ENVIRONMENTAL ASSESSMENT REPORT

VOLUME 3:
APPENDICES 6 TO 9

PNG BIOMASS
MARKHAM VALLEY

MARCH 2017
Report No. 01183B_2_v2

Oil Search

PNG BIOMASS

ERIAS GROUP

ERIAS Group Pty Ltd
ACN 155 087 362

Markham Valley Biomass Limited

PNG Biomass Markham Valley

Environmental Assessment Report

Volume 3 – Appendices 6 to 9

March 2017
(Report No. 01183B_2_v2)

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Appendix 6
Terrestrial Ecology Assessment

TERRESTRIAL ECOLOGY ASSESSMENT

PNG BIOMASS MARKHAM VALLEY ENVIRONMENTAL ASSESSMENT / ENVIRONMENTAL MANAGEMENT PLAN

Prepared for
ERIAS Group Pty Ltd
on behalf of Markham Valley Biomass Limited

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Client: ERIAS Group Pty Ltd on behalf of Markham Valley Biomass Limited

Project Title: Terrestrial Ecology Assessment, PNG Biomass Markham Valley Environmental Assessment / Environmental Management Plan

Project Author/s: Dr Penn Lloyd, David Stanton, David Fell, David Gooding, Frans Arentz

Project Summary: This technical report presents the results of an assessment of the existing terrestrial ecology of the PNG Biomass Markham Valley study area, the likely impacts of the Project on the terrestrial environment, and recommendations for impact mitigation.

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Biodiversity Assessment and Management Pty Ltd has produced this report in its capacity as consultants for and on the request of ERIAS Group Pty Ltd (the "Client") for the sole purpose of providing an assessment of the existing terrestrial ecology of the PNG Biomass Markham Valley study area, the likely impacts of the Project on the terrestrial environment, and recommendations for impact mitigation (the "Specified Purpose"). This information and any recommendations in this report are particular to the Specified Purpose and are based on facts, matters and circumstances particular to the subject matter of the report and the Specified Purpose at the time of production. This report is not to be used, nor is it suitable, for any purpose other than the Specified Purpose. Biodiversity Assessment and Management Pty Ltd disclaims all liability for any loss and/or damage whatsoever arising either directly or indirectly as a result of any application, use or reliance upon the report for any purpose other than the Specified Purpose.

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Signed on behalf of
Biodiversity Assessment and Management Pty Ltd

Date: 06/03/2017

Managing Director

EXECUTIVE SUMMARY

PURPOSE OF THE REPORT

This report has been prepared for ERIAS Group Pty Ltd on behalf of Markham Valley Biomass Limited to describe the baseline terrestrial biodiversity and assess the impacts of the PNG Biomass Markham Valley project (the Project), which proposes to establish up to 16,000 ha of eucalypt plantations to provide biomass (wood) that will be used as fuel for a new 30 MW power plant in the lower Markham Valley in Morobe Province, Papua New Guinea. Terrestrial biodiversity assessed within the study area for the Project included vegetation communities, flora species and vertebrate fauna species. The residual impacts of the Project were assessed based on the implementation of recommended avoidance and mitigation measures.

STUDY APPROACH

The study combined a desktop review of International Union for Conservation of Nature (IUCN) and other biodiversity databases, terrestrial ecology studies previously conducted within the study area and relevant literature on the terrestrial biodiversity of the region with a five-day field survey undertaken by three ecologists over the period 4 to 8 September 2016. The survey sampled representative sites across the study area to cover the full range of habitat types present.

VEGETATION COMMUNITIES

The Project is located in an area that has experienced a long history of disturbance and habitat modification by man, in particular the use of fire to clear the land for cultivation. Consequently, the vegetation of the study area is dominated by grassland (68.4% of the area) and areas where the vegetation has been substantially transformed by land uses such as cattle grazing, village and garden establishment, silviculture, and coconut and palm oil plantations (26.8% of the area). Natural forest covers just 0.2% of the study area, with savannah (2.2%) and active river channels (2.3%) making up the remaining land cover. The condition of vegetation across the study area is generally poor, with 48.1% highly degraded, 46.5% degraded and just 5.4% moderately disturbed or modified. The invasive Raintree (*Albizia saman*) forms the dominant tree cover over at least 16% of the study area.

TERRESTRIAL FLORA

The flora surveys and herbarium records identified 370 species occurring within the study area, including 11 ferns, one cycad, four species of conifer and allies, and 354 flowering plants. The flora included 235 native species and 135 species of introduced/exotic plants (36% of the total flora). Two threatened or near threatened flora species were confirmed as occurring within the study area:

- *Intsia bijuga* (Kwila; IUCN: Vulnerable), recorded as a small regrowth tree associated with degraded forest in a foothill gully at a single location in the study area; and
- *Cycas schumanniana* (IUCN: Near Threatened), recorded as a common cycad growing in grassland on hill foot-slopes throughout the study area with scattered individuals extending onto adjoining outwash plains.

A total of 150 species of plants that are useful to local communities and other stakeholders were identified for the study area, making up 41% of the total flora recorded. These included: 34 species of food plants (including cultivated plants); 11 species that are used medicinally; 109 species that are used for a variety of material uses, including for timber; six species utilised for cultural purposes; and 13 species that are used commercially.

TERRESTRIAL FAUNA

The field survey recorded a total of 89 terrestrial vertebrate fauna species, including 68 bird species, eight mammal species, two reptile species and two frog species. Discussions with reliable local informants identified at least a further 10 mammal species, eight bird species and five reptile species that are likely to occur in the study area. No threatened or near threatened terrestrial vertebrate fauna species were detected in the study area during the field survey. Based on an assessment of habitat suitability and the nature of threatening processes at a broader landscape scale, particularly the relatively high human population density resulting in heavy hunting pressure and extensive rainforest habitat fragmentation and degradation, no threatened or near threatened species are considered likely to occur in the study area. Two introduced fauna pest species, Giant African Snail (*Achatina fulica*) and Cane Toad (*Bufo marinus*), were common throughout the area surveyed, and they were the only fauna species trapped during the trapping survey. Local informants reported that the main terrestrial fauna species that were still hunted in the study area included bandicoots, cuscus and feral pigs, and young boys hunted a variety of birds (particularly doves and pigeons) opportunistically with sling-shots.

INTERNATIONAL FINANCE CORPORATION CRITICAL HABITAT

The assessment of critical habitat in accordance with International Finance Corporation (IFC) guidelines determined that no critical habitat occurs in the assessment area, which instead comprises 1,242 ha of natural habitat and 45,963 ha of modified habitat.

FOREST STEWARDSHIP COUNCIL FOREST TYPE ASSESSMENT

The assessment of forest types under the Forest Stewardship Council (FSC) National Forest Management Standards determined that no High Conservation Value Forests occur in the study area, and natural forests cover just 0.2% of the study area.

IMPACT ASSESSMENT

Potential impacts of the Project include land clearing for the development of plantations and construction of a power station, plantation nursery, access roads and associated infrastructure, habitat fragmentation (including loss of connectivity) associated with land clearing, introduction or spread of invasive weeds, pest fauna and diseases, erosion leading to habitat degradation, and chemical contamination and waste. The impact assessment process for the Project followed a hierarchy of first seeking to avoid impacts and then recommending management measures for mitigating unavoidable impacts.

The direct impact of the Project on terrestrial ecology receptors was calculated as the area of the respective terrestrial ecology receptor that intersected the Project footprint, which comprises all areas subject to Memoranda of Understanding (MOUs) with the land owners. Due to the already modified or degraded condition of vegetation within the broader study area, indirect impacts are considered to be of negligible importance. The residual impact of the Project on various ecological values was calculated as the total area of that value that intersected with the total area under MOUs. However, this residual impact area will be reduced once buffers to waterways and wetlands are accounted for and villages and other sensitive areas are avoided. While the total area under MOUs is 16,097 ha, up to 16,000 ha is expected to be planted to plantations.

The residual impact areas of the Project footprint on terrestrial vegetation communities are summarised in the table below.

Vegetation community code	Vegetation community description[1]	FIM equivalent[2]	Total area (ha)[3]	Area under MOUs (ha)	% under MOUs
Vegetation communities with minimal to moderate present-day disturbance					
1a	Large to medium crowned forest (disturbed).	PL: Large to medium crowned forest	13.6	0.0	0.0
2a	Small crowned forest / regrowth forest	PS: Small crowned forest	102.5	0.0	0.0
3a	*Nauclea orientalis / Albizia procera* savannah	SA: Savannah	53.8	8.4	15.7
4a	Kunai grassland on riverine alluvium	G: Grassland	907.3	146.3	16.1
4b	Kunai grassland on footslopes and hillslopes	G: Grassland	390.3	0.0	0.0
Vegetation communities with moderate to high levels of disturbance					
3b	*Nauclea orientalis / Albizia procera* savannah - moderately degraded	SA: Savannah	937.7	657.7	70.1
4c	Kunai grassland on riverine alluvium -moderately /patchily degraded with weeds	G: Grassland	19,322.6	9,278.6	48.0
12a	Active river channels	O: Other non-vegetation and areas dominated by landuse[4]	1,072.3	347.2	32.4
Vegetation communities that are highly degraded					
2b	Mixed native/exotic secondary forest	O: Non-vegetation and areas dominated by landuse[4]	1,148.5	678.5	59.2
3c	Native savannah woodland with severely degraded ground cover	SA: Savannah	59.5	17.7	29.7
4d	Kunai grassland on riverine alluvium - heavily modified and degraded with weeds and pasture plants	G: Grassland	10,424.6	1,407.5	13.5
4e	Mixed native/exotic grassland, shrubland and woodland on river alluvium.	G: Grassland	553.7	89.9	16.2
4f	*Saccharum robustum, Leucaena leucocephala* grassland/shrubland on recent river deposits	G: Grassland	469.2	118.3	25.2
5a	*Albizia saman* dominated savannah	G: Grassland	210.9	96.4	45.7
10a	Sago swamp - regrowth/degraded forest	O: Non-vegetation and areas dominated by landuse[4]	92.9	46.4	49.9
Vegetation communities resulting from complete habitat modification					
5b	*Albizia saman* dominated open forest	O: Non-vegetation and areas dominated by landuse[4]	7,430.2	2,681.8	36.1
6a	*Leucaena leucocephala, Albizia sp., Albizia saman* dominant shrubland	O: Non-vegetation and areas dominated by landuse[4]	206.1	29.6	14.4

Vegetation community code	Vegetation community description[1]	FIM equivalent[2]	Total area (ha)[3]	Area under MOUs (ha)	% under MOUs
7a	Village area	O: Non-vegetation and areas dominated by landuse[4]	397.3	60.2	15.2
8a	Plantation areas/leucaena/palm oil	O: Non-vegetation and areas dominated by landuse[4]	936.7	0.3	0.0
8b	Plantation areas: *Pinus* and *Araucaria*	O: Non-vegetation and areas dominated by landuse[4]	25.8	0.0	0.0
9a	Former gardens/coconut plantations	O: Non-vegetation and areas dominated by landuse[4]	2,155.4	430.7	20.0
11a	Garden areas with evidence of recent modification	O: Non-vegetation and areas dominated by landuse[4]	294.1	0.0	0.0
Total			**47,205.0**	**16,097.0**	

[1] Description derived from Paijmans (1976), applied to natural vegetation communities only.
[2] Classification derived from Hammermaster and Saunders (1995).
[3] Total area of the vegetation community within the study area.
[4] Referring to areas utilised by humans for agriculture, settlement or other industrial or extractive activity.

The residual impact areas of the Project by vegetation condition category are summarised in the table below.

Condition category code	Condition category description	Total area (ha)	Area under MOUs (ha)	% under MOUs
2b	Moderately disturbed (stable or regenerating)	156.2	8.4	5.4
2a	Moderately disturbed (stable to declining)	1,085.9	347.2	32.0
3	Modified (cultural)	1,297.5	146.3	11.3
4	Degraded	21,970.9	10,780.9	49.1
5	Highly degraded	22,694.4	4,814.1	21.2
Total		**47,205.0**	**16,097.0**	

Of the 16,097 ha under MOUs, 2.2% is moderately disturbed (condition category 2), 0.9% is modified (condition category 3), 67.0% is degraded (condition category 4) and 30.0% is highly degraded (condition category 5). Therefore, the great majority of the residual impact of the Project (approximately 97% of the areas under MOUs) will occur in degraded or highly degraded vegetation communities.

The Project will have a potential impact on up to 355.6 ha of natural habitat under the IFC habitat classification (Performance Standard 6), comprising 347.2 ha of active river channels (VC12a) that will likely be protected by implementation of the watercourse buffers and 8.4 ha of savannah (VC3a). Compliance with IFC Performance Standard 6 requires that the Project should not significantly convert or degrade natural habitats, unless conversion or degradation is mitigated according to the mitigation hierarchy designed to achieve no net loss of the natural habitats affected, for example through habitat restoration or implementation of biodiversity offsets.

The Project will have no impact on natural forest under the FSC forest classification, since all areas of natural forest within the study area occur outside of the areas under MOUs; therefore the Project will avoid impacts on natural forest. Should the proponent wish to apply for FSC certification under the revised draft FSC National Forest Management Standard for Papua New Guinea, which is not currently in force, then compliance with Management Indictor A1 under Principle 5, Annexe C requires that wetlands, peatlands, savannahs or natural grasslands are not converted to plantations or any other land use except where:

- the conversion is producing clear, substantial, additional, secure, long-term conservation benefits in the management unit; and
- the total area of plantation on sites converted is less than 5% of the total area of the management unit.

The implementation of buffers to wetlands will ensure no wetlands in the Project area will be converted to plantations or any other land use. No peatlands or natural grasslands were identified within the Project area. The Project may have a residual impact on up to 8.4 ha of natural savannah (VC3a) unless these areas of savannah are avoided. While conversion of 8.4 ha of savannah would constitute less than 0.1% of the management unit, the conversion is not expected to produce a conservation benefit.

Of the two conservation priority flora species that are known to occur in the study area, namely *Intsia bijuga* (Kwila) and *Cycas schumanniana*, Kwila was not detected within the areas under MOUs; therefore the Project is expected to have no residual impact on this species. While all occurrences of habitat most suitable for *Cycas schumanniana* occur outside of the areas under MOUs that will be potentially directly impacted by the Project, a single small sub-population of the species was detected on the boundary of an area under MOUs. Successful implementation of the recommended avoidance or mitigation measures (conservation buffer to avoid impacts or translocation of plants to mitigate impacts) is likely to result in no net loss of individuals of the species due to the Project.

Assuming successful implementation of the mitigation and management measures recommended for the Project, the residual impacts of the Project on terrestrial ecology values are summarised in the table below.

