TOTAL E&P PNG LIMITED

PAPUA LNG

Upstream Environmental Impact Statement

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Part 8
Upstream Vegetation Regeneration Baseline Report

TOTAL
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Upstream Vegetation Regeneration Baseline Study Report

Papua LNG Project

Total E&P PNG Limited

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EXECUTIVE SUMMARY

Joint venture partners, Total E&P PNG Limited (TEP PNG) (40.13%), ExxonMobil (XOM) (37.03%) and Oil Search Limited (Oil Search) (22.84%), 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.

As part of the Project environmental, social and health impact assessment (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 vegetation regeneration potential conducted as part of the upstream terrestrial biodiversity baseline study. The study was undertaken with the objectives of assessing: rehabilitation potential by natural regeneration of a range of surfaces that reflect potential construction outcomes, rehabilitation requirements, regeneration response/impacts in potential soil sidecasting areas and sensitive vegetation type resilience to potential impacts. The presence and potential cause of dieback[1] was also assessed for the study area since dieback can be inadvertently caused or spread by construction activities.

STUDY AREA: The study area for the assessment of vegetation regeneration includes the following:

- PRL-15 which comprises an area of 763,522 ha.
- The export pipeline corridor which comprises an area of 208,761 ha.

METHODS: The methods included a literature review of tropical forest regeneration, and field survey of a representative range of disturbed sites to characterize regeneration and rehabilitation requirements. The sites assessed included natural forest gaps, slumps and landslips, road alignments and associated cut and fill slopes, disturbed sites where vegetation has been cleared but topsoil remained intact, and disturbed sites where topsoil has been cleared or eroded.

Regeneration assessment involved the recording of species that had regenerated in 12 sites using unbounded plots, with observations recorded at an additional three sites. Most of the sites assessed were in hill forest which is where the majority of accessible disturbed sites were.

Dieback was assessed from a review of the LIDAR imagery, aerial survey and ground truthing.

RESULTS: Data and observations from the field survey indicated that regeneration varied across a range of previously disturbed surfaces. Regeneration was excellent where topsoil remained but was poor or absent where subsoil or bedrock had been exposed. The main regeneration characteristics across the different surfaces are:

Temporary clearance/cutting of woody vegetation: Excellent regeneration, particularly from cut stumps and previously suppressed saplings.

Complete removal of vegetation exposing topsoil: Poor regeneration due to high levels of topsoil erosion exposing subsoil. However, on gentle slopes in hill forest areas several tree species regenerate including *Trichospermum* sp., *Alphitonia incana*, *Duabanga moluccana* and *Pipturus* sp.

Removal of vegetation and topsoil: Poor regeneration in the hill forest zone particularly across mudstone substrates which become dry and friable. Sites often dominated by weeds.

Sidecasting surfaces: Good regeneration where topsoil has been dispersed across the slope but potential for landslips across steep slopes.

Wellpad surfaces: Poor regeneration due to waterlogging across a surface, or poor regeneration caused by compacted well-drained hardpack. Poorly drained surfaces infested by weeds.

DISCUSSION - FACTORS AFFECTING REHABILITATION: Rehabilitation of vegetation was found to be affected by a range of factors. These include:

The vegetation type: Different vegetation types occur on different landforms that vary in species composition, drainage and substrate that present different challenges to successful regeneration.

[1] Dieback refers to areas of forest where the canopy appears in poor health (partly defoliated) or is dead.

Erosivity of rainfall: The project area is located in an area of high rainfall that falls in high intensities that can rapidly erode topsoil making rehabilitation more difficult.

Landform: Landforms in the Project area vary from swamps to steep hill slopes that are susceptible to different erosion forces. Steep hill slopes are subject to high rates of erosion where topsoil is exposed resulting in loss of the important topsoil resource.

Topsoil: Topsoil is the most important resource for rehabilitation by natural regeneration because of its soil seed bank. Where this is not present rehabilitation success is more difficult to achieve.

Sidecasting: Sidecasting is likely to result in high rates of erosion and presents a surface which may be difficult to rehabilitate without intervention.

Weed infestations: Weed infestations can inhibit or slow the rate of rehabilitation of vegetation.

DISCUSSION - REHABILITATION BY NATURAL REGENERATION AND SENSITIVE VEGETATION TYPES: Rehabilitation by natural regeneration is considered to be the best approach to rehabilitate the range of vegetation types that occur in the study area, where topsoil remains intact. Where topsoil has been lost, active rehabilitation is likely to be required involving a range of rehabilitation treatments. Three vegetation types were identified as potentially sensitive and may require additional rehabilitation measures if disturbance cannot be avoided.

Littoral vegetation: Littoral vegetation is considered a sensitive vegetation type because of potential rehabilitation constraints. Littoral vegetation includes, herbaceous beach vegetation, beach scrub, beach woodland and Littoral forest (B). Apart from the herbaceous beach vegetation that can colonize recent sand deposits, the communities have a relatively thin layer of topsoil that would be difficult to salvage for rehabilitation and would be readily dispersed by heavy rainfall if the vegetation is cleared.

Pandanus dominated Swamp woodland (Wsw): Due to heavily waterlogged soils and the restricted distribution, disturbance of this vegetation type should be avoided where practicable due to the potential for substantial soil disturbance and damage to water flows.

Mangrove (M): Rehabilitation by natural regeneration and planting would need to be undertaken. Planting will mostly be required where large clearings are made. An assessment of the level of propagule dispersal and predation from crabs may be required to determine if rehabilitation by natural regeneration will be successful. Rehabilitation will also be reliant on the reinstatement of sediments to the same height above sea level as the original surface.

CONCLUSIONS

The upstream project footprint will impact a range of vegetation types across different landforms including marine sands, mangrove sediments, alluvial soils and coarse sedimentary soils. Moreover, the scale and severity of disturbance associated with the Project footprint will vary from the temporary cutting back of vegetation to complete removal of topsoil, and depending on the pipeline route potential sidecasting of spoil in steep terrain, and associated reshaping of landforms along road line segments may be required. It is likely that a range of rehabilitation measures will warrant consideration to rehabilitate the different surfaces that are likely to be created.

GLOSSARY AND ABBREVIATIONS

Term	Definition
amsl	above mean sea level
cm	centimeter
e.g.	for example
et al.	and others
FIMS	Forest Inventory Mapping System
i.e.	that is
km	kilometer
m	meter
PNG	Papua New Guinea
PRL	Petroleum Retention Licence
sp.	species (singular)
spp.	species (plural)
t/ha	Metric ton per hectare

1 INTRODUCTION

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 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.

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).
  - Central Processing Facility (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, social and health impact assessment (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 rehabilitation conducted as part of the upstream terrestrial biodiversity baseline study.

2 UPSTREAM TERRESTRIAL BIODIVERSITY STUDY AREA AND ECOLOGICAL ZONES

2.1 STUDY AREA

The upstream terrestrial biodiversity study area (hereafter 'study area') covers approximately 7,290 km^2 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.

The study area and its component ecological zones are shown in Figure 5-1. They are described in more detail in the Upstream Terrestrial Biodiversity Baseline Report.

2.2 TECHNICAL STUDY OBJECTIVES

The terrestrial biodiversity baseline study is supported by a multi-disciplinary series of technical studies that provide a range of baseline technical assessments. The purpose of this technical study report is to present results of the vegetation regeneration assessment for the study area. The objectives of the study are to assess:

- Rehabilitation by natural regeneration of a range of surfaces that reflect potential construction outcomes.
- Rehabilitation requirements in potentially sensitive vegetation communities and poorly represented vegetation types (if present).
- Regeneration response/impacts in potential soil sidecasting areas.
- Sensitive vegetation type resilience to potential impacts.

Assessment of the potential for plant pathogens, which are most likely to be encountered in disturbed areas, was also undertaken as part of the vegetation regeneration assessment based on data collected in other vegetation related surveys.

2.2.1 Regulatory Requirements

There are no specific regulations, guidelines or codes of practice relating to site rehabilitation for petroleum developments under the *Oil and Gas Act 1998*. However, there are provisions under the Oil and Gas Act that enable site rehabilitation requirements to be effected and regulated through other laws, such as the *Environment Act 2000*. These provisions include:

- Under s. 56 the grant of a petroleum development license requires applicants to provide evidence of fulfilling site restoration activities through the imposition of security deposits and compliance with conditions handed down under any other legal instrument (e.g., Environment Act). Restoration activities, under normal good practice are understood to include rehabilitation and/or revegetation works, as required.
- Under s. 57 the grant of a petroleum development license is conditional on the Minister being satisfied that the evidence submitted by the applicant provides for the protection of the environment implicit being fulfillment of requirements under s. 56, which as noted above provide for restoration of the environment.
- Separate to the above, an application for a petroleum processing facility license under s.94 requires the applicant to restore the facility site upon termination of the facility license.

