the following limitations:

- Interpretation of change as detected from the Landsat imagery was limited by the 30 m resolution of the imagery. At this resolution, deforested areas >=1 ha can be reliably mapped only.
- Since no single cloud-free image covered the DSA, at least three scenes for each of the years 2000, 2007 and 2014 had to be analyzed to generate a single cloud free image for analysis. Therefore, the final cloud free images can include different time periods in any one year.
- The 2016 LIDAR imagery covered only 18% of the DSA and therefore could not be used to verify the LULC maps.
- Selective harvesting opens the forest canopy, but its successful detection is reliant on having coincident, or near-coincident satellite images to map its extent, as the breach quickly revegetates.
- A buffer distance of 500 m was applied to logging roads as a proxy to estimate the harvest area. This buffer was based on the average distance from roads that harvesting was observed in the imagery. It is possible that in some instances the buffer could over or underestimate the harvested area.

Figure 4-6: LULC map for the upstream terrestrial biodiversity study area in 2016



5. CONCLUSION

The deforestation study has achieved its baseline objectives of providing a review of the national regulatory requirements and international standards in terms of deforestation, determining historic levels of deforestation and forest degradation/harvesting within the DSA. This also includes the current level of deforestation and degradation/harvesting in the upstream terrestrial biodiversity study area, and the non-Project related deforestation activities (drivers of forest change). This report also provides baseline data and a benchmark for future long-term monitoring of deforestation.

Forest degradation in this study is identified as the area which has been harvested (logged) since the PNGFA accepted definition of forest degradation for forestry activities in Papua New Guinea is not met, based on the analysis undertaken here. Although this is the accepted definition the harvested area is effectively a surrogate term for forest degradation when considering the biodiversity value of anthropogenically disturbed verses non-anthropogenically disturbed forest, particularly since analysis undertaken in this study estimates existing forest harvesting practices result in the loss of 55 – 70% of the forest biomass.

Forestry (i.e., harvesting activities) is the main driver of forest change (71,517 ha) across the DSA which is confined to the south of PRL-15, and represents a change of 16% (5108 ha/yr) over the period 2000-2014. This forest change is not deforestation but reflects change associated with selective logging where all commercial trees > 50 cm dbh are harvested. In addition to the removal of the harvested trees, other trees are damaged or uprooted by logging machinery and the associated skid tracks which are formed from dragging (i.e., skidding) the logs to the nearest haul road. A number of the residual trees (trees remaining), if damaged are typically subject to gradual mortality up to five years after logging (Alder 1998). Deforestation is a relatively minor component of the forest change and is predominantly associated with the construction of the main logging haul roads. Overall deforestation across the DSA over the sample period from 2000-2014 is small (net deforestation of 3,129 ha) representing a net change of 0.72% (224 ha/yr) of the total area as at 2000. Anthropogenic factors which include villages and agricultural land expansion is the second most important driver of deforestation, but mostly in the period from 2007–2014 where 14% of deforestation is attributed to this driver. Deforestation from petroleum sector activities was similarly small and deforestation associated with landslides was negligible.

Overall, the majority of the forest change from 2000-2014 is associated with harvesting activities which resulted in the logging of approximately 71,517 ha of predominantly hill forest. This suggests that forestry is likely to be the main driver of non-Project related future forest change across the upstream terrestrial biodiversity study area provided there is an active logging concession with unlogged forest.

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APPENDIX A – VEGETATION TERMINOLOGY

Major vegetation group/FIMS code	FIMS Group/Description	Biodiversity Study term
Natural vegetation types		
Hill forest		
H	***Low altitude forest on uplands (below 1,000 m)***	***Hill forest***
Hm	Medium crowned forest	Hill forest
Hm.Ar	Medium crowned forest - Presence of *Araucaria* noted	Hill forest, *Araucaria* noted
Hm/Hs	Complex: Medium/Small crowned forest	Hill forest/small crowned hill forest
Hm/Sc	Complex: Medium crowned forest/Scrub	Hill forest/Scrub
Hs	Small crowned forest	Small crowned hill forest
Alluvial forest		
P	***Low altitude forest on plains and fans (below 1,000 m)***	***Alluvial forest***
Pl	Large to medium crowned forest	Alluvial forest
Po	Open forest	Open alluvial forest
Po/Fsw	Complex: Open forest/Mixed swamp forest	Open alluvial forest/Swamp forest
Po/Fsw/M	Complex: Open forest/Mixed swamp forest/Mangrove	Open alluvial forest/Swamp forest/Mangrove
Po/Wsw	Complex: Open forest/Swamp woodland	Open alluvial forest/Swamp woodland
Ps	Small crowned forest	Small crowned alluvial forest
Fri	***Seral forest***	
Fri	Riverine mixed successions	Riverine seral forest
Freshwater swamp habitats		
Fsw	***Swamp forest***	
Fsw	Mixed swamp forest	Swamp forest
FswC	Swamp forest with *Campnosperma*	Swamp forest with *Campnosperma*
Fsw/Gsw	Complex: Mixed swamp forest/Swamp grassland	Swamp forest/Swamp grassland
Fsw/M	Complex: Mixed swamp forest/Mangrove	Swamp forest/Mangrove
Fsw/Wsw	Complex: Mixed swamp forest/Swamp woodland	Swamp forest/Swamp woodland
W	***Woodland***	
Wsw	Swamp woodland	Swamp woodland
Wsw/Gsw	Complex: Swamp woodland/Swamp grassland	Swamp woodland/Swamp grassland
Wsw/Hsw	Complex: Swamp	Swamp woodland/Herbaceous

Major vegetation group/FIMS code	FIMS Group/Description	Biodiversity Study term
	woodland/Herbaceous swamp	swamp
G/Hsw	***Grassland and herbland***	
Gri	Riverine successions dominated by grass	Riverine successional grassland
Gsw/Fsw	Complex: Swamp grassland/Mixed swamp forest	Swamp grassland/Swamp forest
Gsw/Wsw	Complex: Swamp grassland/Swamp woodland	Swamp grassland/Swamp woodland
Hsw	Herbaceous swamp	Herbaceous swamp
Hsw/Wsw	Complex: Herbaceous swamp/Swamp woodland	Herbaceous swamp/Swamp woodland
Marine tidal		
M	***Estuarine Communities***	
M	Mangrove	Mangrove
Littoral forest		
B	***Littoral forest***	
B	Mixed forest	Littoral forest
Non-vegetation/areas dominated by land use		
E	Lakes and large rivers	Rivers and lakes
O	Non-forest areas dominated by land use	Land use
U	Larger urban areas	Urban areas

Note: Vegetation types are referred to in the text using a set of Forest Inventory Mapping System (FIMS) -equivalent terms developed specifically for the biodiversity study (Appendix A). These closely follow the formal FIMS descriptors, which are based on the founding vegetation descriptions (Hammermaster and Saunders, 1995, Paijmans, 1976), but are less cumbersome.

Where a specific vegetation type is referred to in the text it is capitalized and followed in brackets by its FIMS code. In this way reference is made to vegetation mapping units present in surveyed areas, for example ‘Hill forest (Hm)’ and ‘Open alluvial forest/Swamp forest (Po/Fsw)’.

Where more general reference is made to broader vegetation types that include multiple possible variants within the study area (and more widely in PNG) it appears without capitals or a FIMS code, for example ‘hill forest’ and ‘alluvial forest’. These generic types closely follow the various basal FIMS vegetation types, which in these examples are coded ‘H’ and ‘P’ respectively.

A full list of FIMS vegetation types present within the study area, and equivalent terms used in the biodiversity study, is presented in the Baseline Characterization Report.