Ecological receptor	Magnitude of impact	Sensitivity	Significance
Intsia bijuga (Kwila)	Negligible	High	Negligible
Cycas schumanniana	Negligible	High	Negligible
Natural forest habitats	Negligible	Moderate	Negligible
Modified habitats, other natural habitats and general flora and fauna biodiversity	Moderate	Low	Low

TERRESTRIAL ECOLOGY ASSESSMENT

PNG BIOMASS MARKHAM VALLEY ENVIRONMENTAL ASSESSMENT / ENVIRONMENTAL MANAGEMENT PLAN

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Table of Terms and Abbreviations

Abbreviation	Explanation
asl	Above sea level
BAAM	Biodiversity Assessment and Management Pty Ltd
BDMt/yr	Bone dry metric tonnes per year
CEPA	Conservation and Environment Protection Authority
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
cm	Centimetre, a unit of length in the metric system
DEC	Department of Environment and Conservation (organisation superseded by CEPA)
E	FIM code for: non-vegetation, including lakes and large rivers, and areas dominated by land use
EA	Environmental Assessment
FIM	Forest Inventory Mapping System
FSC	Forest Stewardship Council
G	FIM code for: grassland vegetation community
GISD	Global Invasive Species Database
ha	Hectare, a unit of area in the metric system
IFC	International Finance Corporation

Abbreviation	Explanation
ILG	Incorporated Land Group
IUCN	International Union for Conservation of Nature
km	Kilometre, a unit of distance in the metric system
m	Metre, a unit of length in the metric system
MW	Megawatt, a unit of power
NPK	Nitrogen-phosphorus-potassium, a fertiliser
O	FIM code for: non-vegetation and areas dominated by landuse
PIER	Pacific Island Ecosystems at Risk Database
PL	FIM code for: large to medium crowned forest on plains and fans vegetation community
PNG	Papua New Guinea
POEA	Polyethoxylated tallowamine
PS	FIM code for: small crowned forest / regrowth forest vegetation community
VC	Vegetation community
WWF	World Wildlife Fund

1.0 INTRODUCTION

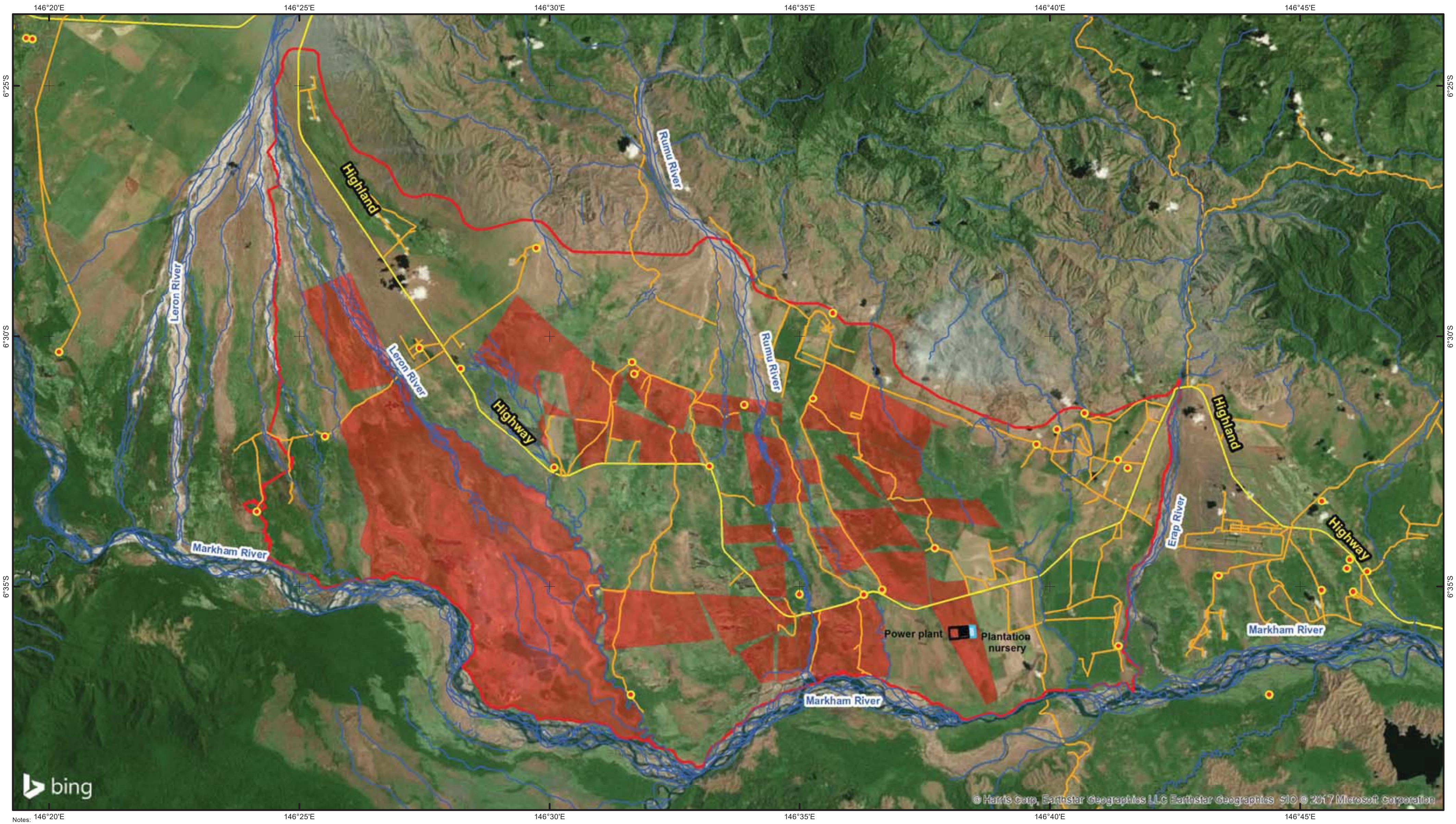
1.1 PROJECT DESCRIPTION

The PNG Biomass Markham Valley project (the Project) is located in the lower Markham Valley, approximately 40 km west of Lae in Morobe Province, Papua New Guinea. The Project has two related major components – establishment of up to 16,000 ha of eucalypt plantations to provide biomass (wood) that will be used as fuel for a new 30 MW power plant (consisting of two separate 15 MW units that will be constructed several years apart). Additional components include a plant nursery and ancillary infrastructure (see **Figure 1.1**).

The Project will develop plant nursery facilities capable of producing 8,000,000 plants per annum in order to establish plantations to produce sufficient biomass to sustainably meet fuel demand for the power plant. In the first two to three years of nursery operations, most plants produced will be *Eucalyptus pellita*, grown from seedlings. Nursery production will progressively move towards propagation from cuttings, and will aim to produce 100% of plants from cuttings after three to four years of nursery operations. Production will progressively move towards hybrids of *E. pellita* x *E. tereticornis*, since hybrid species tend to exhibit improved growth and vigour. Hybrids of *E. pellita* x *E. camaldulensis* will also be grown for planting in wetter areas and/or where heavier clay soils occur.

Establishment of up to 16,000 ha of eucalypt plantations within the Project area will occur over a seven-year period between 2017 and 2023, with the plantation area to be maintained indefinitely. The maximum plantation area established in any one year will be 4,500 ha in 2019, with an average of around 2,000 ha/year established during this initial phase. Prior to site clearing and plantation establishment, road access to the proposed plantation areas will be established or upgraded. In areas to be planted, all existing vegetation including trees up to 30 cm in diameter (at breast height over bark) will be removed to enable clear and unrestricted access to the site by manual or mechanical operations. Cleared Raintrees (the introduced, invasive species *Albizia saman*) will be stockpiled for use as biomass fuel for the power plant. Where practicable (and subject to landowner negotiations), plantations will be established (and eventually harvested) in a dispersed pattern across the landscape in order to reduce localised impacts on environmental and/or socio-cultural values. Plantations will be established progressively across the Project area in 'compartments' of approximately 20 ha each, ranging from 5 to 50 ha based on local constraints such as watercourses, existing gardens/crops, or areas of unsuitable soils. Within a given compartment, planting (and later maintenance and harvesting) will occur concurrently.

Prior to planting, mound ploughing will be undertaken to a minimum of 30 cm depth to ensure that soil is friable to facilitate tree root growth. A non-residual, 'knockdown' herbicide (glyphosate) along with a surfactant will be sprayed two months before planting, to control regrowth of weeds, grasses and shrubs that would compete with the plantation seedlings. Herbicide spraying will be repeated at two to four weeks before planting. Planting will be at a density of 1,333 stems per hectare, with 3 m between rows and 2.5 m between trees. A granular nitrogen-phosphorus-potassium (NPK) fertiliser will be applied manually near each seedling (buried in holes 30 cm from the plant) to encourage its growth. Weed regrowth will be controlled by manual weeding between trees and slashing between rows for the first three months. Spraying of weeds with glyphosate herbicide will also occur in the third and fourth months, and every second month thereafter for the remainder of the first 12 months. After six months, spraying may include an additional herbicide (metsulfuron methyl) designed to control broad-leafed weeds, if necessary. All herbicide spraying undertaken post-planting will be done manually, i.e., by personnel using backpack spray units. Weed control regimes may be modified in locations where intercropping is undertaken by local people. Fertiliser (NPK) will be applied again at 6 and 12 months. Use of pesticides (for control of insect pests) is not proposed unless a significant pest problem arises in a given area.



Notes:

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Coordinate System: GCS GDA 1994
Datum: GDA 1994
Units: Degree

1:135,494 at A4
0 750 1,500 3,000 4,500 6,000 Meters

LEGEND

- Village
- Highland Highway
- Road Network
- Power Plant
- Watercourse
- Plantation nursery
- Potential plantation area under MOU
- Study Boundary

Figure: 1.1

Title: Location of the study area and project footprint

Project: PNG BIOMASS MARKHAM VALLEY TERRESTRIAL ECOLOGY ASSESSMENT

Client: ERIAS Group Pty Ltd

BAAM ECOLOGICAL CONSULTANTS

Drawn By: MG Reviewed by: AC Date: 18-Jan-17

The rotation length (growing phase) of plantations under the biomass production regime will generally be seven to nine years. Commencing in Year 4 (2019), part of the plantation estate will be managed under a veneer/ sawlog regime, which will have a rotation length of 15 to 18 years. These plantations will be thinned in years 4, 8 and 12, with the thinned trees used as biomass fuel.

The power plant is scheduled to commence operations in late 2019. It will be a conventional thermal boiler steam plant, and each of the two 15 MW net power plant modules will consist of one biomass boiler and one steam turbine generator. Raintrees harvested between 2019 and 2022 will be the initial source of biomass fuel, although *Acacia* from existing plantations west of Madang may also be used during this period. By 2023, the fuel source will have transitioned to using biomass grown in its eucalypt plantations within the Project area at a rate of about 175,300 BDMt/yr (bone dry metric tonnes per year) annually. Cooling will involve a wet evaporative mechanical system, using water abstracted from groundwater bores with back-up supply abstracted from the Markham River. The power plant site will cover a total of about 30.8 ha, including the log yard (laydown areas for wood stockpiles) (**Figure 1.1**).

1.2 STUDY OBJECTIVES

The principal aim of this study is to describe the existing terrestrial ecological values within the study area for the Project and to identify and address the potential impacts of the Project on these values. The study aims to characterise the terrestrial ecology of the study area relating to vegetation and terrestrial flora and fauna species in the study area, and assess the potential impacts to vegetation and flora and fauna species of conservation significance at the local, national and international scale, sufficient to fulfil the requirements of an Environmental Assessment (EA) report.

Specific objectives of the study are to:

- describe the existing baseline terrestrial ecological values and sensitive environmental areas relating to terrestrial flora and fauna for the study area and provide context at the local, national and international scale as appropriate for an EA, including characterisation of vegetation communities (type and condition) and their spatial distribution in the study area, and provide lists of species identified and with the potential to occur in the study area with a particular focus on species with conservation priority;
- identify any rare, threatened or otherwise noteworthy species and vegetation communities (i.e., those of conservation significance and/or importance to the local community or areas that can otherwise be classified as 'sensitive environmental areas') that are known to be present or have been recorded in the study area, as well as those that it could be reasonably assumed may occur given geographic location and habitat;
- identify issues related to weeds, pests and/or pathogens that may occur in the study area;
- identify and describe key ecosystem services provided by the vegetation, flora and fauna where applicable;
- conduct the study to satisfy relevant assessment requirements of Papua New Guinea legislation, the Forest Stewardship Council (FSC) National Forest Management Standards for Papua New Guinea (Version 1.1 of May 2010 and Revised Draft 2.0 of December 2016) and International Finance Corporation (IFC) Environmental and Social Performance Standards (2012), particularly Performance Standard 6: Biodiversity Conservation and Sustainable Management of Living Natural Resources;
- describe the potential impacts of the Project on terrestrial ecology during construction and operation of the power plant, and during establishment and operation of the plantations;
- identify and quantify potential impacts with respect to flora, fauna and vegetation communities due to the Project;
- provide recommendations for practicable and economically feasible measures to avoid or mitigate potentially significant adverse impacts on terrestrial fauna, flora and vegetation that may occur as a result of the Project; and

- assess potential residual impacts on terrestrial ecology as a result of the proposed Project (i.e., those impacts that are still likely to occur following effective implementation of management/mitigation measures).

1.3 Study Area Description

The study area for the Project encompasses a large portion of the Markham Valley on the northern side of the Markham River, between the Erap River in the east and the Leron River in the west, and extends from the northern banks of the Markham River to the foothills of the Saruwaged Range in the north (**Figure 1.1**). The study area is the area of assessment of terrestrial ecology values, and for the mapping of vegetation communities and habitat condition. The Project area is a subset of the study area, and comprises the areas under Memoranda of Understanding (MOUs) with the land owners, within which the plantations, power plant, plantation nursery and associated infrastructure will be developed.

1.4 Regulatory Overview

1.4.1 National legislation

The 1975 National Constitution of Papua New Guinea declares as its fourth National Goal and Directive Principle the objective of conserving the country's natural resources and environment for the collective benefit of society and of future generations. The following Papua New Guinea environmental legislation can be considered key national mechanisms for achieving this goal.

Conservation and Environment Protection Authority Act 2014: The *Conservation and Environment Protection Authority Act 2014* provides for the conservation and protection of the environment in accordance with the Fourth National Goal and Directive Principle (National Resources and Environment) of the Papua New Guinea Constitution, provides for the establishment of the Conservation and Environment Protection Authority (CEPA); and repeals the *National Parks Act 1982*. CEPA replaces the Department of Environment and Conservation as the government agency responsible for administering the *Environment Act 2000*, the *Conservation Areas Act (Chapter 362),* the *Fauna (Protection and Control) Act (Chapter 154),* the *International Trade (Fauna and Flora) Act (Chapter 391)* and the *Crocodile Trade (Protection) Act (Chapter 213).*

Environment Act 2000: *The Environment Act 2000* is the primary environmental legislation in Papua New Guinea. The Act provides for protection of the environment in accordance with the fourth National Goal and Directive Principle (National Resources and Environment) of the Papua New Guinea Constitution as well as regulating the environmental impacts of development activities. The main objective of the Act is to protect the environment from harm and in doing so, safeguard the life-supporting capacity of air, water, soil and ecosystems for present and future generations, and preserve Papua New Guinea's traditional social structures. The Environment Act provides the administrative mechanism to evaluate impacts on the environment through an environmental approval and permitting system under the administration of CEPA. The approval process for development projects that are required to submit detailed biological, social and cultural assessments detailing the implications of the development proposal is assessed by a 'Director of Environment' duly appointed for the purposes of this Act. The assessment process for the Project will be administered under this Act and the 2014 amendment to this Act (see below).