The Environment Act contains numerous provisions that promote environmental protection, regulate environmental impacts associated with development activities, and safeguard the life supporting capacity of air, water, land and ecosystems. While none explicitly relate to reinstatement or closure, the Environment Act has an important influence on site closure, as commitments given by operators in documentation prepared under the act, e.g., environment permit application, environmental impact statement (EIS) and environmental and social management plans (ESMP) submitted in support of permit applications. The content of these documents informs the Conservation and Environment Protection Authority's decision on conditions in approvals and permits.

Specifically, s. 66 of the Environment Act allows for:

(1) A permit may be issued subject to such conditions the Director considers are necessary or desirable, including but not limited to conditions containing requirements to do all or any of the following -

(l) Rehabilitation of the affected area.

Permit conditions are usually derived from commitments made in the applicant's EIS and environment permit application. CEPA has expectations that regardless of the level of the activity, i.e., Level 2 or 3, that the operator will not abandon the license area upon cessation of activities and the site will be restored, even if a closure and rehabilitation plan is not specifically articulated in the legislation.

In summary, while there is no specific mention of rehabilitation in the *Oil & Gas Act*, the *Environment Act* includes general requirements on restoration with project specific conditions usually stated in project environment permits.

3 PRIOR STUDIES WITHIN THE STUDY AREA

Previous studies on rehabilitation in the study area are confined to Appendix 15 of the Environmental and Social Management Plan (ESMP) that is associated with the suite of reports for the InterOil EIS undertaken in 2010 (Douglas, 2010). Appendix 15 provides detail of the site rehabilitation ESMP for the InterOil Project footprint. Rehabilitation studies in the wider region were conducted in lowland environments of Gulf Province for the Chevron Kutubu Petroleum Development Project in 1990 (Gillison, 1990) and for the Papua New Guinea portion of the Exxon Mobil PNG Gas Project in 2005 (Rogers, 2005) and the Exxon Mobil PNG LNG Project in 2008 (Rogers, 2008). The 2005 and 2008 studies were conducted in similar areas of the Kikori Basin lowlands, mostly in karst environments and in the Southern Highlands in karst and volcanics.

The InterOil Site ESMP recommended a suite of standard rehabilitation measures including site stabilization, revegetation by natural regeneration and planting, and hydromulching sites with fast growing exotic grasses, provided they are benign once established (e.g., sterile hybrids). The PNG LNG Project identified similar recommendations and highlighted issues associated with sidecasting (CNS, 2009).

These studies were designed for the specific Projects mentioned, and since there is no known Papua New Guinea code of practice for rehabilitation, the studies do not conform to any particular standard.

4 LIMITATIONS

The findings throughout this report are based on a literature review and field survey at locations determined safe to access in remote terrain. The assessment site locations reflect as far as is reasonably possible examples of the landforms and vegetation likely to be traversed by the proposed onshore export pipeline, however the exact locations of disturbance associated with the Project footprint were not known at the time of field survey.

5 METHODS

The methods comprised a literature review of tropical forest rehabilitation and field survey undertaken in 2016. The field survey was restricted to sampling accessible areas that could be reached safely by road, boat or helicopter (Figure 5-1), with a focus on the assessment of sites that potentially reflected surfaces and associated regeneration likely to be present after Project construction, or sites that were potentially analogous to such surfaces, where practicable. This included sites to represent locations where topsoil had been lost (road alignments), sites where sidecasting had occurred (wellpad slopes and a landslip), and sites where vegetation had been disturbed but topsoil remained intact (slumps and natural gaps). Examples of these sites included logging road alignments (Site 11 & 12), the Antelope and Elk wellpads (Sites 4 – 8) and a landslip along the Purari River (Site 13), and slumps and a natural gap at Biodiversity site 3 (Site 2) (see Table 5-1).

The field survey procedure comprised an initial aerial traverse of infrastructure locations and discussion with TEP PNG field staff to select a range of disturbed sites that could be safely accessed either by road, boat or helicopter.

The following sites were selected for assessment:

- Natural gaps (if present and accessible).
- Slumps and landslips.
- Road alignments and associated cut and fill slopes.
- Wellpad sidecast slopes.
- Sensitive/poorly represented vegetation types if present and accessible.

Regeneration assessment involved the recording of species that had regenerated in 12 sites using unbounded plots, with observations recorded at an additional two sites. Unbounded plots, generally 400 to 500 m^2 were used to record the plant species for the main plant life forms (e.g., trees, shrubs, palms, pandans, ferns, herbs, grasses and sedges). Smaller plots were used where a site was limited in area such as a cutting. This survey method was used to rapidly characterize the regeneration. A species lists from the unbounded plots is provided in Appendix A.

Most of the sites assessed were in hill forest where most of the accessible disturbed sites were. Moreover, most vegetation regeneration issues likely to be encountered will be in hill forest areas where steep slopes and exposed sedimentary soils in the high rainfall environment present a range of rehabilitation challenges, as opposed to flat terrain.

The sites assessed to characterize vegetation regeneration issues across the different surfaces are listed in Table 5-1. All the sites were located within PRL-15 and the export pipeline corridor. Vegetation regeneration survey locations are mapped in Figure 5-1.

5.1 FOREST DIEBACK

The presence of forest dieback was assessed from a combination of a review of the available LIDAR imagery, aerial survey and ground truthing at one site.

5.2 VEGETATION TERMINOLOGY

Vegetation types are referred to in the text using a set of Forest Inventory Mapping System (FIMS) - equivalent terms developed specifically for the upstream terrestrial biodiversity baseline study. The vegetation terminology is included as Appendix B of this report. 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 and have been ground-truthed at the terrestrial biodiversity survey sites and reviewed more broadly by aerial survey.

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 Papua New Guinea) 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.

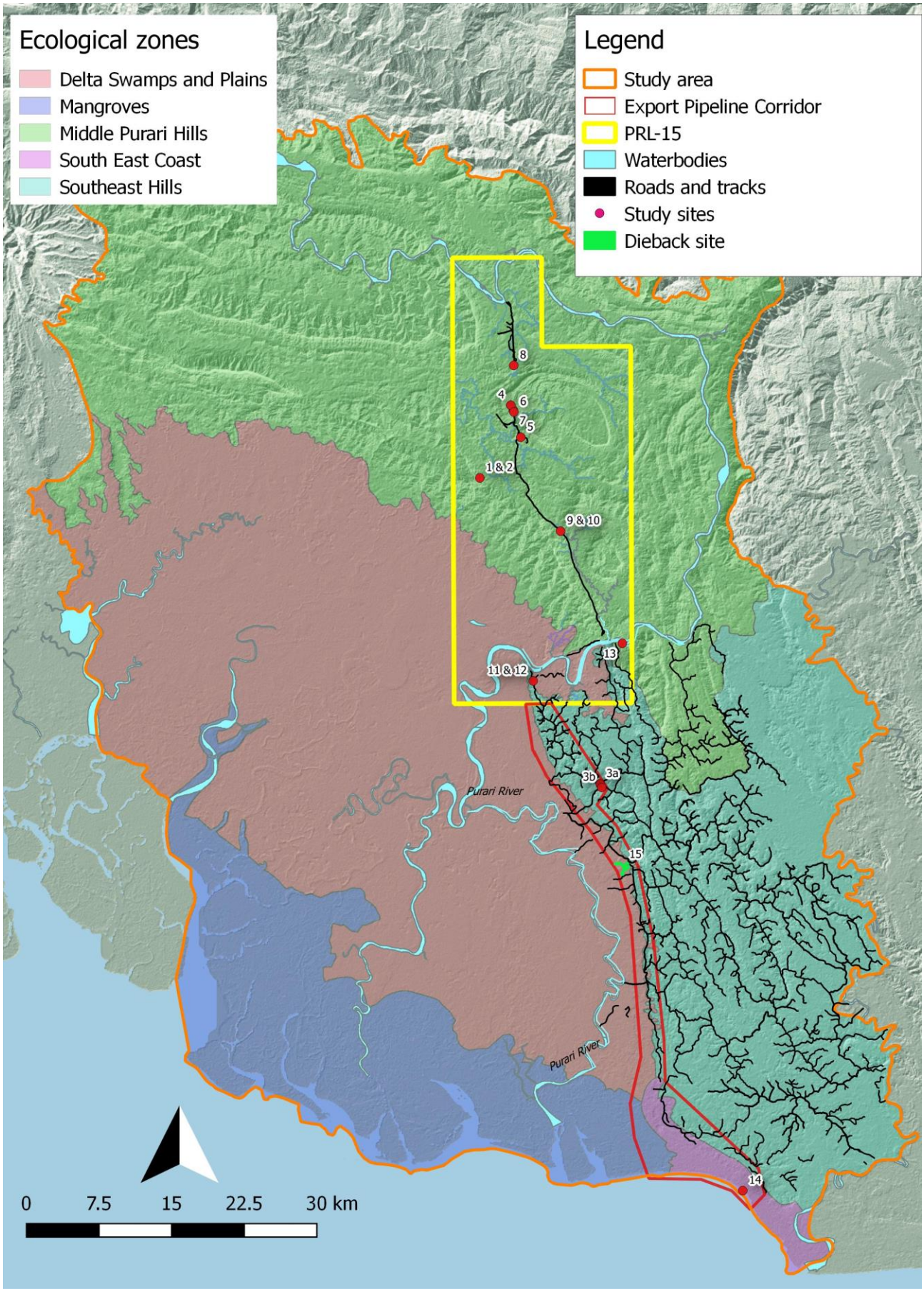
A full list of FIMS vegetation types present within the study area, and equivalent terms used in the Biodiversity Study, is presented in the Upstream Terrestrial Biodiversity Baseline Report.