Environment (Amendment) Act 2014: The *Environment (Amendment) Act 2014* amends the *Environment Act 2000* with respect to a wide variety of matters and in relation with the enactment of the *Conservation and Environment Protection Authority Act 2014*. Matters subject to modification include: environment management planning and policy; environmental audit or investigation; definitions of "contaminants", general environmental duty, causing environmental harm, freshwater pollution; classification of activities as being harmful to the environment; the duty of having environmental permits and conditions of permit; a notice on the applicant requiring the applicant to undertake an environmental impact assessment in relation to the proposed activity; matters to be included in an environmental impact assessment; the duty of submitting an inception report prior to an environmental impact assessment; review of an environmental impact statement; offences; environmental bonds; functions of the Director of Environment; clean-up orders; and regulation-making. A new section allows the Minister to establish a Technical Standard by notice in the National Gazette, following a recommendation by the Director. A Technical Standard may be established in respect of all or any of the following matters: a contaminant; an industry or activity; a technology or process; a beneficial value; waste management or minimization; noise; decommissioning and rehabilitation requirements. The assessment process for the Project will be administered under this Act.

National Parks Act 1982 (repealed): The *National Parks Act 1982* and National Parks Regulation 1984 related to the conservation, management and development of sites, areas and buildings with particular significance whether of biological, topographical, geological, historical, scientific or social importance. National parks, reserves and sanctuaries were managed under this Act by the Director of National Parks for the protection of flora and fauna. The *National Parks Act 1982* was repealed in May 2014 upon commencement of the *Conservation and Environment Protection Authority Act 2014*; however, all subordinate enactments including the National Parks Regulation 1984 and all forms and instruments made, issued or approved under the *National Parks Act 1982* (repealed) continue in force as if made under the *Conservation and Environment Protection Authority Act 2014*, until varied, repealed or replaced in accordance with this Act. As no national parks, reserves or sanctuaries will be impacted by the Project, no aspects of this legislation are expected to be triggered by the Project.

Conservation Areas Act 1978: Conservation and management of sites, areas and buildings of environmental and national cultural inheritance may also be enacted under the *Conservation Areas Act 1978.* This law relates to matters of national interest. A National Conservation Council advises the Minister on relevant matters, including criteria for recommendations on conservation areas, and development proposals affecting or in the vicinity of a conservation area or proposed conservation area. Conservation areas are managed by a Conservation Area Management Committee that reflects the interests of local landowners and the Provincial Government, Local-level Government or Local-level Government Authority. As no sites, areas and buildings of environmental and national cultural inheritance will be impacted by the Project, no aspects of this legislation are expected to be triggered by the Project.

Fauna (Protection and Control) Act 1966: The *Fauna (Protection and Control) Act 1966* allows for the systematic protection and control of Papua New Guinea's native fauna species, particularly fauna species involved in international trade activities, and allows for the declaration of protected areas in relation to a species or class of animal, and declaration of Wildlife Management Areas. Activities in these areas relate strictly to the management of fauna, unlike the *Conservation Areas Act 1978*, which may relate to protection of a range of cultural and natural resources. No Wildlife Management Area will be impacted by the Project; therefore aspects of this Act relating to Wildlife Management Areas are not expected to be triggered by the Project.

Papua New Guinea International Trade (Fauna and Flora) Act 1979: Papua New Guinea became a signatory in 1976 to the international intergovernmental agreement CITES (the Convention on International Trade in Endangered Species of Wild Fauna and Flora). This agreement is designed to regulate international trade in threatened species in order to prevent over-exploitation, and lists in its Appendices relevant species recommended for protection. The Papua New Guinea *International Trade (Fauna and Flora) Act 1979* and associated Regulations implements this commitment through the Management Authority and the Scientific Authority and by controlling and regulating the trade, possession, transport, exportation and importation of regulated species. The Project may trigger aspects of this Act should on-site salvage, propagation and transport of threatened plant species be proposed as mitigation measures should the Project impact upon CITES-listed plant species.

Crocodile Trade (Protection) Act 1974: The *Crocodile Trade (Protection) Act 1974* regulates and protects the crocodile skin trade, and regulates the management of crocodiles for related purposes. The Project will have no bearing on crocodile trade or management, and will therefore not trigger aspects of this Act.

Forestry Act 1991: The *Forestry Act 1991* relates to the management, development and protection of forest resources and environments as a renewable asset for succeeding generations whilst contributing to the Nation's economic growth, employment creation, and processing of forest resources. Scientific study and research into forest resources is encouraged to contribute to a sound ecological balance. Under the Act, Government land may be dedicated as a National Forest, and trees or members of any species or class of trees may be declared as reserved trees. The Papua New Guinea Forest Authority is responsible for implementation of the Act, for providing advice to the Minister on forest policies and legislation, and for the preparation and review of the National Forest Plan. Each Provincial Government is responsible for preparation of a Provincial Forest Plan. The Act entitles the State (the Forest Authority) to enter into Forest Management Agreements with landowners and for the National Forest Board to recommend to the Minister on appropriate logging companies, and timber permits and licenses.

***Lands Groups Incorporation Act 1974*:** The *Land Groups Incorporation Act 1974* recognises customary land-holding groups, legally identified as incorporated land groups (ILGs) and establishes local community control over land and resources. The ILG process proceeds via consultation among members and consultation and cooperation with incorporated land groups in the same community. Resources tend to be owned by groups but some rights are held by individuals, such as ownership of economic or other valuable trees (Holzknecht 1994). In Papua New Guinea, almost all land (97%) is privately owned by local kinship groups (clans) under traditional land tenure systems, and with respect for customary land rights guaranteed under the National Constitution (Holzknecht 1994).

1.4.2 International agreements

Papua New Guinea is a signatory to a number of international conventions and treaties associated with the conservation of terrestrial biodiversity. These include:

- the *Convention on Biological Diversity*, dedicated to promoting sustainable development through the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources;
- the *Convention on International Trade in Endangered Species of Wild Fauna and Flora* (CITES), which aims to ensure international trade in specimens of wild animals and plants does not threaten their survival;
- the *Ramsar Convention on Wetlands of International Importance* (Ramsar Convention), which provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources;
- the *International Plant Protection Convention* (IPPC), which aims to secure coordinated, effective action to prevent and control the introduction and spread of pests of plants and plant products; and
- the *Convention on Conservation of Nature in the South Pacific* (APIA Convention), a partnership among nations in the Oceania region dedicated to taking action for the conservation, utilisation and development of the natural resources of the South Pacific region through careful planning and management for the benefit of present and future generations; however the operation of this convention has been suspended since 2006.

1.4.3 Forest Stewardship Council (FSC) Standards

The Forest Stewardship Council (FSC) is an international, non-profit, non-government membership association, governed by its members. These members include institutions, organizations and individuals that are stakeholders focussed on achieving environmentally appropriate, socially beneficial and economically viable forest management and use of forest products. To achieve this aim, the FSC operates a certification system with different types of certificates related to the different origins of forest products, stages of production and subsequent progress of forest products through the value chain. The FSC has developed ten Principles and Criteria that set out the global requirements for achieving FSC forest management certification (FSC 2002). This international standard for forest management is adapted at the regional or national level through the development of FSC National Forest Management Standards in order to reflect the diverse legal, social and geographical conditions of forests in different parts of the world (FSC 2015a,b). The FSC National Forest Management Standards for Papua New Guinea set the Principles, Criteria, Indicators and Verifiers by which all forest operations in Papua New Guinea can be judged, uniquely tailored to reflect the social, economic and environmental situation in Papua New Guinea (PNG FSC National Working Group 2010, FSC 2016).

The National Forest Management Standards for Papua New Guinea of May 2010 (Version 1.1) currently apply. The FSC National Forest Management Standards for Papua New Guinea are currently being revised to bring them in line with a new version of the FSC International Generic Indicators that was approved by the FSC Board in 2015 (FSC 2015b). The most recent version of this revision is the December 2016 Draft 2.0 of the Revised FSC National Forest Management Standards for Papua New Guinea (FSC 2016). However, until the revised national standard is approved by the FSC Policy and Standards Unit, FSC certification processes in Papua New Guinea will continue to be based on the current version of the FSC National Forest Management Standards for Papua New Guinea of May 2010 (Version 1.1).

Included in the Principles of the FSC National Forest Management Standards for Papua New Guinea are requirements to (PNG FSC National Working Group 2010, FSC 2016):

- characterise the ecosystems in the forest management area using biological and geophysical information, including the identification and mapping of natural forests and High Conservation Value Forests (HCVF), guided by the HCVF Toolkit for Papua New Guinea (PNG FSC 2006), and identification and description of high conservation values, key ecosystem functions, values and natural cycles with participation of the landowners;
- identify the environmental impacts of the operation on native plants, animals and ecosystems, habitats of rare and endangered species, forest connectivity and fragmentation, and high conservation values; and
- design the layout of plantation forests to promote the protection, restoration and conservation of natural forests, and not increase pressures on natural forests, including through identifying and protecting natural vegetation areas within and adjacent to the forest management area, and protecting and restoring where necessary wildlife corridors, habitat zones, and prescribed buffer zones.

1.4.4 International Finance Corporation

The International Finance Corporation (IFC) has developed eight Environmental and Social Performance Standards that define IFC clients' responsibilities for managing the environmental and social risks of projects receiving financing from the IFC. The IFC performance standards on social and environmental responsibility also support the Equator Principles (EPs), a credit risk management framework for determining, assessing and managing environmental and social risk in project finance transactions to fund the development and construction of major infrastructure and industrial projects. Recognising that protecting and conserving biodiversity, maintaining ecosystem services, and sustainably managing living natural resources are fundamental to sustainable development, IFC *Performance Standard 6: Biodiversity Conservation and Sustainable Natural Resource Management* (IFC Performance Standard 6) outlines three key requirements for sustainably managing and mitigating the impacts on biodiversity and ecosystem services throughout a project's lifecycle.

First, the risks and impacts identification process should consider direct and indirect project-related impacts on biodiversity and ecosystem services and identify any significant residual impacts, taking into account: (a) any relevant threats to biodiversity and ecosystem services, especially focusing on habitat loss, degradation and fragmentation, invasive alien species, overexploitation, hydrological changes, nutrient loading and pollution; and (b) the differing values attached to biodiversity and ecosystem services by affected communities and, where appropriate, other stakeholders.

Second, where avoidance of impacts is not possible, measures to minimise impacts and restore biodiversity and ecosystem services should be implemented, and should adopt a practice of adaptive management in which the implementation of mitigation and management measures are responsive to changing conditions and the results of monitoring throughout the project's lifecycle.

Third, biodiversity offsets should be considered only after appropriate avoidance, minimisation, and restoration measures have been applied, yet a residual impact remains. A biodiversity offset should be designed and implemented to achieve measurable conservation outcomes that can reasonably be expected to result in no net loss and preferably a net gain of biodiversity in natural habitats; however, a net gain is required in critical habitats. The design of a biodiversity offset must adhere to the "like-for-like or better" principle and must be carried out in alignment with best available information and current practices.

These requirements are incorporated in most environmental impact assessment processes. IFC Performance Standard 6 recognises three different types of biodiversity habitats (see **Section 1.5.5**), each of which triggers compliance with operational standards that differ in level of stringency.

1.5 CONVENTIONS USED

1.5.1 Global conservation status

The conservation status of a species is an indicator of how likely the species is to become extinct in the near future. Species at higher risk of extinction are said to have a higher conservation status. The International Union for the Conservation of Nature (IUCN) is the world's principal authority on the conservation status of species. The IUCN Red List of Threatened Species is the world's most comprehensive information source on the global conservation status of wild species and their links to livelihoods. The IUCN Red List uses standardised criteria to evaluate the extinction risk of species and subspecies (collectively called taxa), recognising seven extinction risk categories, as summarised in **Table 1.1** below.

Table 1.1 IUCN Red List categories of risk of extinction (IUCN 2012).

Category	Explanation
Extinct (EX)	A taxon is Extinct when there is no reasonable doubt that the last individual has died.
Extinct in the Wild (EW)	A taxon is Extinct in the Wild when it is known only to survive in cultivation, in captivity or as a naturalised population (or populations) well outside the past range.
Critically Endangered (CR)	A taxon is Critically Endangered when it is facing an extremely high risk of extinction in the wild (probability of extinction in the wild is at least 50% within 10 years or three generations).
Endangered (EN)	A taxon is Endangered when it is facing a very high risk of extinction in the wild (probability of extinction in the wild is at least 20% within 20 years or five generations).
Vulnerable (VU)	A taxon is Vulnerable when it is facing a high risk of extinction in the wild (probability of extinction in the wild is at least 10% within 100 years).
Near Threatened (NT)	A taxon is Near Threatened when it has been evaluated against the criteria but does not qualify for Critically Endangered, Endangered or Vulnerable now, but is close to qualifying for or is likely to qualify for a threatened category in the near future.
Least Concern (LC)	A taxon is Least Concern when it has been evaluated against the criteria and does not qualify for Critically Endangered, Endangered, Vulnerable or Near Threatened. Widespread and abundant taxa are included in this category.

The IUCN Red List may also categorise a taxon as either Not Evaluated, when it has not yet been evaluated against the criteria listed in **Table 1.2**, or Data Deficient, when there is inadequate information to make a direct or indirect assessment of its risk of extinction based on its distribution and/or population status. Data Deficient is therefore not a category of threat. Species listed as Critically Endangered, Endangered or Vulnerable are collectively referred to as threatened species.

1.5.2 National conservation status

The Papua New Guinea *Fauna (Protection and Control) Act 1966* (Fauna Act) recognises two categories of conservation status for fauna species:

- Protected (P): species that are declared protected; and
- Restricted (R): species that are not declared protected but are restricted for trade because of international market demand and traditional utilisation within Papua New Guinea.

1.5.3 Conservation priority species

In the context of the environmental impact assessment process in Papua New Guinea, conservation priority species for the purpose of this assessment are considered to include:

- species of international conservation priority, listed as threatened (critically endangered, endangered or vulnerable) or near threatened in the IUCN Red List;
- species of international conservation priority, listed under Appendix I of CITES as species threatened with extinction that are, or may be, affected by trade;
- species of national conservation priority, listed under the Papua New Guinea *Fauna (Protection and Control) Act 1966* (Fauna Act) as protected or restricted; and
- new or undescribed species known only from the study area.

1.5.4 FSC forest habitat assessment criteria

The FSC National Forest Management Standards for Papua New Guinea (PNG FSC National Working Group 2010, FSC 2016) include the definitions listed below to guide assessment.

- **Ecosystem**: A community of all plants and animals and their physical environment, functioning together as an interdependent unit.
- **Forest management area**: The physical area in which forest management operations take place and including areas that are not necessarily forest.
- **High Conservation Value Forests:** Those forests that possess one or more of the following attributes:
  - forest areas containing globally, regionally or nationally significant concentrations of: bio-diversity values (e.g. endemism, endangered species, refugia); or large landscape level forests, contained within, or containing the management unit, where viable populations of most if not all naturally occurring species exist in natural patterns of distribution and abundance;
  - forest areas that are in or contain rare, threatened or endangered ecosystems;
  - forest areas that provide basic services of nature in critical situations (e.g. watershed protection, erosion control); and
  - forest areas fundamental to meeting basic needs of local communities (e.g. subsistence, health) and/or critical to local communities' traditional cultural identity (areas of cultural, ecological, economic or religious significance identified in cooperation with such local communities).
- **Natural forest**: Forest areas where many of the principal characteristics and key elements of native ecosystems such as complexity, structure and diversity are present.

- **High conservation values**: High conservation values include the following categories relevant to terrestrial ecology:
  - HCV 1 – Species diversity. Concentrations of biological diversity including endemic species, and rare, threatened or endangered species, that are significant at global, regional or national levels;
  - HCV 2 – Landscape-level ecosystems and mosaics. Intact forest landscapes and large landscape-level ecosystems and ecosystem mosaics that are significant at global, regional or national levels, and that contain viable populations of the great majority of the naturally occurring species in natural patterns of distribution and abundance;
  - HCV 3 – Ecosystems and habitats. Rare, threatened, or endangered ecosystems, habitats or refugia; and
  - HCV 4 – Critical ecosystem services. Basic ecosystem services in critical situations, including protection of water catchments and control of erosion of vulnerable soils and slopes.

1.5.5 IFC habitat types and critical habitat assessment criteria

The IFC Performance Standard 6 (IFC 2012b) classifies habitats as:

- **Modified habitat**: areas that may contain a large proportion of plant and/or animal species of non-native origin, and/or where human activity has substantially modified an area's primary ecological functions and species composition;
- **Natural habitat**: areas composed of viable assemblages of plant and/or animal species of largely native origin, and/or where human activity has not essentially modified an area's primary ecological functions and species composition; or
- **Critical habitat**: areas with high biodiversity value that satisfy one or more of the following criteria:
  - Criterion 1: habitat of significant importance to species listed as Critically Endangered or Endangered on the IUCN Red List of Threatened Species;
  - Criterion 2: habitat of significant importance to endemic and/or restricted-range species;
  - Criterion 3: habitat supporting globally significant concentrations of migratory species and/or congregatory species (e.g. cave-dwelling bats);
  - Criterion 4: highly threatened and/or unique ecosystems; and/or
  - Criterion 5: areas associated with key evolutionary processes.

IFC Guidance Note 6 (IFC 2012c) recognises gradients in critical habitat, and makes a distinction between Tier 1 and Tier 2 critical habitat for each of Criteria 1 through 3, as outlined in **Table 1.2**.

IFC Guidance Note 6 defines a highly threatened or unique ecosystem as one that: (1) is at risk of significantly decreasing in area or quality e.g. is losing a high percentage of its area each year; (2) has a small spatial extent; and/or (3) contains unique assemblages of species including assemblages or concentrations of biome-restricted species (IFC 2012c). It further outlines that ecosystems are typically classified and mapped at specific scales with a focus on vegetation structure and composition, land cover, and key abiotic factors, and that the prioritisation of highly threatened or unique ecosystems should employ similar factors to those used for the IUCN Red List of Threatened Species, including long-term trend, rarity, ecological condition, and threat (IFC 2012c). The IUCN Commission on Ecosystem Management is in the process of developing a Red List of Ecosystems and has supported the publication of a guideline on how to assess the extinction risk and conservation status of ecosystems (Rodriguez *et al.* 2015).

Table 1.2 Summary of criteria for categorising Tier 1 and Tier 2 critical habitat (IFC 2012c).

Criteria	Tier 1 critical habitat characteristics	Tier 2 critical habitat characteristics
Criterion 1: Critically Endangered (CR) and Endangered (EN) species	Habitat required to sustain ≥ 10 percent of the global population of a CR or EN species where there are known, regular occurrences of the species and where that habitat could be considered a discrete management unit for that species. Habitat with known, regular occurrences of CR or EN species where that habitat is one of 10 or fewer discrete management sites globally for that species.	Habitat that supports the regular occurrence of a single individual of an IUCN Red-listed CR species and/or habitat containing regionally-important concentrations of an IUCN Red-listed EN species where that habitat could be considered a discrete management unit for that species. Habitat of significant importance to CR or EN species that are wide-ranging and/or whose population distribution is not well understood and where the loss of such a habitat could potentially impact the long-term survivability of the species. As appropriate, habitat containing nationally/regionally-important concentrations of an EN, CR or equivalent national/regional listing.
Criterion 2: Endemic[1] and Restricted-range[2] species	Habitat known to sustain ≥ 95 percent of the global population of an endemic or restricted-range species where that habitat could be considered a discrete management unit for that species (e.g. a single-site endemic).	Habitat known to sustain ≥ 1 percent but < 95 percent of the global population of an endemic or restricted-range species where that habitat could be considered a discrete management unit for that species, where adequate data are available and/or based on expert judgment.
Criterion 3: Migratory and Congregatory species	Habitat known to sustain, on a cyclical or otherwise regular basis, ≥ 95 percent of the global population of a migratory or congregatory species at any point of the species' life-cycle where that habitat could be considered a discrete management unit for that species.	Habitat known to sustain, on a cyclical or otherwise regular basis, ≥ 1 percent but < 95 percent of the global population of a migratory or congregatory species at any point of the species' life-cycle and where that habitat could be considered a discrete management unit for that species, where adequate data are available and/or based on expert judgment. For birds, habitat that meets BirdLife International's Criterion A4 for congregations and/or Ramsar Criteria 5 or 6 for identifying Wetlands of International Importance. For species with large but clumped distributions, a provisional threshold is set at ≥5 percent of the global population for both terrestrial and marine species. Source sites that contribute ≥ 1 percent of the global population of recruits.

[1] An endemic species has ≥ 95 percent of its global range inside the country or region of analysis.
[2] A restricted-range species is defined as: (a) for terrestrial vertebrates: a species with an extent of occurrence of 50,000 km^2 or less; or (b) for terrestrial plants: an endemic species.

The development of the IUCN guideline was informed by, and is therefore very similar to, an empirical guideline for the assessment of threatened ecological communities in Australia (TSSC 2013). The latter guideline is considered to have greater relevance to the data available to the present study; therefore, it informed the assessment of the extinction risk of vegetation communities present within the study area. This guideline assesses the risk of extinction of vegetation communities on the basis of one or more of six different criteria, as outlined in **Table 1.3**. In accordance with Rodriguez *et al.* (2015), the highest category obtained by any of the assessed criteria will be the overall status of the ecosystem. The extinction risk categories of Critically Endangered and Endangered are considered in this assessment to be aligned with IFC critical habitat Criterion 4, as this is consistent with the both the definition of a highly threatened ecosystem under IFC Guidance Note 6 and the categories used for IFC critical habitat Criterion 1.

Table 1.3 Summary of criteria for assessing the extinction risk of vegetation communities (reproduced from TSSC 2013).

	Extinction risk category		
Criterion	**Critically Endangered**	**Endangered**	**Vulnerable**
1) Its decline in geographic distribution is any of:	very severe[1]	severe[2]	substantial[3]
a) Decline relative to the longer-term (beyond 50 years ago e.g. since 1750); or,	≥90%	≥70%	≥50%
b) Decline relative to the shorter-term (past 50 years).	≥80%	≥50%	≥30%
2) Its geographic distribution is:	very restricted[4]	restricted[5]	limited[6]
and the nature of its distribution makes it likely that the action of a threatening process could cause it to be lost in:	the immediate future[7]	the near future[8]	the medium-term future[9]
3) For a population of a native species that is likely to play a major role in the community, there is a:	very severe decline[10]	severe decline[11]	substantial decline[12]
to the extent that restoration of the community is not likely to be possible in:	the immediate future[7]	the near future[8]	the medium-term future[9]
4) The reduction in its integrity across most of its geographic distribution is:	very severe[13]	severe[14]	substantial[15]
as indicated by degradation of the community or its habitat, or disruption of important community processes, that is:	very severe[13]	severe[14]	substantial[15]
5) Its rate of continuing detrimental change is:	very severe	severe	substantial
as indicated by: (a) rate of continuing decline in its geographic distribution, or a population of a native species that is believed to play a major role in the community, that is:	very severe[1,10]	severe[2,11]	serious[3,12]
or (b) intensification, across most of its geographic distribution, in degradation, or disruption of important community processes, that is:	very severe[13]	severe[14]	serious[15]
6) A quantitative analysis shows that its probability of extinction, or extreme degradation over all of its geographic distribution, is:	at least 50% in the immediate future[7]	at least 20% in the near future[8]	at least 10% in the medium-term future[9]

[1] An estimated decline of at least 80% over the last 50 years or at least 90% since 1750.
[2] An estimated decline of at least 50% over the last 50 years or at least 70% since 1750.
[3] An estimated decline of at least 30% over the last 50 years or at least 50% since 1750.
[4] Very restricted means: a total area of occupancy of less than 10 km^2 (1,000 ha); or a total extent of occurrence less than 100 km^2 (10,000 ha); or an average patch size of less than 0.1 km^2 (10 ha).
[5] Restricted means: a total area of occupancy of less than 100 km^2 (10,000 ha); or a total extent of occurrence less than 1,000 km^2 (100,000 ha); or an average patch size of less than 1 km^2 (100 ha).
[6] Limited means: a total area of occupancy of less than 1,000 km^2 (100,000 ha); or a total extent of occurrence less than 10,000 km^2 (1,000,000 ha).
[7] Immediate future means: the next 10 years, or 3 generations of any long-lived or key species believed to play a major role in sustaining the community, whichever is the longer, up to a maximum of 60 years.
[8] Near future means: the next 20 years, or 5 generations of any long-lived or key species believed to play a major role in sustaining the community, whichever is the longer, up to a maximum of 100 years.
[9] Medium-term future means: the next 50 years, or 10 generations of any long-lived or key species believed to play a major role in sustaining the community, whichever is the longer, up to a maximum of 100 years.
[10] An estimated population decline of at least 80% over the last 10 years or 3 generations, whichever is longer.
[11] An estimated population decline of at least 50% over the last 10 years or 3 generations, whichever is longer.
[12] An estimated population decline of at least 20% over the last 10 years or 3 generations, whichever is longer.
[13] Restoration is unlikely within the immediate future, even with positive human intervention.
[14] Restoration is unlikely within the near future, even with positive human intervention.
[15] Restoration is unlikely within the medium-term future, even with positive human intervention.

1.5.6 Taxonomy and nomenclature

The following authorities have been followed with respect to the taxonomy (classification, identification and nomenclature of currently recognised species) and common names of species within the main terrestrial vertebrate fauna groups:

- **flora:** International Plant Names Index (IPNI);
- **mammals**: The IUCN Red List nomenclature (IUCN 2016);

- **birds**: The International Ornithologists' Committee/Union (IOC) checklist of world bird species (Gill and Donsker 2016); and
- **herpetofauna** (reptiles and frogs): The IUCN Red List nomenclature (IUCN 2016), modified by recent taxonomic revisions, including Oliver *et al.* (2015).

1.5.7 Likelihood of occurrence

The likelihood of occurrence in the study area of species of conservation priority was assessed through integration of the following sources of information:

- database search results and the results of any previous surveys of the study area that identify whether there are records of the species in the study area or nearby;
- review of the published literature pertaining to the known distributions and habitat requirements of the species; and
- field survey and habitat assessment results and professional experience.

Based on the above, the criteria and categories used in the likelihood of occurrence assessment are summarised in **Table 1.4.**

Table 1.4 Criteria and categories used to assign likelihood of occurrence of species in the study area.

Likelihood of occurrence in the study area	Explanation
Known	The species was detected during field assessment, or is known from past surveys in the study area and is not now considered locally extinct.
Likely	A medium to high probability (40% or greater probability of occurrence) that the species occurs in the study area or visits the study area because suitable habitat occurs, the study area is within the known distribution of the species, there are records of the species in the vicinity of the study area, and the species is not now considered locally extinct.
Potential	Either: (a) there are no past records of the species in the vicinity of the study area but suitable habitat occurs and there is insufficient information on the distribution of the species (e.g. it is naturally rare and difficult to detect, or there has been insufficient survey effort) to categorise the species as likely or unlikely to occur; or (b) there are past records of the species in the vicinity of the study area but habitat in the study area is marginal or spatially limited meaning that the species' presence on the study area would be transitory at best.
Unlikely	A low probability (less than 40% probability of occurrence) that the species occurs in the study area because suitable habitat does not occur, the study area is outside the known distribution of the species, there are no records of the species in the local region despite adequate survey effort, the species is considered locally extinct, or the species has not been observed despite sufficient spatial and temporal survey effort for detecting the species.

2.0 TERRESTRIAL FLORA METHODS

2.1 DESKTOP ASSESSMENT

The purpose of the desktop assessment was to undertake literature searches, biodiversity database searches, review of previous terrestrial ecology studies for the Project, and review of other available studies for the local area to summarise existing terrestrial flora information for the study area and surrounds. The desktop assessment included a review of the following literature and databases:

- international databases including the International Union for Conservation of Nature (IUCN) Red List of Threatened Plants (IUCN 2016);
- international conservation assessments undertaken by non-government organisations, including the World Wildlife Fund (WWF);
- national databases including the Papua New Guinea Plants Database (Conn *et al.* 2006), spatially referenced records of Papua New Guinea plants records held by the Queensland Herbarium (Queensland Herbarium, 2016), and Papua New Guinea's Forest Inventory Mapping (FIM) (Hammermaster and Saunders 1995);
- descriptive texts relevant to the flora and landscape that included Paijmans (1975,1976), Whitmore (1984), Conn (1995) and Gressit (1982); and
- academic research papers relevant to floristic taxonomy and botanical survey, both in the study area and broader Papua New Guinea environs.

2.2 CLASSIFICATION OF VEGETATION COMMUNITIES

A hierarchical approach is applied to the classification of habitats, land and associated vegetation within this report, using the three categories listed below.

- **Broadest scale (global):**– Terrestrial ecoregions. Ecoregions define distinct ecosystems that share broadly similar environmental conditions and natural communities (Wikramanayake *et al*. 2002). Ecoregions are defined at 1:1 000 000 scale.
- **National / regional scale:**– Forest Inventory Mapping System (FIM) vegetation types. Vegetation is described with reference to the national scale vegetation mapping produced at 1:250 000 scale by Hammermaster and Saunders (1995). Provides context to the finer scale vegetation community mapping undertaken in this study.
- **Local scale:**– Vegetation community mapping. Vegetation mapping produced specifically for the purpose of this study at a scale of 1:50 000. A vegetation community is best described as a unit of vegetation that demonstrates similarities in both structure and floristic composition. Vegetation communities are used to describe fine scale variation in floristic composition that may not be apparent at broader scale (global and national) mapping such as FIM.

For the purpose of regional consistency, the field characterisation of vegetation and description of vegetation communities is based on the classification of Paijmans (1976), which provides the basic framework for vegetation assessment within Papua New Guinea and recognises distinctive forest types based on geographic distribution and environment. The major subdivisions of relevance to this assessment are:

- lowland freshwater swamps;
- lowland alluvial plains and fans; and
- foothills and mountains below 1,000 m asl.

These forest types are further subdivided into a number of distinctive and consistently recognised vegetation types.

2.3 Classification of Vegetation Condition

The vegetation condition assessment identified different categories of vegetation condition based on the structural integrity of vegetation communities. The different categories of vegetation condition were then related to the IFC Performance Standard 6 habitat classifications, as well as the FSC Standard. The condition classification specifically aims to identify those habitats that have been subject to minimal human intervention, thus demonstrating a high degree of 'intactness'. Additional categories identify varying levels of disturbance ranging from partial clearing or thinning of natural vegetation to complete clearing and/or vegetation dominated by planted gardens or invasive exotic species. The classification of vegetation condition used in this assessment is described in **Table 2.1**.

Table 2.1 Habitat condition categories applied to vegetation communities.