Table 5-1 Vegetation regeneration survey locations

Site number	Site name	Site description	Local landform	Site type	Slope	PNGRIS Landform	PNGRIS rock type	Surface assessed	FIMS
1	Biodiversity site 3	Natural gap	Hill	Hill forest (Hm)	Gentle	Homoclinal ridges and cuestas	Mixed or undifferentiated sedimentary	Root mounds	Hm
2	Biodiversity site 3	Disturbed forest	Hill	Hill forest (Hm)	Gentle	Homoclinal ridges and cuestas	Mixed or undifferentiated sedimentary	Gentle slope of slump	Hm
3	Site 3a & 3b	Logging road regen	Hill	Road	Gentle	Homoclinal ridges and cuestas	Mixed or undifferentiated sedimentary	Road margins where forest previously cleared	Hm
4	Antelope 1	Wellpad sidecast slope	Sidecast slope	Wellpad sidecast	Steep	Homoclinal ridges and cuestas	Mixed or undifferentiated sedimentary	Sidecast slope with topsoil	Hm
5	Antelope 2	Wellpad sidecast slope	Sidecast slope	Wellpad sidecast	Steep	Homoclinal ridges and cuestas	Fine grained sedimentary	Sidecast slope with topsoil	Hm
6	Antelope 3	Wellpad sidecast slope	Sidecast slope	Wellpad sidecast	Steep	Homoclinal ridges and cuestas	Mixed or undifferentiated sedimentary	Sidecast slope with topsoil	Hm
7	Antelope 3 Heli pad	Helipad sidecast slope	Sidecast slope	Wellpad sidecast	Steep	Homoclinal ridges and cuestas	Mixed or undifferentiated sedimentary	Sidecast face with topsoil	Hm
8	Elk 1	Wellpad sidecast slope	Sidecast slope	Wellpad sidecast	Steep	Homoclinal ridges and cuestas	Mixed or undifferentiated sedimentary	Sidecast slope with topsoil	Hm
9	Kuku Creek*	Kuku creek Road	Sidecast slope	Road	Gentle	Homoclinal ridges and cuestas	Fine grained sedimentary	Sidecast face with topsoil	Hm
10	Kuku Creek	Kuku Creek Cutting	Cutting	Cutting	Steep	Homoclinal ridges and cuestas	Fine grained sedimentary	Road cutting through ridge	Hm
11	Logging road -1*	Purari strip Logging Rd	Hill	Road	Gentle	Homoclinal ridges and cuestas	Mixed or undifferentiated sedimentary	Road margins where forest previously cleared	Hm
12	Logging road -2	Purari strip Logging Rd	Sidecast slope	Road	Gentle	Homoclinal ridges and cuestas	Mixed or undifferentiated sedimentary	Sidecast slope with topsoil	Hm
13	Landslip	Purari River landslip	Landslip slope	Landslip	Medium	Homoclinal ridges and cuestas	Fine grained sedimentary	Landslide slope. Recent	Hm
14	Herakela	Herekela marine sands	Recent sand dune	Sand dune	Flat/Gentle	Beach ridge complexes and beach plains	Marine sands	Coastal sand dunes	B
15	Dieback*	Alluvial forest	Alluvial plain	Open alluvial forest (Po)	Flat	Composite levee plain	Alluvial deposits	Alluvial plain	Po

* = Observations made only.

Figure 5-1 Vegetation regeneration and dieback study sites



6 LITERATURE REVIEW – TROPICAL FOREST REHABILITATION

Terrestrial ecosystems across Papua New Guinea vary substantially despite occurring on the same latitudinal zone. This is highlighted by forest variation in the study area where major differences in forest type (e.g. hill forest, alluvial forest, Swamp woodland (Wsw)) are associated with different landforms. The different landforms reflect major differences in drainage and potentially soil type.

The different vegetation and soil types associated with the different landforms may be impacted in different ways by construction works, reflecting variation in natural regeneration capacity and associated soil properties such as stability (resistance to erosion), and fertility. Therefore, a range of approaches may be required for the mitigation of impacts and rehabilitation of disturbed areas. The following sections review broad approaches to tropical rainforest rehabilitation that are likely to be applicable to the study area.

6.1 TROPICAL SOILS

There are five major soil-forming factors: climate, parent material, vegetation, relief, and time. Differences in the combination of these factors result in soils varying over relatively short distances such as between ridge, slope, toe slope and valley. Most soils are derived from the weathering of the underlying rock (parent material). Such weathering is at its most rapid in the humid tropics that is typical of lowland rainforest environments, and may result in very deep soils (less than 10 m), particularly across stable volcanic landforms. However, in Papua New Guinea shallow soils (less than 2 m deep) are a more common feature, reflecting the active landscapes (Wood, 1982). Erosion, instability, continuing accessions of alluvium, wind borne dust (loess) and organic matter (peat soils), and the relative youth of much of the landforms are a feature of the active soil formation environment. Thus soil parent material often originates from multiple sources in Papua New Guinea (Hope and Hartemink, 2006).

Assessment of soils in the study area for the Papua LNG Project (SLR, 2017) indicate that the soils of the study area are typically shallow (less than 1.2 m) and are dominated by Entisol and Inceptisol soil orders. These are considered poorly formed soils with no, to limited soil pedological development due to either the young age of the soil as in the depositional profiles of the alluvial beach plains, or due to erosional factors in the steep hill areas in PRL-15 preventing soil from developing over the bedrock parent material. Entisols are very young soils which occur mainly on alluvium or on steep slopes where soil erosion takes place, or on coastal deposits. Entisols include mangrove clay soils that are continuously waterlogged and riverine beach sands. Inceptisols are moderately weathered soils, with slightly weathered horizons (Hope and Hartemink, 2006). Histisols are also present in the study area which occur across the inundated tidal flats, swamps and saturated alluvial soils which typically form under waterlogged conditions and have high organic matter (peaty soils) in the upper layers. The different soils types are characterized by differences in chemical and physical properties (Bleeker, 1983) which may affect their response to disturbance and their ability to act as successful rehabilitation substrate once they are disturbed.

Differences in soil type typically influence the vegetation, however in Papua New Guinea, specific soil types have less influence on vegetation than altitude, topography and climate (Paijmans, 1975), and relatively uniform forest types can extend across a variety of soil types in humid tropical forest regions (Burnham, 1989).

This has positive implications for rehabilitation, particularly in very disturbed areas where soil profiles may be severely damaged and soil profile reconstruction is required. Provided that the materials used to create a soil profile (e.g., subsoil and mulch) after construction are not physically and/or chemically hostile to plant growth, then the key soil factors influencing rehabilitation performance are likely to be the rate of surface erosion, available nutrients, and water infiltration and its availability over time for plant growth, rather than the specific soil type (Jasper and Tongway, 2005).

6.2 INFILTRATION

Infiltration of rainfall into tropical soils is also essential for ecosystem function and natural recovery processes. If infiltration is inadequate, then accelerated runoff is likely to lead to an increased risk of erosion. Infiltration and deep drainage in tropical forest soils are dominated by two systems:

- Rapid drainage with short residence time through macropores (e.g., created by soil fauna).

- Slow drainage and longer residence in micropores where the moisture is retained by capillarity (Nortcliff and Thornes, 1989).

Infiltration in reconstructed soil profiles will depend on the method of preparation and the intrinsic properties of the soils, and less on the natural porosity typical of undisturbed soils. The predominant control of surface erosion of soils is plant cover (Schuman and Ries, 1996). For example, if greater than 50% vegetative cover is achieved then soil loss is reduced to less than 10% of that from equivalent bare soil (Bleeker, 1983). Soils on rehabilitated areas will be at their most vulnerable to rain splash and water erosion in the first few weeks or months of growth (Jasper and Tongway, 2005).