Condition category		Condition description	IFC Performance Standard 6	FSC Standard*
1	Intact	The vegetation community exists in unmodified condition. No structural disturbance of canopy, sub-canopy or ground cover layers is evident. Some selective harvesting of poles or timber species may have occurred although this is minor in nature and has not compromised structural integrity of the vegetation community.	Natural Habitat	Natural Forest
2a	Moderately disturbed: stable to declining	Vegetation in this category has been subject to structural modification, resulting in a general reduction in forest stature and complexity. A sub-set of the original floristic diversity is retained within the habitat and small vestiges of unmodified habitat may remain. Habitat is subject to ongoing degradation through weed invasion or continued thinning. Also includes river gravel beds subject to weedy degradation.	Natural Habitat	Natural Forest
2b	Moderately disturbed: stable or regenerating	Category 2b represents areas of remnant vegetation providing good representation of natural savannah habitat in native condition, and regenerating regrowth rainforest habitats that are developing some of the structural complexity of the native forest ecosystems and are comprised predominantly of native flora species.	Natural Habitat	Natural Forest
3	Modified (cultural)	Modified habitats composed of native species that have had long term stability through regular intervention by man (e.g. Kunai grasslands that represent rainforest transformed to grassland through a long history of regular burning). Differentiated from category 4 by the dominance of native species and absence of invasive exotic species.	Modified Habitat	
4	Degraded	Secondary forest composed of a mix of native pioneer species and exotic trees in which the structure and floristic assemblage of the original forest has been modified through prior complete clearing or long term continuous disturbance. Differentiated from category 3 by the presence of invasive exotic species that limit the potential for recovery of native species if the source disturbance was removed.	Modified Habitat	
5	Highly degraded	Highly degraded habitats generally comprising a mix of native and exotic food plants, garden plants and also weeds. Includes maintained and abandoned garden areas with large areas of the latter occupied by the invasive pest plants such as *Piper aduncum.*	Modified Habitat	

* The FSC Standard is relevant to forest habitats only. Forests comprise vegetation where the tree layer has projective foliage cover greater than 30%.

2.4 FIELD SURVEY

2.4.1 Survey timing and team

A single phase of field survey was undertaken over a period of five field days 4 to 8 September 2016. The study area was visited by a specialist botanist (David Fell) and landscape ecologist (David Stanton) with additional field assistance provided by staff from Aligned Energy Limited (AEL), in particular Jordan Cox, Kelly Jim and John Riwasino. The survey was completed by sampling representative habitats throughout the study area, traversing the area by vehicle along suitable access tracks and with foot traverses in areas where access was permissible. The survey coincided with significant rainfall with the major watercourses and tributaries in flood during part of the assessment, which made some potential access tracks impassable due to boggy conditions.

2.4.2 Survey site selection

Satellite imagery was reviewed prior to the field survey to identify potentially different habitat types throughout the study area based on differences in photo-pattern. This provided a preliminary understanding of field conditions and informed the selection of sites for targeted on-ground assessment during the field survey. The initial list of sites was screened by AEL staff who advised the extent to which sites could be accessed based on land-access agreements and the presence of access tracks. The refined list of survey targets was visited on the ground where possible with sites added opportunistically throughout the survey to ensure that the survey:

- sampled a representative range of habitats in varying states of structural integrity;
- sampled those communities that were useful as providing reference condition for disturbed communities (i.e. best type examples); and
- directed detailed sampling towards those communities that might host a range of ecologically significant species or those with particular conservation significance.

Selection of field survey sites also considered the future planting layout and concentrated on those areas most likely to be subject to the siting of future plantations, although habitats adjacent to these areas, including mountain foot-slopes, were also targeted to provide useful survey context.

2.4.3 Field assessment

Prior to targeted assessment, a general reconnaissance of the study area was undertaken on the first day to refine survey site selection and obtain a preliminary overview of the study area to assist habitat classification and vegetation community mapping.

Field survey site assessments were largely descriptive to allow for rapid assessment, particularly since most habitats were highly degraded across the study area. Each survey site assessment included a general description of landform and geological features, vegetation height and structure as well species composition (both native and exotic), supplemented with a search for IUCN listed flora species within potentially suitable habitats. A Garmin GPS 60 (Geographic Positioning System) was used to accurately record coordinates for site locations (WGS 84).

2.4.4 Flora resource use assessment

An ethnobotanical survey of plants used by the Wampar language group community was undertaken in the Bampu Village area of the Markham Valley. The assessment was completed using unstructured open-ended interviews to derive information on useful plants and resource use within habitats across the study area. These habitats were traversed and assessed as part of the broader assessment of floristic ecological values. The uses and language names of plants were identified by a senior local informant, and botanical names applied by the field botanist. Plant information captured in the field was consolidated in the village setting using a review of plant photographs and specimens by a senior elder and members of his extended family. The considerable traditional knowledge demonstrated by the informants provided confidence that the assessment was of sufficient rigor to characterise traditional resource use of plant species within the study area.

2.5 INVASIVENESS ASSESSMENT

A desktop review was undertaken to assess the potential invasiveness of two primary tree species proposed to be used in the Project (*Eucalyptus pellita* and *E. camaldulensis* subsp. *simulata*), two hybrids (*E. pellita* x *E. tereticornis* and *E. pellita* x *E. camaldulensis*) as well as a further species being trialled (*Acacia crassicarpa*). The review was informed by academic research papers relating to the ecology, aetiology and potential invasiveness of the target tree species growing in similar tropical environs. The weed risk assessment model developed by Pheloung *et al*. (1999) was used to quantify the potential invasiveness of the species of interest.

2.6 FOREST PATHOGENS ASSESSMENT

A desktop review was undertaken to assess the potential impact of pathogens on the plantation tree species to be used by the Project, which include *Eucalyptus pellita* and *E. camaldulensis* subsp. *simulata*) together with *E. pellita* x *E. tereticornis* and *E. pellita* x *E. camaldulensis* hybrids that will be introduced after the initial establishment phase. The review was informed by academic research papers relating to the known pathogens of the target tree species growing in similar tropical environs, together with an assessment of relevant pathogens potentially present in the study area. An overview is provided of potential disease problems in nursery and plantation situations along with steps that can be taken to mitigate these problems. In addition, pathogens of *E. pellita* and related species that may become potential pathogens of vegetation in natural habitats were identified and the potential impact of these pathogens on the native flora was assessed.

3.0 TERRESTRIAL FAUNA METHODS

3.1 DESKTOP ASSESSMENT

The purpose of the desktop assessment was to review and summarise all available existing terrestrial vertebrate fauna information for the study area and surrounds. This review was informed by literature searches, database searches of IUCN and other biodiversity databases such as that of the Bishop Museum (Bishop Museum 2016), previous terrestrial ecology studies for the Project, BAAM records from previous ecological studies in the local area, and any other available studies for the local area.

3.2 FIELD SURVEY

3.2.1 Survey timing and team

A single terrestrial fauna field survey was undertaken over five days from 4 to 8 September 2016 by Dr Penn Lloyd (Principal Ecologist). This survey involved the following phases:

- an initial reconnaissance of the study area via a guided driven tour of portions of the study area on 4 September; and
- a general fauna trapping and observational survey over three nights and four days from 5 to 8 September 2016.

The field surveys were conducted with the support of AEL staff and local residents, particularly John Riwasino and Kelly Jim, with field activities coordinated by Jordan Cox.

3.2.2 Survey site selection

Due to the large size of the indicative study area and limited, rough access tracks, the selection of survey sites aimed to provide a survey of sites representative of the different fauna habitat types within the study area.

3.2.3 Bird surveys

Birds were surveyed by walking slowly along survey trails that followed existing road tracks or forest interior walking trails to maximise the detectability of birds with minimal noise disturbance. Extra time was spent in the vicinity of flowering or fruiting trees that are particularly attractive to foraging birds. Birds were identified through visual observation using high-quality Swarovski binoculars or by the characteristic calls of different species. Call recognition in the field was assisted through the use of a digital call library of most birds with potential to occur in the study area loaded on an iPhone 5. The call library included calls sourced from xeno-canto, an online repository of bird call recordings from around the world. Bird surveys were conducted primarily within the first two hours of each survey day, when bird activity is greater, but also opportunistically at intervals throughout the day. A cumulative species list was maintained for each hour of survey effort. Mist-netting for birds was not undertaken because survey based on direct observation and call identification is substantially more effective in surveying for birds in the habitat types present in the study area.

3.2.4 Herpetofauna (frogs and reptiles) ground searches

Reptiles were surveyed through active searching during the warmer parts of the day when reptile activity is greatest, and opportunistically whenever reptile movement was detected while undertaking other survey activities. Active searching focused particularly on sunlit patches of leaf litter, hunting trail edges and lower tree trunks that attract sun-bathing reptiles. Wherever possible, photographs were taken of any reptiles detected to facilitate identification.

3.2.5 Small-mammal trapping surveys

Traps were deployed to survey for small, rodent-sized mammals at four locations in different habitat types: in kunai grassland and adjoining Raintree-dominated regrowth forest; in a patch of regrowth rainforest disturbed by gardening activities; in Raintree-dominated riparian forest besides a medium-sized creek; and in the vicinity of a small village. A total of 20 traps were installed over three consecutive nights at each trapping survey site. Traps were placed on the ground at the bases of trees or within patches of dense ground cover, approximately 10-20m apart, and baited with peanut butter. Traps were cleared and rebaited each morning.

3.2.6 Camera trapping surveys

Three remote cameras were deployed during the survey at locations where animal tracks were detected in regrowth rainforest. Each camera was tied to a sturdy tree trunk approximately 1-1.5m from the ground (**Photo 3.1**), and directed at a point on the ground 2-3m from the camera at which a small amount of rice was scattered as bait. The remote cameras comprised two RECONYX HyperFire HC500 cameras (set to high motion detector sensitivity) and one Faunatech Trail Cam KG-680 cameras (set to medium motion detector sensitivity). The cameras were set for 24-hour operation, and set to take three photos at 1-second intervals per trigger, with a 15-second quiet period before being able to respond to additional triggers.

Photo 3.1 Remote camera tied to tree trunk.

Photo 3.2 Anabat bat detector setup in the field.

3.2.7 Anabat survey for echo-locating bats

Microbats find their way around at night and locate their prey (typically insects) through echolocation, producing high-frequency calls that are sent out either through the mouth or nostrils. The calls bounce back from surrounding objects and are picked up as echoes by the bat's often enlarged, sensitive ears. Ultrasound detectors, commonly called bat detectors, are used to listen to and record the calls of echo-locating bat species. Echo-locating bats were surveyed using an Anabat II detector and associated ZCAIM unit enclosed within a waterproof housing (**Photo 3.2**), deployed overnight at different locations to record microbat calls throughout the night, ensuring sampling of peak nocturnal activity periods.

Using appropriate computer software, recorded microbat calls can be viewed as a graphic signature of frequency against time. The shape and duration of the call, and the upper and lower frequencies, all provide information that can be used to distinguish different species by comparing the recorded calls to calls in reference libraries, i.e. libraries of calls recorded from trapped individuals of different species. The Anabat recordings of echolocating bats were sent to Dr Kyle Armstrong for identification and analysis.

3.2.8 Significant ecological features

The field survey also focused on recording the presence of significant ecological features, including the features listed below.

- **Caves.** Caves can provide roosting and maternity sites for significant concentrations of cave-dwelling bats.
- **Waterbird nesting colonies**. Egrets, herons and other waterbirds can gather together to nest in large nesting colonies.
- **Megapode nest mounds**. Two species of megapode bird occur in the study area, Collared Brush-Turkey and New Guinea Scrubfowl. The males of these species construct large mounds of leaf-litter and other decomposing vegetation mixed with loose soil. The females dig deep holes into the mounds in which they lay an egg every few days. Incubation of the eggs then occurs through the heat generated by the decomposing vegetation. Megapode eggs are large, weighing up to 200 g each, include a large proportion of nutritious yolk, and females may lay between 28 and 50 eggs each year (Coles 1937, Baltin 1969). As the best quality mounds are large and energetically costly to build, they are maintained and used by the birds over many years (Jones 1990, Marchant and Higgins 1993). This combination of features means that megapode eggs are valued by local communities as an important source of food, with community members visiting mounds regularly to harvest freshly-laid eggs.

3.2.9 General survey considerations

During the survey, fauna observations were continuous and included species records obtained outside the systematic methods of the survey. Survey tracks, the locations of survey sites and the locations of all observations of rare or conservation priority species and ecological features were recorded via hand-held Garmin GPS. The weather during the survey was variable. On 4 September, the weather was fine, hot and dry. On 5 September overnight rain cleared up to a cloudy day, but heavy rain set in from late afternoon until mid-morning on 6 September, resulting in very wet conditions. The weather was partly cloudy and dry on 7 September. Due to local logistic considerations and travel time, the day-time surveys were conducted from 10:00 am at the earliest, through to 15:00. This meant that the optimal time for bird surveys, within four hours of sunrise was missed; however, overcast conditions on two mornings meant that bird activity continued to be good through until midday.

3.2.10 Fauna resource use assessment

The use of local fauna resources and the local names of fauna species were discussed opportunistically with local field assistants during the field survey, as well as during a village meeting with Kelly Jim and elder Jim Ouogore on the final day of the survey.

Photo 3.3 Reconnaissance of the study area on the first day of the survey.

Photo 3.4 Village meeting to identify fauna names and resource use.

4.0 TERRESTRIAL FLORA RESULTS AND DISCUSSION

4.1 OVERVIEW OF PAPUA NEW GUINEA'S TERRESTRIAL FLORA

At a global level, the ecology of Papua New Guinea is described in relation to ecoregions which are defined as large areas of land containing a distinct assemblage of natural communities and species with boundaries that approximate the original extent of natural communities prior to major landuse change or disturbance (DEC 2010). The study area falls entirely within the 'Northern Papua New Guinea Lowland Rain and Freshwater Swamp Forest Ecoregion (Terrestrial Ecoregion 123)' as defined by Wikramanyake *et al.* (2002) with the conservation status of natural vegetation within the ecoregion classified as 'Critical – Endangered'.

Papua New Guinea, including its island provinces, is covered by 28.2 million hectares of rainforest that makes up 80% of the country's forest estate, hosts some of the most biologically diverse forests in the world (Davis, 1995), and is one 17 megadiverse countries in which over 70% of the earth's species occur (Conservation International 2012). Conservative estimates suggest that in excess of 15,000 to 20,000 flora species occur in Papua New Guinea (Davis, 1995; Womersly, 1978), including an estimated 2,000 species of orchids alone (Nita 2006). Papua New Guinea also exhibits a high level of species endemism (60-80%) among plants (Johns 1993, Davis 1995, Balgooy *et al*. 1996).

There is considerable structural and floristic diversity within Papua New Guinea's forests. These forests are classified into a number of sub-divisions based on altitude and landform, including: forest on plain and fans; lowland hill forests; lower-montane forest; montane forest; and dry evergreen forest restricted to the south-west portion of Papua New Guinea (Paijmans 1975). Paijmans (1975) also identifies a number of broad structural non-forest formations including: woodland; scrub; savannah; grassland; mixed herbaceous vegetation; pioneer vegetation, mangrove vegetation; and gardens. Of the latter vegetation types, savannah and grassland are of considerable relevance to the Markham Valley and occupy extensive areas of riverine flood-plain and mountain foot-slope. These grassland habitats are generally accepted to be anthropogenic, relating in particular to man's use of fire (Lane-Poole 1925, Paijmans 1975, Henty 1982, Gillison 1993). Climate does however play an important role in the distribution of grassland and savannah vegetation and there is evidence that non-forest vegetation has been increasing in the Markham Valley since about 9,500 years ago (Garrett-Jones, 1979). Furthermore, during glacial times (18,000 to 15,000 years ago) closed forest had a restricted distribution in the southern part of Papua New Guinea, particularly in the upper Markham and middle Sepik areas (Nix and Kalma 1972). The postulated dominance of savannah vegetation in the Markham Valley would have been influenced to a large degree by a relatively dry climate that prevails in the Markham Valley due to its location within a rain-shadow; a large portion of the area experienced seasonally distributed annual rainfall of less than 1,500 mm (Garret Jones 1979). Average monthly rainfall within the study area ranges from approximately 30-60 mm per month during the dry season period July to August, to approximately 130-180 mm per month during the wet season period October to April (White 2016).