Within many tropical rain forest ecosystems, the major proportion of the nutrient capital is held within plant and litter biomass (Burghouts *et al.*, 1992, Grubb, 1989, McDonald and Healey, 2000). This contrasts with more temperate ecosystems, where a much larger proportion of nutrients are held in the soil. In parallel with nutrient and organic matter distribution and oxygen availability, plant roots are predominantly in the surface layers of tropical soils, their mass declining rapidly with depth (Golley, 1983). The mat of fine roots and their associated mycorrhizal hyphae in surface soils and litter layers, act to capture a large proportion of nutrients mineralized and leached from these layers (Golley, 1983). The number of roots in surface soils (5 – 10 cm depth) is typically around 10 times that occurring at 40 cm depth. If barriers to root exploration and extension occur within 1.8 m of the surface then these are considered to potentially influence forest rehabilitation performance (Burnham, 1989).

6.3 MODIFIED SOILS

Construction activities create a range of new soil surfaces where soil quality typically declines due to degradation of the soil nutrient status and physical properties. Soil fertility is typically lower due to loss of topsoil exposing less fertile subsoil and or leaching of nutrients from loss of the protective vegetation cover. Changes to soil physical properties include changes to soil texture (the proportion of (sand, silt and clay), an increase in the proportion of rock fragments and an increase in the bulk density and an associated decrease in infiltration due to compaction (Ahirwal and Kumar, 2016). In some circumstances soils are completely lost leaving bare rock which may have a 1 - 2 cm bryophyte[2] crust on flat surfaces, that will eventually facilitate soil development and the establishment of pioneer plants in the thinnest of new soils. Bryophyte crusts were present in the study area, particularly on the flat Antelope 1 wellpad surface.

6.4 REHABILITATION OF TROPICAL FORESTS

Information regarding successful rehabilitation of tropical forest ecosystems is relatively sparse. Most tropical forest rehabilitation literature focuses on abandoned farmland (Holl and Cairns, 2002), and on the development of forestry and agroforestry systems, aiming at maximizing productivity of a limited number of economically important species (Parrotta, 2002). It is less common for rehabilitation projects to focus on creating a diverse ecosystem of locally-occurring species that resembles that which previously occupied the landscape. The complexity of achieving this objective appears more likely to occur by natural successional processes with limited intervention. A good example of this comes from Hong Kong where cleared tropical forest is reverting to forest by natural processes (succession/regeneration) after conversion to grassland and partial plantation, although this is dependent on the exclusion of fire (Abbas et al., 2016). However, there are many problems with relying entirely on such passive rehabilitation which can be slow and ineffective depending on the landscape and ecological conditions. Factors such as insufficient seed rain, lack of suitable germination microsites, depauperate soil seed banks, seed predation and competition from grasses and other weeds can collectively hinder forest rehabilitation (Barnes and Chapman, 2014). However, studies of regeneration for the PNG LNG Project showed that satisfactory vegetation regeneration occurred along the existing oil export ROW after construction in flat and gently sloping karst terrain provided a soil dominated substrate was present (Rogers, 2005).

[2] Bryophytes are a group of non-vascular plants that includes moss, hornworts and liverworts. They all reproduce via spores.

6.5 NATURAL REGENERATION

Many plant species from tropical forests have the potential to rapidly regenerate/re-establish without intervention, depending on the degree of disturbance. Natural regeneration is highly successful for re-establishing native species to restore forest along flat terrain and even on gently sloping terrain in Papua New Guinea, provided topsoil remains, erosion is not excessive and fire is excluded. This was identified for the PNG LNG Project (Rogers, 2005). Key aspects in natural regeneration that have been identified by both Parrotta (2002) and Holl and Cairns (2002) include:

- Seed availability.
- Seed germination.
- Competition with existing vegetation.
- Microclimate, microhabitats, and fire.
- Soil nutrients and soil microbial communities.
- Herbivores and predation.
- Social factors.
- Time.

There is potential for limitations or constraints to occur within each of the identified aspects of the rehabilitation process, which in turn may represent a limitation to the overall rate of development of a forest ecosystem. For example, the absence of seed is frequently reported as limiting to vegetation establishment and diversity, e.g., one eighth of seeds that fall in forest, fall on adjacent open areas (Holl, 1999). Distance from forest edge is also critical since beyond 30 m from the forest edge seed rain drops to less than 2% of seed rain in forested environments and is limited to seed with specific traits such as wind dispersed seed, small fleshy fruit and fruit of a specific color that are favored by animal dispersers (Barnes and Chapman, 2014).

Indirect measures such as provision of perches to encourage seed-dispersing birds, as reviewed by (Lamb, 1990), are reported to increase seed numbers within the vicinity of the perches. In early phases of re-establishment, predation of seeds or grazing of seedlings is also a potential limitation (Holl et al., 2000). The particular micro-habitat for plant establishment in bare areas can be less favorable than forested areas, particularly in terms of higher soil and air temperatures, greater light, and lower humidity (Holl et al., 2000). These physical environmental factors can limit both seedling survival and germination. An additional constraint that is common in many restoration efforts is high levels of competition from groundcover species and grasses (Jasper and Tongway 2005). This competition may be in terms of reduced access of forest species to nutrient and water resources, but also physical smothering of newly-established plants by the established groundcover plants (Parrotta, 2002). The soil environment is a key component influencing the likely success of any revegetation initiative (Jasper and Tongway 2005). In natural soils that have been cleared and abandoned but otherwise largely undisturbed, soil compaction and lack of both nutrients (Holl 1999) and beneficial soil microbes (Janos, 1996) have been reported as constraints on successful forest restoration. These potential constraints are likely to be even more relevant in areas where topsoil may be degraded or absent. Consequently, prior identification of constraining factors is important in assessing the likely success of natural re-establishment of forest.

6.6 DELIBERATE (ACTIVE) REHABILITATION OF TROPICAL FORESTS

Deliberate rehabilitation, otherwise known as active rehabilitation, of tropical forests, as distinct from relying entirely on natural processes, is an important approach to restore forest ecosystems, particularly on previously-cleared lands (ITTO, 2002). Typical strategies are built on an understanding of the establishment ecology of tropical forest species and may include:

- Defining any potential soil constraints to plant establishment and growth.

- Introducing topsoil where appropriate and when available.
- Planting seedlings of appropriate early colonizing tree species.
- Controlling grasses and groundcovers to prevent smothering and competition for resources.

As an appropriate microclimate develops, enrichment planting including the use of shade-tolerant species may occur, or establishment of these species may be encouraged indirectly by attracting seed-dispersing fauna, such as through fruit bearing trees (Jasper and Tongway 2005).

7 POTENTIALLY IMPACTED VEGETATION TYPES AND LANDFORMS

The Project footprint will traverse a range of lowland vegetation types and associated landforms. These are summarized in Table 7-1. The potential rehabilitation constraints and opportunities for the different vegetation types and landforms are discussed in the following sections.

Table 7-1 Vegetation types potentially impacted

PNGRIS vegetation type (Hammermaster and Saunders, 1995)	Landform (Loffler, 1974) and field observations	Main rock type
Low altitude forest on uplands - below 1000 m		
Hill forest (Hm)	Hilly terrain with weak or no structural control[3] Homoclinal ridges and cuestas	Mixed or undifferentiated sedimentary Fine grained sedimentary
Small crowned hill forest (Hs)	Hilly terrain with weak or no structural control	Mixed or undifferentiated sedimentary
Low altitude forest on plains and fans - below 1000 m		
Large to medium crowned forest (Pl)	Composite levee plain	Alluvial deposits
Open alluvial forest (Po)	Composite levee plain	Alluvial deposits
Mixed swamp forest (Fsw)	Composite levee plain	Alluvial deposits
Freshwater swamp habitats		
Swamp woodland (Wsw)	Composite levee plain	Alluvial deposits
Herbaceous swamp (Hsw)	Composite levee plain	Alluvial deposits
Grassland swamp (Gsw)	Composite levee plain	Alluvial deposits
Estuarine community		
Mangrove (M)	Mangrove swamps	Estuarine deposits
Littoral forest		
Littoral forest (B)	Beach ridge complexes	Marine sands

[3] Weak or no structural control refers to landforms where rock structures are not the dominant factor determining the morphology of the landform. Rock structures typically guide weathering and erosion and through time produce distinctive landforms of differential weathering and erosion (e.g. where there are alternating bands of soft and hard rock).

8 RESULTS & DISCUSSION – REGENERATION RESPONSE TO DISTURBANCE ACROSS DIFFERENT SURFACES

Regeneration across the disturbed sites is summarized in the following sections.