Hence, whilst human use of fire has undoubtedly played a significant role in the current nature and distribution of vegetation within the study area, it is possible that some savannah vegetation would have persisted irrespective of human land management practice.

4.2 SURVEY COVERAGE OF THE STUDY AREA

4.2.1 Previous surveys

The study area has been subject to several preliminary studies including:

- a Field Scoping Report completed in August 2013 (ERIAS Group 2013);

- a Rapid Environmental and Socio-economic Assessment Report for the Markham Valley prepared by Eco Care Engineering Ltd (2013); and
- a Draft Environmental Inception Report completed in May 2016 (ERIAS Group 2016).

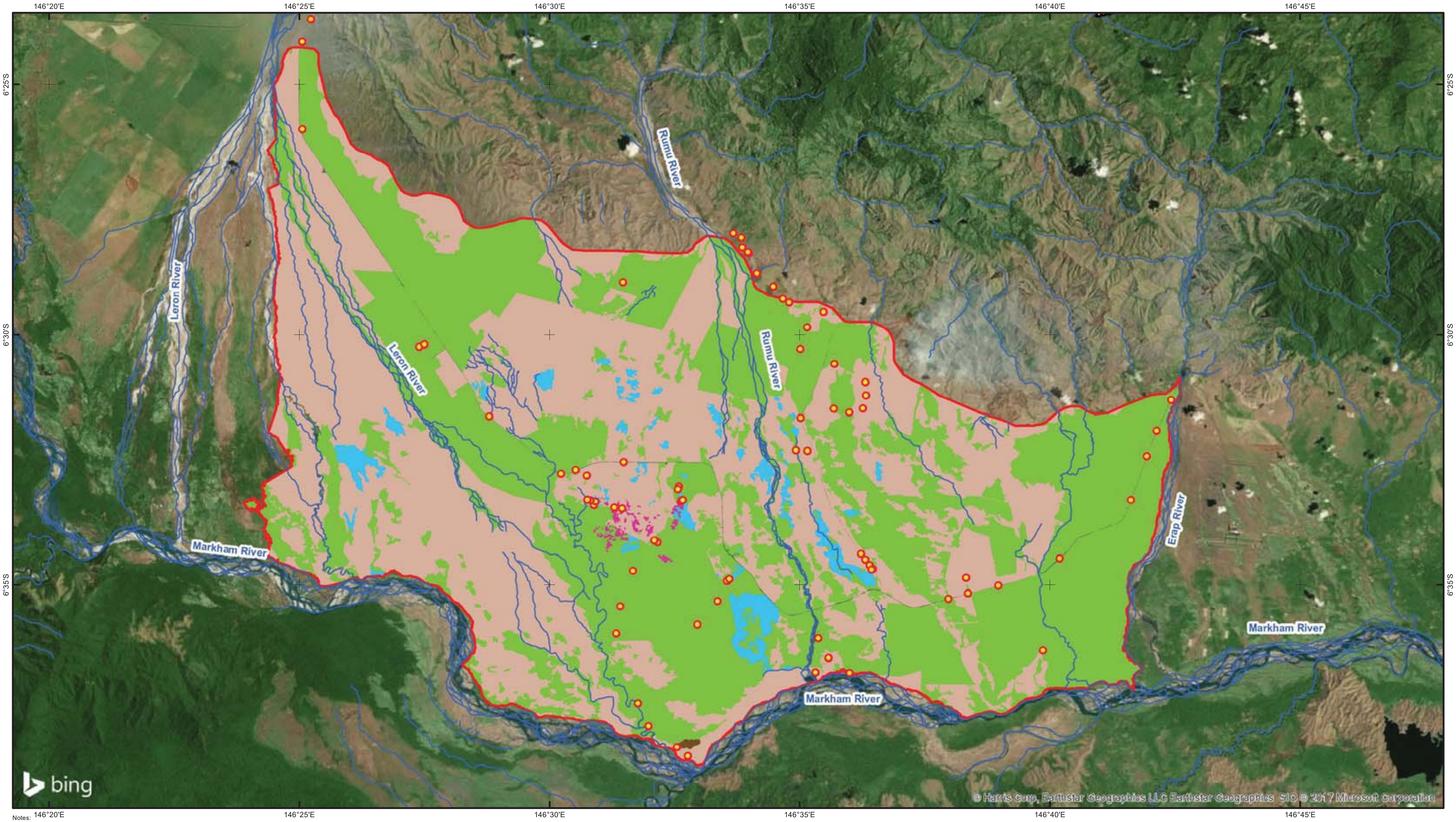
These reports provided brief qualitative accounts of the terrestrial vegetation that included limited ecological context and did not include spatial mapping of the distribution of vegetation communities.

4.2.2 2016 survey

Floristic information was gathered at a total of 72 floristic survey sites distributed across the study area during the course of the field assessment. The locations of these survey sites are shown in **Figure 4.1** and site data descriptions are provided in **Appendix A.**

4.3 VEGETATION COMMUNITIES AND MAPPING

Table 4.1 provides a summary of vegetation communities identified in the study area, together with their equivalent Forest Inventory Mapping System (FIM) classifications as described by Hammermeister and Saunders (1995). The distribution of these vegetation communities across the study area is mapped in **Figure 4.1**. For assessment purposes, the area subject to mapping assessment covers an area of approximately 470 km^2, focused on the floodplain of the Markham River. This area is bounded by the Leron River in the west, the Erap River in the east, the Markham River in the south and the foot-slopes of the Saruwaged and Finisterre ranges in the north. The study area is suitably broad to provide context to the existing and planned plantation areas as well as to accommodate future modifications to the plantation layout. Structural and floristic descriptions of vegetation communities sampled in the field survey are presented in **Section 4.3.1** to **Section 4.3.9**. The condition of vegetation communities is assessed in **Section 4.4** and the conservation status of vegetation communities is assessed in **Section 4.8**.



Notes:

Data Source: Image from ArcGIS Online Bing Maps data (c) 2010 Microsoft Corporation and its data suppliers.

Coordinate System: GCS GDA 1994
Datum: GDA 1994
Units: Degree

1:135,494 at A4
0 750 1,500 3,000 4,500 6,000 Meters

LEGEND

- Flora survey sites
- Watercourse
- Study Boundary

Vegetation Communities

- **G** - Grassland
- **O** - Other non-vegetation and areas dominated by land use
- **PL** - Large to medium crowned forest
- **PS** - Small crowned forest / regrowth forest
- **SA** - Savannah

Figure:	4.1
Title:	Flora survey sites and vegetation communities
Project:	PNG BIOMASS MARKHAM VALLEY TERRESTRIAL ECOLOGY ASSESSMENT
Client:	ERIAS Group Pty Ltd

BAAM ECOLOGICAL CONSULTANTS

Drawn By: MG Reviewed by: AC Date: 18-Jan-17

Table 4.1 Vegetation communities occurring within the study area, together with their Forest Inventory Mapping System (FIM) classifications and area coverage within the assessment area.

Vegetation community code	Vegetation community description[1]	FIM vegetation type[2]	Area (ha)	% of total area
Vegetation communities with minimal to moderate present-day disturbance				
1a	Large to medium crowned forest (disturbed).	PL: Large to medium crowned forest on plains and fans below 1000m	13.6	<0.1
2a	Small crowned forest / regrowth forest	PS: Medium crowned forest/ Small crowned forest on plains and fans below 1000m	102.5	0.2
3a	*Nauclea orientalis / Albizia procera* savannah	SA: Savannah	53.8	0.1
4a	Kunai grassland on riverine alluvium	G: Grassland	907.3	1.9
4b	Kunai grassland on footslopes and hillslopes	G: Grassland	390.3	0.8
Vegetation communities with moderate to high levels of disturbance				
3b	*Nauclea orientalis / Albizia procera* savannah - moderately degraded	SA: Savannah	937.7	2.0
4c	Kunai grassland on riverine alluvium -moderately /patchily degraded with weeds	G: Grassland	19,322.6	40.9
12a	Active river channels	O: Other non-vegetation and areas dominated by landuse[3]	1,072.3	2.3
Vegetation communities that are highly degraded				
2b	Mixed native/exotic secondary forest	O: Non-vegetation and areas dominated by landuse	1,148.5	2.4
3c	Native savannah woodland with severely degraded ground cover	SA: Savannah	59.5	0.1
4d	Kunai grassland on riverine alluvium - heavily modified and degraded with weeds and pasture plants	G: Grassland	10,424.6	22.1
4e	Mixed native/exotic grassland, shrubland and woodland on river alluvium.	G: Grassland	553.7	1.2
4f	*Saccharum robustum, Leucaena leucocephala* grassland/shrubland on recent river deposits	G: Grassland	469.2	1.0
5a	*Albizia saman* dominated savannah	G: Grassland	210.9	0.4
10a	Sago swamp - regrowth/degraded forest	O: Non-vegetation and areas dominated by landuse[3]	92.9	0.2
Vegetation communities resulting from complete habitat modification				
5b	*Albizia saman* dominated open forest	O: Non-vegetation and areas dominated by landuse[3]	7,430.2	15.7
6a	*Leucaena leucocephala, Albizia* sp., *Albizia saman* dominant shrubland	O: Non-vegetation and areas dominated by landuse[3]	206.1	0.4
7a	Village Area	O: Non-vegetation and areas dominated by landuse[3]	397.3	0.8

Vegetation community code	Vegetation community description[1]	FIM vegetation type[2]	Area (ha)	% of total area
8a	Plantation areas/leucaena/palm oil	O: Non-vegetation and areas dominated by landuse[3]	936.7	2.0
8b	Plantation areas: *Pinus* and *Araucaria*	O: Non-vegetation and areas dominated by landuse[3]	25.8	0.1
9a	Former gardens/coconut plantations	O: Non-vegetation and areas dominated by landuse[3]	2115.4	4.6
11a	Garden areas with evidence of recent modification	O: Non-vegetation and areas dominated by landuse[3]	294.1	0.6
Total			**47,205.0**	**100.0**

[1] Description derived from Paijmans (1976), applied to natural vegetation communities only.
[2] Classification derived from Hammermaster and Saunders (1995).
[3] Referring to areas utilised by humans for agriculture, settlement or other industrial or extractive activity.

4.3.1 Large to medium crowned forest on plains and fans (VC1a; FIM PL)

A single 14 ha patch of large to medium crowned forest was identified and mapped within the study area. This patch is located close to the Markham River approximately 2.5 km to the south-east of Kokok Village. The habitat is a closed forest with a broken and uneven canopy, with canopy heights ranging from 15 m to 35 m and occasional emergent trees to 45 m tall. The dominant canopy trees are White Siris (*Ailanthus integrifolia*), *Sterculia shillinglawii, Litsea* spp. and Labula (*Anthocephalis chinensis*) mixed with native pioneer species that include Breadfruit (*Artocarpus altilis*), *Macaranga aleuritoides, Trema orientalis, Dysoxylum sp., Endospermum medullosum*, *Hydriastele costata, Commersonia bartramia, Buchanania* spp., *Melanolepis multiglandulosa, Myristica fatua,* and Poison Fig (*Antiaris toxicarya* var. *macrophylla*). Scattered Raintree (*Albizia saman*) occur in the habitat although this invasive species was more abundant on the habitat margins.

The shrub and understory layers are variable and very dense with an upper shrub layer of *Kleinhovia hospita, Melanolepis multiglandulosa, Macaranga quadriglandulosa, Macaranga tanarius, Macaranga involucrata var. mallotoides, Casearia clutiifolia, Leea novoguineensis, Endospermum medullosum, Mallotus mollisimus, Mallotus peltatus*, *Mallotus paniculatus, Ficus wassa, Ficus mollior, Ficus septica, Gnetum gnemon, Glochidion novoguineensis, Homalanthus novoguineensis, Neoloebra atra, Trichospermum pleiostigma Aglaia sapindina, Caryota rumphiana, Calamus* spp., *Piper* spp., *Pycnarrhena novoguineensis, Pleomele angustifolia* and *Dioscorea* sp. Hemi-epiphytes including *Rhaphidophora* sp., *Freycinetia* spp., *Scindapsus altissumus*., *Epipremnum amplissimum* and *Asplenium* spp. are common throughout all structural layers as are thick woody lianas representing the genera *Smilax, Cissus, Mucuna, Flagellaria* and *Combretum*. Typical groundcovers include the gingers *Hornstedtia scottiana, Alpinea,* spp., *Amomum aculeatum, Etlingera* sp., and *Phrynium macrocephalium.*

This habitat has been significantly degraded through the removal of most of the canopy tree species that are typical of undisturbed forests of this type. In particular, the more valuable timber species such as Erima (*Octomeles sumatrana*), New Guinea Walnut (*Dracontomelum dao*), Taun (*Pometia pinnata*), Garamut (*Vitex cofassus*), Milky Pine (*Alstonia scholaris*), Rosewood (*Pterocarpus indicus*) and Kwila (*Intsia bijuga)* are largely absent from the forest structure, yet these species occur commonly in less disturbed large crowned forest patches on the southern side of the Markham River.

4.3.2 Small crowned forest – regrowth forest (VC2a; FIM PS)

The small crowned forest – regrowth forest vegetation community occurs as a number of small, scattered patches growing in a mosaic with well-preserved savannah woodland habitats in the central portion of the study area. The canopy is typically medium height (18 to 28 m) with occasional emergent trees to 35 m. This habitat has a relatively diverse mix of trees including *Terminalia complanata,* Yellow Cheesewood (*Nauclea orientalis*)*, Tristiropsis acutangula, Albizia procera, Ficus variegata,* Ivory Mahogany (*Dysoxylum gaudichaudianum*)*, Dysoxylum parasiticum, Timonius timon,* Brown Kurrajong (*Commersonia bartramia*)*, Commersonia novoguineensis, Trichospermum pleiostigma, Glochdion novoguineensis, Planchonia papuana, Hydriastele costata,* Fishtail Palm (*Caryota rumphiana*)*, Litsea* sp.*, Berrya javanica, Melicope bonwickii, Sterculia shillinglawii* and occasional Cotton Tree (*Bombax ceiba* var*. leiocarpum*)*.* Raintree is an occasional canopy component, most typically on the margins of the habitat.

The shrub layer is variable in both species composition and structure, depending on the degree of disturbance. The predominant shrub species include *Melanolepis multiglandulosa, Macaranga tanarius, Leea novoguineensis, Macaranga involucrata* var*. mallotoides*, *Mallotus mollisimus, Mallotus paniculatus, Macaranga quadriglandulosa, Glochidion novoguineensis,* Bleeding Heart (*Homalanthus novoguineensis*)*, Trichospermum pleiostigma, Ptychosperma* sp.*,* with often dense tangles of *Calamus longipinna*. The exotic Bamboo Piper (*Piper aduncum*)*, Leucaena leucocephala* and *Senna* sp*.* form thickets around the margins of the habitat in areas where fringing grasslands have been heavily disturbed.

These habitats are derived from the natural capture of savannah woodland by rainforest species, evident by the relict specimens of *Nauclea orientalis* and *Albizia procera* scattered throughout the canopy with development of the rainforest canopy to a degree that fire will no longer penetrate the habitat margins. The protection of these habitats from fire has been facilitated by swampy ground in some examples and development of more complex structural features, including plank buttresses in some trees. Further development towards rainforest will be an ongoing process in the absence of further disturbance.

Photo 4.1 Degraded large to medium crowned forest (VC1a) with an abundance of hemi-epiphytes in the lower structural layers (Site 29)

Photo 4.2 Native regrowth forest (VC2a) demonstrating development of complex structural features including plank buttressing (Site 18)

4.3.3 Nauclea orientalis / Albizia procera savannah woodland (VC3a, VC3b, VC3c; FIM SA)

Savannah habitats are characterised by the continuous grassy ground layer and may occur with or without a canopy of woody vegetation. In its best-preserved condition, savannah habitats exhibit a dense grassy ground-layer of predominantly native grasses with a sparse woody canopy layer dominated by either *Nauclea orientalis* or *Albizia procera*. The canopy trees in undisturbed habitats typically form up to 40% canopy cover with canopy heights ranging from 15 to 25 m. The shrub layer is very sparse and limited to scattered shrubs of *Antidesma ghaesembilla.* The natural grassy ground-layer is dominated by thick swathes of Kunai (*Imperata cylindrica*). Whilst fire is necessary to maintain habitat condition, it has not been of sufficient intensity to thin the woody canopy. This vegetation community approximates the savannah habitats that have likely been more extensive and in relatively stable condition in the Markham Valley since the last glacial period (15,000 to 18,000 years ago) (Lane-Poole 1925, Robbins 1960, Paijmans 1976).

Across much of the study area, savannah habitats have been subject to significant degradation, mainly through the impacts of cattle grazing as well as extraction of timber. Grazing has severely impacted the floristic and structural integrity of this habitat type through introduction and spread of weed species, in particular Siam Weed (*Chromolaena odorata),* Giant Sensitive Weed (*Mimosa diplotricha*), Leucaena (*Leucaena leucocephala*)*,* Bamboo Piper (*Piper aduncum*) and Raintree (*Albizia saman*)*.* Where habitat degradation is severe, resulting in pervasive replacement of the majority of native grassy groundcovers with exotic weeds, the habitat is mapped as Vegetation Community 3c (Native Savannah Woodland with severely degraded ground cover). Where weed invasion is incipient or less pronounced, or the habitat has been subject to timber extraction, savannah vegetation is mapped as VC3b (*Nauclea orientalis / Albizia procera* dominant savannah - moderately degraded).

Photo 4.3 Mosaic of savannah (3a), small crowned forest (VC2a) and native kunai grassland (VC4a) in the central portion of the study area

Photo 4.4 Well preserved savannah vegetation (VC3a) with *Nauclea orientalis* at the location of Site S17.

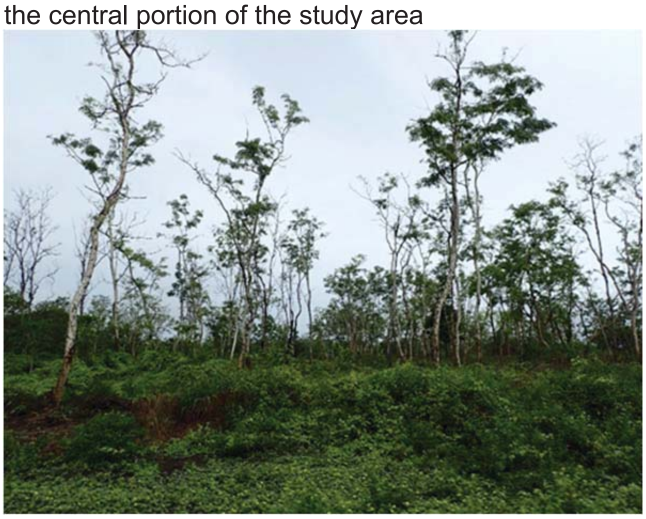


Photo 4.5 Severely degraded savannah woodland with ground cover displaced by Siam Weed (VC3c)

Photo 4.6 Savannah vegetation where tree cover has been thinned (VC3b).

4.3.4 Native grassland (VC4a, VC4b, VC4c, VC4d, VC4e, VC4f; FIM G)

Native grasslands, referred to as 'Kunai' in Papua New Guinea form the most extensive habitat type in the Markham Valley although these areas have been affected to varying degrees by degradation, usually associated with intensive cattle grazing. In their best condition, native grasslands are identified as VC4a and VC4b, being grasslands associated with alluvium (river flats and fans) and grasslands associated with footslopes respectively. Dominant native species include Kunai (*Imperata cylindrica*)*,* Kangaroo Grass (*Themeda triandra* and *Themeda avenacea*) and

Cane Grass (*Mnesithea rottboelliodes*), as well as *Polytocca macrophylla, Isheamum* sp. and *Phragmites vallatorius* on better-developed riverine alluvium. Additional species recorded in the habitat include *Bothriochloa bladhii*, Cockatoo Grass (*Alliopteris semiulata*)*,* Scented-top Grass (*Capillipedium parviflorum*)*, Cyanthileum cinereum, Euphorbia bifida, Ophiurus exaltata, Phyllanthus virgata, Uraria picta, Desmodium rhtidiophyllum, Fimbristylis* sp*.* and *Phyllanthus virgata,* Typical native shrub species include *Albizia procera, Antidesma ghaesembilla*, *Clerodendrum tomentosa,* and *Cycas schumanniana*, the latter restricted to hill foot-slopes and scattered specimens on coarse fan deposits. Although these grasslands are considered as native they may contain a number of introduced species that may occur as scattered individuals throughout. These include scattered shrubs of *Leucaena leucocephala* and *Chromolaena odorata,* exotic grasses such as Red Natal Grass (*Melinus repens*) and Mission Grass (*Pennisetum polystachyon*)*,* the vines Siratro (*Macroptilium atropurpureum*) and Stinking Passionflower (*Passiflora foetida*)*,* and herbs such as *Euphorbia hirta, Sida acuta, Stylosanthes* spp*.* and *Tridax procumbens.* Henty (1982) describes the typical floristic variations in native grassland, which are largely associated with substrate. Soils that experience a moisture deficit, including those formed on foot-slopes and coarse textured gravelly soils associated with outwash fans are typically dominated by *Themeda triandra*. Heavier alluvial soils with greater moisture retention capacity are dominated by *Imperata cylindrica*, but *Saccharum robustum* becomes dominant in permanently wet soils such as on watercourse margins. Habitats dominated by *Saccharum robustum* are mapped as VC4f, although these are typically heavily degraded with woody weeds (see **Section 4.3.7**).

Photo 4.7 Native grassland in good condition (VC4a) dominated by Kunai (*Imperata cylindrica)* on river flats.

Photo 4.8 Native grassland on foot-slopes dominated by Kangaroo Grass (*Themeda triandra*) (VC4b).

Degradation in grassland habitats is generally associated with heavy grazing regimes and is evident across large areas of the study area. Native grasses are in varying stages of being displaced by woody weeds, introduced pasture grasses and tropical legumes. Siam Weed is the most pervasive weed in heavily disturbed areas, mixing with Knobweed (*Hyptis capitata*), Giant Sensitive Weed, Sensitive Weed (*Mimosa pudica*) Siratro and Butterfly Pea (*Clitorea terneata*)*.* Complete displacement of native groundcover by Para Grass (*Urochloa mutica*) has occurred in some localities. Other introduced grasses include Red Natal Grass, Broad leaved Carpet Grass (*Axonopus compressus*)*,* Indian Couch (*Bothriochloa pertusa*)*,* Buffel Grass (*Cenchrus ciliaris*)*,* Mossman River Grass (*Cenchrus echinatus*)*,* A Windmill Grass (*Chloris inflata*)*,* Spiny top Grass (*Chrysopogon acicularis*)*,* Button Grass (*Dactyloctinuem aegyptum*)*,* Crowsfoot Grass (*Eleusine indica*)*,* Guinea Grass (*Megathyrsus maximus* var*. maximus*)*,* Mission Grass (*Pennisetum polystachyon*), Johnson River Grass (*Sorghum halepense*) and Rats Tail Grass (*Sporobolus* sp*.*)*.* Herbs such as *Hyptis suaveolens, Sida acuta and Sida cordifolia* also proliferate in some areas*.* The woody weeds Leucaena and Pigeon Bundleflower (*Desmanthus pernambucanus*) form thickets in some areas particularly along disturbed roadsides and fencelines. Raintree is establishing across extensive areas of heavily grazed grassland and is considered a precursor to the formation of closed forest. Where grasslands are severely degraded across large areas by invasion of exotic shrubs or dense thickening of woody weeds, they are mapped as VC4d and VC4e respectively. Such areas are typically associated within grazing paddocks and the boundaries between native and degraded grasslands are often defined by paddock fence-lines. Vegetation Community 4c is allocated to those areas where degradation is less severe and native floristic composition is preserved over a significant portion of the landscape.

Photo 4.9 Degraded grassland in a heavily grazed paddock where Siam Weed and Knob Weed dominate the shrub cover (VC4d).

Photo 4.10 Former native grassland where native grasses have been replaced with dense cover of the invasive Giant Sensitive Weed (*Mimosa diplotrocha*) (VC4d).

Native grasslands represent either fire dis-climax communities, or, in the case of Kunai grassland, indicate historical clearing for cultivation (Paijmans 1976). Despite a history that originates from human activity, the relatively dry climate that characterises the Markham Valley would have facilitated conversion of forests to grasslands. Grasslands are therefore likely to have been increasing their extent in the Markham Valley over the last 9,500 years.

Long-term, regular burning of grasslands would undoubtedly modify soil conditions and Henty (1982) describes the process of soil degradation that occurs following the dis-climax succession from rainforest to grassland. Under grassland, the organic content of the soil declines, and higher soil temperatures increase decomposition rates of organic matter thereby reducing surface leaf litter cover and limiting organic replenishment. With loss of organic matter, soil structure is degraded, leading to decreased moisture absorption, increased runoff and erosion. Hence the ecology of the original forest habitat and the edaphic features that sustain it are irreversibly modified.

4.3.5 Mixed native / exotic regrowth forests (VC2b) and forests and shrublands dominated by exotic species (VC5a, VC5b, VC6a; FIM O)

Regrowth forests are ubiquitous across much of the Markham Valley, forming thickets along the river frontage as well as broad mosaics across areas of native grassland. These regrowth forests are severely degraded by the dominance of exotic species, of which Raintree is the most abundant. Raintree forms closed-canopy forest patches over an extensive portion of the study area. Areas of open forest dominated by Raintree are mapped as VC5b. The establishment of Raintree forests is likely promoted by grazing since cattle eat the seed pods and disperse the undigested seeds across the landscape in their dung. Intensive grazing also reduces grass cover, which promotes the recruitment of tree seedlings. The associated reduction in grassy fuel loads also means that fire intensity is insufficient or too patchy to control the developing saplings. Once the trees have developed a closed canopy cover, the grassy ground cover is shaded out. Raintree savannah develops in areas where sufficient grassy cover is present between individual trees to arrest further shrub development, with such areas mapped as VC5a (Raintree savannah).

The sub-canopy and shrub layers of long established Raintree forests develop increased structural and floristic complexity over time as native rainforest shrubs and trees become established in the mesic habitats, especially along the fringes of drainage lines. Associated canopy species are *Litsea guppyi, Melanolepis multiglandulosa, Senna* sp., and *Dysoxylum gaudichaudianum,* often with climbing hemi-epiphytes such as *Epipremum amplissimum* and epiphytes of *Asplenium nidus.*

Typical species of the mid and understorey include *Alstonia scholaris, Antidesma* sp., *Buchanania macrocarpa, Carica papaya, Clerodendrum tomentosum, Cynanchum* sp., *Endospermum medullosum, Ficus adenosperma, Ficus copiosa, Ficus septica, Glochidion novoguineensis, Hornesteadia schottiana, Ipomoea obscura, Leea novoguineensis, Mikania micrantha, Myristica fatua, Passiflora edulis, Piper adunctum, Pometia pinnata, Passiflora subpeltata, Rhaphidophora* sp., *Trophis scandens* subsp. *scandens.* The groundcover supports species such as *Achyranthes aspera, Alpinea* sp., *Asystasia gangetica, Dioscorea* sp., *Mormochodia charanta, Nephrolepis bisserata, Oplismenus compositus, Sida* sp., *Stephania japonica* var. *timorensis* and *Urena lobata*.

Some habitats have a much greater canopy proportion of native trees and extensive areas of mixed native/ exotic forest has been mapped across the study area under the classification of VC2b. Whilst Raintree consistently contributes a considerable portion of the canopy, it mixes with a range of native colonising species including *Ficus nodosa, Commersonia bartramia, Artocarpus altilis, Macaranga tanarius, Melanolepis multiglandulosa, Pometia pinnata, Alstonia scholaris, Nauclea orientalis, Kleinhovia hospita, Albizia procera, Sterculia shillinglawii* and *Endospermum medulosum.* Shrub layers are variable although thickets exotic shrubs including Bamboo Piper, Leucaena, *Senna javanica* and *Glyricidia sepium* are common in most habitats, most abundantly on habitat margins. Where exotic species form mid-dense to dense shrublands, generally displacing grassland habitats, VC6a is recognised with several mapped units of exotic shrubland scattered throughout the study area.

Photo 4.11 Typical stand of Raintree forest where Raintree forms the only canopy species (VC5b).

Photo 4.12 Mixed exotic/ native regrowth forest (VC2b) fringing a river channel near Kokok Village.

4.3.6 Sago swamp - secondary forests dominated by Sago Palm (VC10a; FIM O)

Only a few scattered areas of Sago Palm (*Metroxylon sagu*) are mapped throughout the study area. These areas are typically poorly-formed secondary forests located along drainage lines and swampy areas where Sago Palm has persisted in the presence of more extensive and selective forest clearing (**Photo 4.13**). These habitats are floristically simple, characterised by dense secondary growth and lack the structural and floristic diversity of intact swamp forest habitats. Sago swamp habitats are often formed through regrowth following total clearing or more typically represent a residual habitat formed through partial removal of the original forest canopy.

4.3.7 Watercourses and gravel bars (VC12a; FIM O)

The rapidly evolving channel planform of the larger rivers has created a continuum of fluvial features in seral stages (i.e. intermediate stages in ecological succession) ranging from bare river braids (**Photo 4.14**) to point bars occupied by grasslands and developing shrublands. Dense swards of *Saccharum robustum,* often mixed with small trees and exotic shrubs including Leucaena and *Glyricidia septica*, typify many stabilising gravel bars (mapped as VC4f) although these habitats are usually transient given the dynamic process of river erosion and deposition.

Photo 4.13 Small area of secondary forest dominated by Sago Palm in a swampy watercourse VC10a).

Photo 4.14 Gravel braids of the Leron River, which are largely devoid of vegetation (VC12a).