8.1 TEMPORARY CLEARANCE/CUTTING OF WOODY VEGETATION

Where woody vegetation has been temporarily cleared and soils and cut stumps remain relatively intact, vegetation is expected to rapidly regenerate. Examples of good recovery from an analogous natural disturbance event occur throughout the hill forest zone where slumping has occurred. Slumping is a form of mass movement that occurs in much of the hill forest of the study area on bedrock sedimentary substrates, where the loosely consolidated sandstone/mudstone rock layers moves a short distance down a slope resulting in total collapse of the forest canopy layer. Movement is characterized by sliding along concave slopes. Regeneration across large slumps was assessed at Site 2 where the forest was heavily disturbed from slumps. Across the slumps regeneration was represented by primary tree species including *Dracontomelon dao*, *Barringtonia*, *Pouteria*, *Homalium foetidum*, *Goniothallamus*, and *Myristica*. The main secondary species (pioneer) was *Ficus*. However, the regeneration in the very wet soils which characterized much of Site 2 was partly suppressed by the high abundance of the native thorny climbing palm *Korthalsia*, which covered much of the regeneration. Some regeneration of the primary tree species occurred from suckers from the broken stumps and from the release of previously suppressed seedlings and saplings resulting in abundant primary species, rather than fast growing and shorter lived secondary species which typically colonize forest gaps.

The rate of recovery from this type of disturbance is likely to be relatively fast with a closed canopy at approximately 9 m height being reached approximately five years after disturbance based on forest recovery rates in logging gaps (Rogers, 2010). Regeneration after slumping is shown in Plate 8-1.

Small clearings will also regenerate although typically regeneration is less abundant than a large clearing. At Site 1, a natural treefall gap, regeneration was characterized by a small number of tree species, including the primary species *Cryptocarya*, and the secondary species *Macaranga* and *Trema orientalis*. Regeneration in the gap was most abundant on the root mound suggesting the importance of raised microsites from plant establishment. A raised microsite typically has better drainage and may receive more direct sun exposure to promote seedling/sapling growth.

Plate 8-1 Good regeneration on a slumped surface (Site 2)

8.2 COMPLETE REMOVAL OF VEGETATION EXPOSING TOPSOIL

For this study, where vegetation had been totally cleared, including removal of stumps, but topsoil was present, excellent regeneration was observed on gentle slopes around existing infrastructure sites, including the wellpad side slopes and associated roads from Antelope 1 to Antelope 3 (Sites 4, 5, 6, 7 & 8). This capacity reflects moisture and temperature conditions that are favorable for germination, a relative lack of competition from weed species, the application or dumping of salvaged topsoil with a viable soil seed bank, and or relatively abundant seed rain from the adjacent forest.

However, sites where vegetation is cleared from will be exposed to erosive rainfall events, particularly on steep sloping sites. In the lowlands of Papua New Guinea rainfall erosivity is at its highest, and in the study area falls into erosivity classes ranging from moderate across the coastal lowlands to very high in the Wabo area, where 30 – 40% of annual rainfall falls at intensities of 25 mm/hr. The large mass of individual raindrops in the lowlands also contributes to its erosivity (Bellamy, 1995). Field observations suggest the topsoil and subsoil is rapidly lost in high rainfall events exposing unconsolidated sand stone and or mudstone in the hill forest zone (Plate 8-2). These surfaces provide poor rehabilitation substrates and are mostly colonized by weeds, or on steeper slopes may be free of vegetation. However, where surfaces are on gentle slopes with exposed unconsolidated sandstone, several tree species will regenerate, particularly *Trichospermum*, *Alphitonia incana*, *Duabanga moluccana* and *Pipturus*. *Trichospermum* is one of the fastest growing species with a diameter growth rate of up to 3 cm/year (Alder, 1998). *Duabanga moluccana* was common along the Antelope 3 access road and had a wide spreading crown that may assist with weed suppression (Plate 8-3).

Plate 8-2 Erosion of a sandstone substrate leaving a subsoil pedestal

Plate 8-3 *Duabanga moluccana* with a ground layer of the grass *Paspalum conjugatum* (Antelope 3 access road)

8.3 REMOVAL OF VEGETATION AND SOIL

Infrastructure construction typically results in the complete removal of vegetation and topsoil, exposing subsoil and bedrock, some of which may require reinstatement, particularly across the hill forest zone where erosion will be at its highest. This zone is underlain by predominantly siltstone and mudstone bedrock that form part of the Southern Fold Mountains geomorphology region. Field observations suggest these substrates are difficult to rehabilitate, possibly reflecting the absence of topsoil and the associated soil seed bank, a combination of poor rooting medium because of poor water holding capacity, the blocky mudstone structure (Plate 8-4) with little potential to form soil aggregates, and possibly low fertility. In particular, on slopes exposed to the sun the mudstone is friable and dry and becomes hot with increasing sun exposure. Regeneration was poor and vegetation cover was low across these sites apart from occasional weeds, e.g., the grass *Paspalum conjugatum* (Plate 8-5).

Plate 8-4 Mudstone exposed in a landslip adjacent to the Purari River showing poor rehabilitation potential

Plate 8-5 Regeneration failure on a convex mudstone substrate surface

8.4 SIDECASTING SURFACES

In hilly terrain sidecasting excess spoil has been undertaken related to previous exploration works in PRL-15 resulting in exposed surfaces. Good examples of sidecast impacts in hill forest are associated with the construction of the Antelope and Elk wellpads (Sites 4, 5, 6, 7 & 8) where spoil has been sidecast to construct the wellpads. Good regeneration was present on all the observed sidecast surfaces (Plate 8-6), except on a steep slope at Antelope 3 (Site 6) where subsequent surface landslips had occurred in what appeared to be an unconsolidated sandstone substrate (Plate 8-7). Unconsolidated/poorly consolidated sandstone is likely to be one of the dominant sidecast substrates in the Project area. Where slopes of the sandstone substrate are stable the majority of the sidecast slopes support good regeneration. The presence of regenerating forest on the sandstone substrate reflects the sidecasting of topsoil, within which the first 10 cm supports the majority of the soil seed bank. The soil seed bank is essential for providing rapid regeneration across disturbed surfaces and may contain almost 1,000 viable seeds/m^2 in the top 5 cm of soil (Rogers and Hartemink, 2000). Most of these seeds (99%) are pioneer species with fast growth rates, and short life cycles that quickly reproduce to replenish the soil seed bank. The seed of pioneer species remain viable in the soil for several years from which forest regeneration occurs.

Common tree species represented in the regeneration across the sidecast slopes included *Ficus pungens*, *Ficus damaropsis*, *Macaranga*, *Neonauclea*, and *Trema orientalis*. In addition, *Anthocephalus chinensis*, *Ficus nodasa* and *Rhus taitensis* may be locally abundant depending on the site.

The other main substrate likely to be sidecast is mudstone. Although no sidecast slopes of mudstone substrate were observed, the friable and blocky structure of mudstone together with its propensity to dry out (see Section 8.3) suggests it may be a poor substrate for regeneration, unless there is sufficient covering of topsoil to prevent it drying out.

Plate 8-6 Good regeneration on a sidecast slope at Antelope 1

Plate 8-7 Landslip on an Antelope 3 sidecast slope showing failed rehabilitation

8.5 WELLPAD SURFACES

Wellpad surfaces are a constructed landform where typically vegetation and topsoil is cleared prior to the construction of a flat landform that forms the wellpad surface, often with steep side slopes. The surfaces are typically characterized by flat hardpack, normally made of crushed bedrock with variable drainage, possibly attributable to differing degrees of compaction.

Wellpad surfaces are a universally poor substrate for regeneration, based on field observations, with little or no regeneration across all the wellpad sites (Sites 4, 5, 6, 7 & 8). Some sites were waterlogged while others presented hard dry surfaces. Where surfaces were waterlogged weeds were abundant, but forest regeneration was absent. At Site 8 (Elk 1), the poorly drained wellpad surface was infested by the weed *Angelonia angustifolia* (Plate 8-8). In contrast, at Site 4 (Antelope 1) much of the wellpad hardpack surface was well drained which provided a poor surface for any type of vegetation establishment other than occasional grasses and bryophytes (Plate 8-9).

Plate 8-8 Infestation of the Elk 1 wellpad surface with *Angelonia angustifolia*

Plate 8-9 Bare hardpack wellpad surface

8.6 DIEBACK

Forest dieback was identified at one location in the export pipeline corridor in an area of Open alluvial forest (Po). The dieback occurred across 60 ha of forest but was patchy (Plates 8-10 and 8-11, Figure 5-1). The dieback had caused canopy dieback and tree mortality across the site in low-lying areas. The area had been partly logged and a major logging truck haul road was within 100 m of the dieback. Field observations suggest the low lying swampy area was a natural feature although drainage may have been further impeded by logging activities and the haul road construction.

Plate 8-10 Oblique aerial view of the dieback (note dead trees adjacent to river)

Plate 8-11 LIDAR imagery showing dieback site (note grey dead trees)

9 REHABILITATION

This section considers the rehabilitation requirements of the main vegetation formations, including sensitive vegetation types.

9.1 SENSITIVE AND POORLY REPRESENTED VEGETATION TYPES

For the purposes of this study sensitive vegetation types refers to vegetation types that are likely to be difficult to rehabilitate or may be subject to regeneration failure if disturbed, or are a particularly important resource of restricted distribution for local communities for ecosystem services. However, disturbances that result in loss of topsoil, change of drainage, soil compaction, or substantial sedimentation, may impact all the vegetation types. Consequently, where impacts are more severe any vegetation type may be more difficult to rehabilitate (potentially sensitive) than at other locations.

There are two poorly represented vegetation types; Littoral forest (B) that occurs on the marine sands near the coast, and *Pandanus* dominated Swamp woodland (Wsw). The poor representation of Littoral forest (B) in the study area reflects its naturally restricted distribution on older marine sands. The limited distribution of *Pandanus* dominated Swamp woodland (Wsw) may reflect a different soil type and associated flood regime. The rehabilitation requirements and the potential sensitivities of these and the other main vegetation formations are provided in the following sections.

9.2 HILL FOREST

Hill forest is the dominant forest type across the upstream study area and occurs across soils derived from sedimentary bedrock. The hilly terrain and erosive soils may present constraints to rehabilitation because of rapid topsoil loss in the high rainfall environment where the vegetation cover has been removed. Field observations suggest the subsoil is a poor substrate for natural regeneration, reflecting a poor soil structure and possibly lower fertility. Exposed subsoil, particularly on slopes is typically colonized by the ubiquitous grass *Paspalum conjugatum* and several weed species. Where the subsoil is not compacted occasional pioneer tree species may establish, particularly *Trichospermum* sp., *Timonius timon*, and occasional *Ficus* spp.

Rehabilitation of hill forest will be most challenging across steep sidecast slopes where erosion is likely to be high, and particularly where mudstone is exposed which quickly dries to a blocky friable structure in which plants appear not to regenerate (Plate 8-4). Factors influencing rehabilitation success of sidecast slopes is discussed in Section 8.4.

9.3 ALLUVIAL FOREST (LARGE TO MEDIUM CROWNED FOREST, OPEN ALLUVIAL FOREST AND MIXED SWAMP FOREST)

Rehabilitation of alluvial forest across the upstream study area may present constraints due to the potential for damage of poorly drained soils if disturbed (e.g., compaction/damage to soil structure and the associated soil seed bank). Mixed swamp forest (Fsw) is the most poorly drained alluvial forest type and is likely to be subject to more prolonged inundation than the other alluvial forest types. Consequently, there is a potential for a higher degree of water ponding and localized regeneration failure if this occurs. More poorly drained soils will also be more sensitive to damage to the soil structure from compaction where subject to movements of heavy machinery. The impact of prolonged waterlogging on alluvial forest was evident in the dieback site where prolonged flooding from 2014 floods had caused extensive canopy dieback and mortality of large trees, indicating the sensitivity of alluvial forest to excessive periods of inundation. Forest dieback is discussed in Section 10.3.

9.4 SWAMP WOODLAND (WSW)

Swamp woodland is usually dominated by sago palms (*Metroxylon sagu*) which have good regeneration characteristics since the palms can regenerate from seed and suckers. Consequently, Swamp woodland (Wsw) can recover quickly from suckers where palms are cut back only. Moreover, seed is water transported and will float back into disturbed sites once construction has been completed. The main limitation to rehabilitation is sedimentation, which has the potential to cause dieback. Sedimentation can cover the aerial roots and can impede drainage resulting in a lack of oxygen causing fine root death.

Pandanus sp. also occasionally dominates swamp woodland. *Pandanus* sp. regenerate from seed but many species of *Pandanus* regenerate from branch cuttings too.

For both types of Swamp woodland (Wsw) the waterlogged nature of the soil profile is potentially very susceptible to disturbance from construction damage, particularly from heavy machinery.

9.5 MANGROVES (M)

Mangroves across the study area vary from those that are dominated by the palm *Nypa fruticans* to those dominated by forest. The palm dominated mangroves are lower lying and are important for preventing coastal erosion (Ellison, 1997), and are therefore a priority for rehabilitation. Regeneration is primarily from seed but also from its rhizomatous stem when the plant is damaged. Regeneration from seed may not always be effective since most of the seed is likely to washed away at high tide (Rozainah and Aslezaeim, 2010). Rhizomatous vegetative regeneration occurs after severe disturbances such as tsunamis which suggests palm dominated mangrove may regenerate effectively without intervention (Dahdouh-Guebas et al., 2005).

Mangrove forest rehabilitation has been achieved by planting and natural regeneration, with different degrees of success. Where large scale planting has been undertaken, even after 60 years mangrove forest can still lack the stand structure and diversity of the original forest, reflecting a high planting density and associated shade preventing natural regeneration. Mangroves are mostly shade intolerant and can also suffer heavy seed predation by crabs preventing seedling establishment (Barnuevo *et al.*, 2017).

Regeneration of mangroves has been found to be more successful than planting. Mangrove forest with similar species composition to the study area occurs in West Papua, where after logging it regenerates to a similar stand structure to the original stand by natural regeneration in approximately 40 years. However, the initial species composition is strongly influenced by tidal flows which results in wide dispersal (i.e., reduced retention) of lighter propagules (e.g. *Ceriops tagal*) and large clusters of species with heavier propagules such as *Rhizophora apiculata*, particularly in cleared areas. Overall the suite of regenerating species is determined by the level of tidal inundation a disturbed site is influenced by, due to the species-specific thresholds to flooding (Friess, 2016). These thresholds are represented by different tidal inundation classes which are based on tide height and the frequency of flooding (Watson, 1928) resulting in a continuum of change in species composition from high tides and frequent flooding to low tides and infrequent flooding. These factors are central to mangrove rehabilitation and are incorporated into various mangrove rehabilitation manuals, e.g. (Lewis and Brown, 2014).

Since mangroves are an important resource for erosion protection and are an important resource for local communities for fishing and harvesting mud crabs, the rehabilitation of mangroves is a priority.

9.6 LITTORAL VEGETATION

The littoral zone is typically colonized by herbaceous beach vegetation, beach scrub, beach woodland and Littoral forest (B). These communities colonize marine sands from the first ridge behind the beach to inland beach ridges and flats respectively. The site assessed for this study comprised herbaceous beach vegetation and beach scrub only. The herbaceous beach vegetation was dominated by the creeper *Ipomea pes-caprae* (Plate 9-1), the grass *Ischaemum muticum* and the lauraceous parasite *Cassytha filiformis*. The beach scrub mostly comprised scattered shrubs of *Desmodium umbellatum* and small trees of *Hibiscus tilliaceous* (also a component of beach woodland). These species were widespread across the first sand ridge behind the beach and appeared to be the species most likely to colonize the youngest sand dunes if disturbed, and in particular *Ipomea pes-caprae* and the grass *Ischaemum muticum* which rapidly spread once established. Littoral forest (B) comprises canopy trees that also occur in alluvial forest including *Pterocarpus indicus*, *Syzygium* spp. and *Terminalia* sp. but may also contain species that occur in beach woodland such as *Barringtonia asiatica*, the deciduous *Terminalia catappa*, *Calophyllum inophyllum* and *Pandanus tectorius* (Paijmans, 1976). This vegetation is likely to have a relatively thin topsoil that would be difficult to salvage in rehabilitation works. Therefore, littoral woodland/forest may potentially be sensitive to disturbance due to potentially thin topsoil that would be easily eroded if exposed to high intensity rainfall events.

Plate 9-1 The littoral zone pioneer creeper *Ipomea pes-caprae* (Herekela)

9.7 GRASSLAND SWAMP (GSW)

Swamp grassland in the study area is mostly dominated by the tall grasses *Saccharum spontaneum* and *Phragmites karka*. These species readily regenerate after disturbance from seed, and vegetatively from cut stems and underground rhizomes if disturbed.

10 FACTORS INFLUENCING REHABILITATION SUCCESS

10.1 EROSION

Disturbance from construction activities will expose the landscape to modified levels of erosion forces from rain, flowing water, and gravity (mass movement) which will vary according to the soil type, terrain and position in the landscape (e.g. ridge, slope or valley), resulting in different erosion hazards throughout the Project footprint.

The variable terrain in the study area includes marine sands, mangrove sediments, gently sloping alluvial plains, and steep hills composed of mudstone and sandstone. Within each of these environments rainfall energy/erosivity (the potential ability of rain to cause soil erosion) is dissipated, modified or concentrated. Resistance to rainfall erosivity (the potential of rain to cause erosion) is provided by vegetation, other forms of surface cover (e.g., salvaged vegetation debris), and soil/regolith properties. In relation to soil properties this resistance is referred to as erodibility, and varies with soil type (Bellamy, 1995), with unstable dispersive soils on steep slopes being most susceptible. Steep slopes are common throughout the hill forests of the study area and are subject to moderate to very high annual rainfall erosivity which suggests future Project construction surfaces are potentially likely to be subject to high rates of erosion where soil is exposed. Soil loss by erosion in the humid tropics after removal of vegetation can range from 10 – 62 t/ha for slopes of 10 and 42 degrees respectively. By comparison, soil loss from forested slopes is negligible. A forested slope of 22 degrees has a soil loss of less than 1 t/ha. Soil loss above 50 t/ha is rated as a high level of soil degradation (Bleeker, 1983). Therefore, large volumes of soil could potentially be eroded during construction without prompt mitigation, creating challenging rehabilitation surfaces.

The construction and use of roads can be a significant source of soil erosion in Papua New Guinea forested basins where sidecasting is used as a means of managing excess spoil. Road and pipeline right-of-way construction removes vegetation from the road or right-of-way cutslope, fillslope, ditch, and pavement, leaving these areas susceptible to erosion resulting in a poor substrate for rehabilitation, often subsoil or bedrock dominated. Over time, the cutslope and fillslope revegetate, often slowly and erosion from these sources is reduced, however, the road pavement and ditch will

continue to be sediment sources while in use and the right-of-way will be susceptible to erosion until vegetation regenerates.

Sidecast slopes are also poor rehabilitation mediums because of a lack of topsoil and the small aggregate size of the upper slopes. Large aggregates (e.g., large blocks) are important for trapping organic matter (e.g., leaf litter and other plant debris) and plant propagules. The organic matter decomposes providing a growing medium for seed germination. Large aggregates typically accumulate at the base of sidecast slopes where better regeneration can occur.

Factors that influence the level of surface erosion from roads are site conditions including topography, stability or erodibility of the exposed surface soils and/or sub-soils, the techniques of construction drainage, and rainfall erosivity. Direct additions of sidecast soils during road construction and some surface erosion of fill slopes immediately adjacent to road culverts, can account for much of the erosion (sediment generation) during and immediately following road construction creating a challenging environment for vegetation rehabilitation because of soil loss, particularly in the 18 months following construction when most erosion occurs.

10.2 WEEDS

Construction activities potentially provide a pathway for the migration of weeds into previously weed free areas. Severe weed infestations could potentially reduce the success of rehabilitation measures by competing out native species. Common weeds that may typically invade construction surfaces are provided in the baseline weeds report (Rogers, 2017).

10.3 DIEBACK

Forest dieback has the potential to prevent successful rehabilitation, and if caused by a plant pathogen, has the potential to be spread widely by direct and indirect project related activities. However, there are two main natural causes of forest dieback in Papua New Guinea; root rot associated with the fungal pathogen *Phytophthora* sp. and prolonged inundation from severe flood events, particularly across the lowlands of Papua New Guinea (Pers. Obs. Howard Rogers). However, flooding can also be caused by changed hydrological conditions associated with construction earthworks. Phytophthora related dieback in Papua New Guinea is confined to montane *Nothofagus* forests (southern beech) (Arentz, 1984, Arentz, 1988). Plant pathogen (probably fungal) related dieback also occurs in the lowland zone (i.e., below 1000 amsl) of Papua New Guinea, but appears to be restricted to volcanic soils and is associated with roads and extensive pig activity (Pers. Obs. Howard Rogers).

Field observations suggest the forest dieback identified in the study area occurred in a poorly drained low lying swampy area, although drainage may have been further impeded by logging activities and the nearby haul road construction. The area is likely to have been subject to prolonged inundation associated with the 2014 flood event, particularly as it is adjacent to a watercourse. The prolonged inundation is the most likely cause of the dieback, which causes fine roots to die due to lack of oxygen (anaerobic conditions) resulting in tree mortality (Thomas, 2000). Such catastrophic flooding is likely to be a rare event, and under the normal cycle of flood events, proximity to a watercourse is not known to have any adverse impact on vegetation or its rehabilitation.

11 CONCLUSIONS

The study has achieved its baseline objectives of assessing the rehabilitation of a range of surfaces that reflect potential construction outcomes, the identification or potentially sensitive/poorly represented vegetation communities and their resilience to potential impacts, and the regeneration response in potential sidecasting areas.

The upstream Project footprint will impact a range of vegetation types across different landforms including marine sands, mangrove sediments, alluvial soils and coarse sedimentary soils. Moreover, the scale and severity of disturbance associated with the Project footprint will vary from the temporary cutting back of vegetation to complete removal of topsoil, potential sidecasting of spoil in steep terrain, and associated reshaping of landforms along road line segments.

Where temporary clearance occurs and topsoil remains intact, sites are likely to recover by natural regeneration of vegetation provided topsoil is not exposed for a lengthy period. Where topsoil is

exposed, particularly on sloping sites, in the high rainfall environment of the Project, erosion will occur removing the topsoil and associated soil seed bank. This will expose the lower productivity subsoil which may become permanently dominated by grasslands and herbaceous and woody weed communities, thus not reverting to forest without rehabilitation intervention. If sidecasting is required high rates of erosion are expected, in places exposing mudstone bedrock which appears to present severe rehabilitation challenges because of its friable and blocky structure.

The level of rehabilitation required will vary depending on the intensity of the disturbance and what is required to meet the associated rehabilitation completion criteria[4]. Avoiding problematic areas, limiting vegetation and soil disturbance, and salvaging topsoil and cleared vegetation, including coarse woody debris to spread over exposed areas will be important measures to promote effective regeneration and limit the need for costly active rehabilitation measures.

[4] Rehabilitation completion criteria provide a realistic goal to which rehabilitation should aim to meet and are typically represented by milestones in the biophysical processes of rehabilitation that provide a high degree of confidence that the rehabilitated site will eventually reach the desired sustainable ecosystem state.

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APPENDIX A

UNBOUNDED PLOT SPECIES LIST

Species	Life form	(1) Site 2 - gap	(2) Site 2 - slump	(3a&b) Site 3 - logging rd	(4) Ant 1	(5) Ant 2 - sidecast	(6 & 7) Ant 3 - sidecast	(8) Elk 1	(10) Kuku Creek Rd	(12) Purari Airstrip logging rd	(13) Purari landslip	(14) Herekela beach
Bambusa sp.	Bamboo										×	
Christella arida	Fern		×						×			
Not identified* - (dusty white spores on undersurface)	Fern										×	
Lindsea sp.	Fern				×							
Lycopodium sp.	Fern								×			
Lygodium sp.	Fern									×	×	
Nephrolepis sp.	Fern				×							
Pteris sp.	Fern						×		×			
Selaginella sp.	Fern				×			×		×		
Stenochlaena palustris	Fern								×			
Chloris barbata	Grass											×
Imperata cylindrica	Grass					×	×		×	×		
Paspalum conjugatum*	Grass					×	×				×	
Saccharum spontaneum	Grass								×	×	×	
Setaria palmifolia (pit-pit)	Grass		×									
Sphaerostephanus sp.	Grass										×	
Urochloa mutica*	Grass										×	
Ageratum conzyoides*	Herb						×					
Alocasia sp.	Herb										×	
Alpinia pulchra	Herb								×			
Alpinia sp.	Herb				×		×	×	×	×	×	
Angelonia angustifolia*	Herb					×						
Blumea sp.	Herb						×				×	
Comminsia sp.	Herb	×	×							×	×	
Crassocephalum crepidioides*	Herb										×	
Debregeasia/Pilea	Herb						×					
Dianella sp.	Herb				×							
Emilia sonchifolia*	Herb										×	

Species	Life form	(1) Site 2 - gap	(2) Site 2 - slump	(3a&b) Site 3 - logging rd	(4) Ant 1	(5) Ant 2 - sidecast	(6 & 7) Ant 3 - sidecast	(8) Elk 1	(10) Kuku Creek Rd	(12) Purari Airstrip logging rd	(13) Purari landslip	(14) Herekela beach
Erigeron sumatrensis*	Herb											×
Euphprbia hirta*	Herb						×					
Heliconia sp.	Herb										×	
Holochlamys beccaria	Herb							×			×	
Homalomena sp.	Herb				×							
Hornstedtia scottiana	Herb		×						×	×		
Ludwigia sp.*	Herb										×	
Musa sp.	Herb										×	
Phyrnium sp.	Herb				×			×				
Physalis angulata*	Herb										×	
Polygala paniculata*	Herb							×				
Riedellia sp.	Herb							×				
Spathoglottis sp.	Herb				×	×	×		×	×		
Symbegonia sp.	Herb							×				
Tapeinochilos sp.	Herb		×									
Arenga macrocarpa	Palm										×	
Caryota rumphiana	Palm									×	×	
Hydriastele costata	Palm										×	
Calamus sp.	Palm - climbing							×				
Korthalsia zippelii	Palm - climbing		×					×				
Pandanus sp.	Pandanus				×				×	×	×	
Mapanea sp.	Sedge							×				
Calicarpa sp.	Shrub		×	×						×		
Clerodendon sp.	Shrub			×							×	
Cordyline terminalis	Shrub				×	×	×	×	×		×	
Cyrtandra sp.	Shrub							×				
Desmodium sp.	Shrub											×
Dodanea sp.	Shrub											×
Dracaena sp.	Shrub										×	
Leucosyke sp.	Shrub	×		×	×		×		×	×	×	
Leukosyke capitalata	Shrub					×		×				

Species	Life form	(1) Site 2 - gap	(2) Site 2 - slump	(3a&b) Site 3 - logging rd	(4) Ant 1	(5) Ant 2 - sidecast	(6 & 7) Ant 3 - sidecast	(8) Elk 1	(10) Kuku Creek Rd	(12) Purari Airstrip logging rd	(13) Purari landslip	(14) Herekela beach
Melastoma sp.	Shrub	×			×			×	×			
Mussaenda sp.	Shrub					×	×	×		×	×	
Phyllanthus sp.	Shrub								×		×	
Piper aduncum*	Shrub									×	×	
Aglaia sp.	Tree				×							
Alphitonia incana	Tree						×			×		
Alstonia scholaris	Tree							×	×	×		
Anthocephalus chinensis	Tree			×	×		×		×	×	×	
Antiaris toxicaria	Tree					×						
Aporusa sp.	Tree							×				
Barringtonia sp.	Tree							×	×		×	×
Campnosperma brevipetiolata	Tree									×		
Cananga odorata	Tree			×								
Canarium sp.	Tree							×		×	×	
Celtis sp.	Tree									×		
Cerbera floribunda	Tree				×	×	×	×		×		
Commersonia bartramia	Tree									×		
Cryptocarya sp.	Tree	×								×		
Dendrocnide sp.	Tree				×							
Dillenia sp.	Tree							×			×	
Dracontomelon dao	Tree								×	×		
Duabanga moluccana	Tree						×		×			
Duabanga sp.	Tree							×				
Elaeocarpus sp.	Tree							×				
Endopsermum sp.	Tree							×		×		
Fagraea sp.	Tree				×					×		
Ficus adenosperma	Tree						×		×		×	
Ficus copiosa	Tree				×							
Ficus damaropsis	Tree			×	×	×	×				×	
Ficus nodosa	Tree			×	×			×	×	×		

Species	Life form	(1) Site 2 - gap	(2) Site 2 - slump	(3a&b) Site 3 - logging rd	(4) Ant 1	(5) Ant 2 - sidecast	(6 & 7) Ant 3 - sidecast	(8) Elk 1	(10) Kuku Creek Rd	(12) Purari Airstrip logging rd	(13) Purari landslip	(14) Herekela beach
Ficus polyantha	Tree			×					×		×	
Ficus pungens	Tree		×		×	×	×	×	×	×	×	
Ficus sp.	Tree	×	×		×	×	×	×	×	×	×	
Ficus wasa	Tree						×	×			×	
Garcinia sp.	Tree									×		
Garuga floribunda	Tree										×	
Glochidion sp.	Tree							×	×	×	×	
Gnetum gnemon	Tree									×		
Goniothalamus sp.	Tree		×									
Hibiscus sp.	Tree										×	×
Homalanthus novo-guinensis	Tree								×			
Homalium foetidum	Tree		×						×	×		
Homolanthus sp.	Tree			×								
Leea indica	Tree				×							
Leea sp.	Tree					×					×	
Litsea sp.	Tree				×			×				
Macaranga alueritoides	Tree		×	×					×		×	
Macaranga sp.	Tree	×			×	×	×	×		×	3	
Mastixiodendron sp.	Tree					×						
Melicope sp.	Tree				×				×			
Myristica sp.	Tree		×					×		×	×	
Nauclea sp.	Tree								×	×	×	
Neonauclea sp.	Tree			×	×	×	3	×	3	×		
Octomeles sumatrana	Tree			×				×	×	×	×	
Osmoxylon sp.	Tree				×				×			
Paraserianthes falcataria	Tree		×	×					×	×	×	
Pipturus sp.	Tree			×			×		×		×	
Pittosporum sinuatum	Tree		×									
Planchonia papuana	Tree								×			
Planchonia sp.	Tree							×				

Species	Life form	(1) Site 2 - gap	(2) Site 2 - slump	(3a&b) Site 3 - logging rd	(4) Ant 1	(5) Ant 2 - sidecast	(6 & 7) Ant 3 - sidecast	(8) Elk 1	(10) Kuku Creek Rd	(12) Purari Airstrip logging rd	(13) Purari landslip	(14) Herekela beach
Polyscias sp.	Tree										×	
Polyalthia sp.	Tree							×				
Pometia pinnata	Tree							×	×	×	×	
Pouteria sp.	Tree									×		
Premna sp.	Tree										3	×
Pterocarpus indicus	Tree			×						×		
Rhus taitensis	Tree				×						×	
Saurauia sp.	Tree		×		×			×		×	×	
Semecarpus sp.	Tree				×			×			×	
Sloania sp.	Tree									×		
Spondias sp.	Tree			×								
Syzygium sp.	Tree				×		×			×	×	
Talipariti sp.	Tree									×	×	
Teijsmanniodendron sp.	Tree							×				
Terminalia complanata	Tree									×		
Terminalia sp.	Tree			×				×		×		
Timonius sp.	Tree				×			×				
Timonius timon	Tree					×	×		4	×	×	
Trema orientalis	Tree	×	×	×	×	×	×		×	3	3	
Trichopsermum sp.	Tree						×	×	×	×	×	
Vatika rassak	Tree							×				
Xanthophyllum papuana	Tree							×				
Zizyphus sp.	Tree							×				
Acalypha sp.	Tree									×		
Angiopteris evecta	Tree fern							×		×		
Cyathea sp.	Tree fern				×			×				
Cassytha filiformis	Vine											×
Derris sp.	Vine										×	
Dioscorea sp.	Vine										×	
Flagellaria indica	Vine				×							
Ipomea pes-caprae	Vine											×

Species	Life form	(1) Site 2 - gap	(2) Site 2 - slump	(3a&b) Site 3 - logging rd	(4) Ant 1	(5) Ant 2 - sidecast	(6 & 7) Ant 3 - sidecast	(8) Elk 1	(10) Kuku Creek Rd	(12) Purari Airstrip logging rd	(13) Purari landslip	(14) Herekela beach
Ipomea sp.	Vine										×	
Merremea peltata	Vine					×	×				×	
Mikania micrantha*	Vine										3	
Mucuna sp.	Vine										×	
Passiflora foetida*	Vine										×	
Pueraria phaseoloides*	Vine					×	×					
Rhapidophora sp.	Vine				×							
Uncaria sp.	Vine	×			×						×	

× = Present, * = Weed species
Notes: (Site number in parenthesis).
Data combined for site numbers 6 & 7.
Site numbers 9, 11 & 15 – No plot data. Observation made only.

APPENDIX B

VEGETATION TERMINOLOGY

Broad 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
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
Pl/Fsw	Complex: Large to medium crowned forest/Mixed swamp forest	Alluvial forest/Swamp forest
Po	Open forest	Open alluvial forest
Po/Fsw	Complex: Open forest/Mixed swamp forest	Open alluvial forest/Swamp forest
Po/Fsw/Hm	Complex: Open forest/Mixed swamp forest/Medium crowned low altitude forest on uplands	Open alluvial forest/Swamp forest/Hill forest
Po/Fsw/M	Complex: Open forest/Mixed swamp forest/Mangrove	Open alluvial forest/Swamp forest/Mangrove
Po/Hsw	Complex: Open forest/Herbaceous swamp	Open alluvial forest/Herbaceous Swamp
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 vegetation		
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/Fsw	Complex: Swamp woodland/Mixed swamp forest	Swamp woodland/Swamp forest

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