4.3.8 Plantation areas (VC8a, VC8b, VC9a; FIM O)

A variety of plantations (excluding biomass plantations) are scattered throughout the study area including small scale plots of *Leucaena*, most likely for cattle fodder, palm oil plantations (VC8a) near the Erap River in the eastern portion of the study area, and some minor forestry plantation areas of *Araucaria* and *Pinus* (VC8b) (**Photo 4.15**).

Large areas of coconut plantation (**Photo 4.16**) occur throughout the study area focused largely around village areas and riparian fringes. The majority of these areas are not maintained and are thickening with an understory of regrowth trees and shrubs beneath the tall open canopy of coconut. Canopy heights of up to 30 m for the coconut trees are typical with a mid-dense sub-canopy or *Artocarpus altilis, Commersonia bartramia, Cananga odorata, Kleinhovia hospita* mixed with scattered Raintree. The lower shrub layer is typically formed by *Glyricidia septica, Musa* spp. and papaya (*Carica papaya*), and may also include managed and unmanaged plantings of cacao (*Theobroma cacao*). These forests are progressing structurally toward a closed forest and have developed many of the structural features of native secondary forest.

Photo 4.15 *Araucaria* plantation (VC 8b) at the Papua New Guinea Forest Research Station, Leron.

Photo 4.16 Coconut plantation with developing secondary forest understory (VC 9a).

4.3.9 Village Areas; Garden areas with evidence of recent modification (VC7a, VC11a; FIM O)

Areas of current occupation and intensive landuse are mapped under this classification which includes village and associated garden areas. The vegetation is typically dominated by planted food and other utility species including coconut, mango (*Mangifera indica*), papaya, banana (*Musa* sp.), *Glyricidia sepium,* cacao and garden food resources including cassava (*Cassava manihot*) and taro (*Calocasia esculenta*).

4.4 VEGETATION CONDITION AND MAPPING

Through much of the available literature, the Markham Valley landscape is considered the product of anthropogenic activities, in particular the use of fire to clear the land for cultivation (Robbins 1960, Lane-Poole 1925, Paijmans 1975, Henty 1982). This use of fire is manifest in the extensive native grassland habitats that blanket the valley, occupying both the broad river flats and adjacent mountain foot-slopes to a considerable elevation. As previously discussed in **Section 4.1**, savannah vegetation has been present in the Markham Valley at least since the most recent glacial period (15,000 to 18,000 years ago) and its extent has most likely increased from 9,500 years ago. Hence, savannah vegetation in the Markham Valley, including native grasslands, has been a relatively stable ecosystem for a significant period, with sufficient time to develop its own specialised biota.

Whilst human impacts on the natural environment over a long history of subsistence cultivation are noted, accelerated degradation has come with industrialisation that has increased under European influence, most likely since the start of the 1800's (Garret-Jones 1979). This included the establishment of copra and cacao plantations, and a likely increased human population that has placed additional pressure on natural resources such as timber. No forest habitats currently present in the study area can be considered to exist in a natural condition; in particular, extensive timber extraction has left the last remaining small areas of forest in a degraded condition.

Further pressure was placed on the natural landscape with the introduction of cattle grazing, which expanded rapidly following an increase in foreign aid after 1963 (Connell 1979); the Markham Plains / Ramu district is considered the most important beef producing region in Papua New Guinea (Banguinan *et al*. 1996). With the introduction of cattle came the incipient impacts of introduced pasture weeds including a number of exotic pasture grasses and herbs such as Para Grass (*Brachiara mutica*) and Townsville Lucerne (*Stylosanthes humilis*) plus woody forage species including Leucaena that have been established in a number of paddocks. Raintree was probably introduced during this period; the pods of this species have high protein value and make a useful fodder supplement. Other non-desirable weeds have also been introduced that are spread by cattle, including Siam Weed and Knobweed that directly compete with native grasses.

Following the introduction of cattle, grassy fuel loads diminished, decreasing the intensity of fires and their capacity to control weed growth. Cattle spread the seeds of Raintree and, with reduction of fire intensity, these seedlings proliferated to a degree that Raintree-dominated forests now cover up to a quarter of the total study area. Hence, with consideration given to the pre-existing anthropogenic landscape, the mapping of vegetation condition is largely an exercise in the mapping of categories of habitat degradation and modification. Habitat condition however grades across a continuum, resulting in boundaries that are diffuse in some instances and difficult to accurately demarcate.

The framework for assessment of vegetation condition has been detailed in **Section 2.3**. The following trends are noted:

1. No intact forest vegetation was identified within the study area. A single degraded (14 ha) patch of disturbed large to medium crowned forest (VC1a) that remains on the river frontage was classified Moderately Disturbed (Stable to declining) (Condition Category 2a).

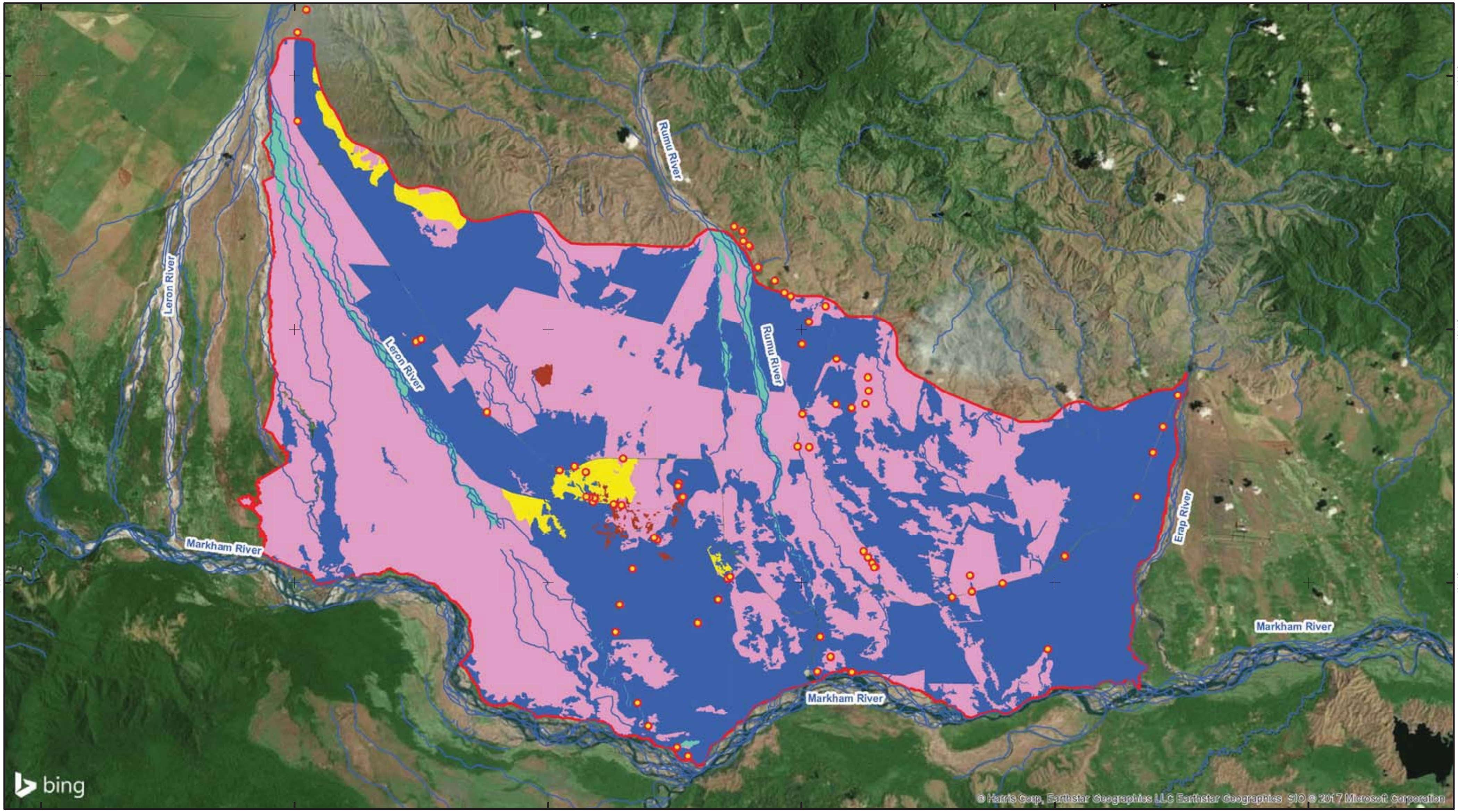
2. Vegetation Community 3a represents the best-preserved representation of savannah habitat in the study area, the habitat being largely free of exotic weeds and in a stable natural condition. Associated patches of rainforest (VC2a) are predominantly native and developing structural attributes of a natural forest. These habitats are of relatively minor extent within only 53 ha of VC3a and 102 ha of VC2a mapped across the assessment area. These habitats are assigned to the condition category of Moderately Disturbed (Stable or Regenerating) (Condition Category 2b).
3. Regrowth vegetation comprising a mix of native pioneer and exotic trees and shrubs (VC2b) occupies 1,147 ha or 2.4% of the mapped assessment area. These are considered degraded forest patches (Condition Category 4) that are subject to decline in habitat condition through continued expansion of exotic species, notably Raintree, on the forest margins and into forest canopy gaps.
4. Highly degraded vegetation (Condition Category 5), represented by exotic forests dominated by Raintree (VC5a and VC5b) form 7,641 ha or 16.1% of assessment area); severely degraded grasslands (VC4d, VC4e and VC4f) forming 11,448 ha and 24% of the assessment area; and other degraded areas including villages and plantation forming 11,922 ha, or 25% of the assessment area.

On the whole, the assessment area is dominated by vegetation in a degraded, highly modified condition with natural vegetation an extremely limited component of the landscape (**Table 4.2**). The mapping of vegetation condition across the assessment area, according to the framework described in **Section 2.3**is provided in **Figure 4.2**. No intact vegetation (Condition Category 1) was recorded. The moderately disturbed (stable or regenerating) Condition Category 2b represents habitats that have been subject to moderate levels of human disturbance but remain dominated by native species characteristic of the original natural state prior to human impacts. The limited extent of this condition class indicates the pervasiveness of exotic species that are symptomatic of habitat degradation throughout the majority of habitats in the study area.

Table 4.2 Spatial extent of vegetation condition classes across the Project assessment area.

Vegetation condition class	Vegetation communities	Area (ha)	% of total area
Moderately Disturbed (stable or regenerating) (Category 2b)	2a, 3a	156.2	0.3
Moderately Disturbed (stable to declining) (Category 2a)	1a, 12a	1,085.9	2.3
Modified (cultural) (Category 3)	4a, 4b	1,297.5	2.7
Degraded (Category 4)	10a, 2b, 3b, 4c, 4f	21,970.9	46.5
Highly Degraded (Category 5)	11a, 3c, 4d, 4e, 5a, 5b, 6a, 7a, 8a, 8b, 9a	22,694.4	48.1
Total*		47,205.0	100.0

*Sum of individual values before rounding.



Notes:

Data Source: Image from ArcGIS Online Bing Maps data (c) 2010 Microsoft Corporation and its data suppliers.

Coordinate System: GCS GDA 1994
Datum: GDA 1994
Units: Degree

1:135,494 at A4
0 750 1,500 3,000 4,500 6,000 Meters

LEGEND

- Flora survey sites
- Watercourse
- Study Boundary

Vegetation Condition

- Moderately Disturbed (Stable or Regenerating)
- Moderately Disturbed (Stable to declining)
- Modified (Cultural)
- Degraded
- Highly Degraded

Figure: 4.2
Title: Flora survey sites and vegetation condition

Project: PNG BIOMASS MARKHAM VALLEY TERRESTRIAL ECOLOGY ASSESSMENT

Client: ERIAS Group Pty Ltd

BAAM ECOLOGICAL CONSULTANTS

Drawn By: MG Reviewed by: AC Date: 17-Jan-17

Document Location: C:\Users\Owner\Documents\Clients\3D Environmental\PNG\BAAM_PNG\BAAM_A3_Landscape_PNG_17117.mxdDate: 17-Jan-17 10:54:31 AM

4.5 FLORA SPECIES OVERVIEW

There are few targeted floristic studies focusing on habitats in the Markham Valley, or New Guinea savannah landscapes in general. Studies by Takeuchi (2000) within the lowland rainforests (below 400 m asl) of the Josephstaal Forest Management Agreement Area, approximately 250 km north of the study area, identified 139 families, 445 genera and 730 distinct morpho-species with an unaccounted proportion of the flora considered undocumented. However, due to the highly disturbed and degraded nature of the forests in the study area, coupled with the considerable extent of relatively homogenous grassland, floristic diversity is likely to be significantly diminished. The exception however is likely to be a considerable abundance of exotic species promoted by grazing and cultivation, with 36% of the species recorded in the study area considered to be of exotic origin (see **Appendix B**). The high proportion of exotic flora is due to the land use history and extensive areas of highly disturbed and degraded vegetation.

The results of this survey, augmented with floristic records sourced from historic collections within the botanical database of the Queensland Herbarium, identify a flora of 370 species occurring within 85 families and 267 genera (see **Appendix B**). This comprises 235 (64%) native species and an introduced/exotic flora of 135 species (36% of the total flora). There are 11 ferns, one cycad, four gymnosperms and 354 flowering plants. One species is listed as significant under the IUCN and 150 (41%) of the flora are significant to the local landholders on account of traditional and/or current uses and value (refer **Appendix D**).

4.6 CONSERVATION PRIORITY SPECIES

Although Papua New Guinea is a signatory to conventions such as the International Plant Protection Convention and Convention on Biological Diversity, there is no formalised system within Papua New Guinea legislation dealing specifically with the protection of threatened or significant plant species. Nor has any structured national system applying conservation status to flora species been devised or applied. The recognition of threatened species in this report is based on information provided in the IUCN Red List of Threatened Species (IUCN 2014a). This system has no legislative or legal significance within Papua New Guinea other than to provide guidance to the relative conservation significance and/or rarity of any given plant species at a particular location. Reference to the IUCN database indicates 143 plant species within Papua New Guinea listed as threatened (vulnerable, endangered, or critically endangered), 34 listed as near threatened and a further 20 species listed as data deficient. **Table 4.3** provides information relevant to the four threatened and near threatened species that, on the basis of field survey and floristic review, are either known to occur based on the results of field survey (two species), or are considered likely to occur based on known distributions and habitat preferences. The following two significant flora species were detected during the field survey (see **Figure 4.3** for locations):

- ***Intsia bijuga* (Kwila) (IUCN: Vulnerable).** Kwila is a valuable timber in Papua New Guinea (Eddows 1977, Tong *et al*. 2009) and forms a large canopy tree in intact primary lowland rainforest on the southern side of the Markham River, outside of the study area. The species was recorded at a single location within the study area, as a small regrowth tree associated with degraded gully line forest in foothills behind Dinsu Village, just outside the assessment area (**Photo 4.17**). Historical timber extraction and forest clearing is likely responsible for the current rarity of this species in the study area.
- ***Cycas schumanniana* (IUCN: Near Threatened).** A common species in native grasslands on hill foot-slopes throughout the study area with scattered individuals extending onto adjoining outwash plains (**Photo 4.18**). This species is most typically associated with VC4b (Kunai grassland on foot-slopes and hill-slopes) where relatively large populations occur as scattered plants over large areas. **Figure 4.3**shows the locations of *Cycas schumanniana* populations at sites that were visited during the field survey. However the species is highly likely to be more widely distributed than the limited sites surveyed. Therefore the distribution of habitat suitable for *Cycas schumanniana* is also mapped in **Figure 4.3**.

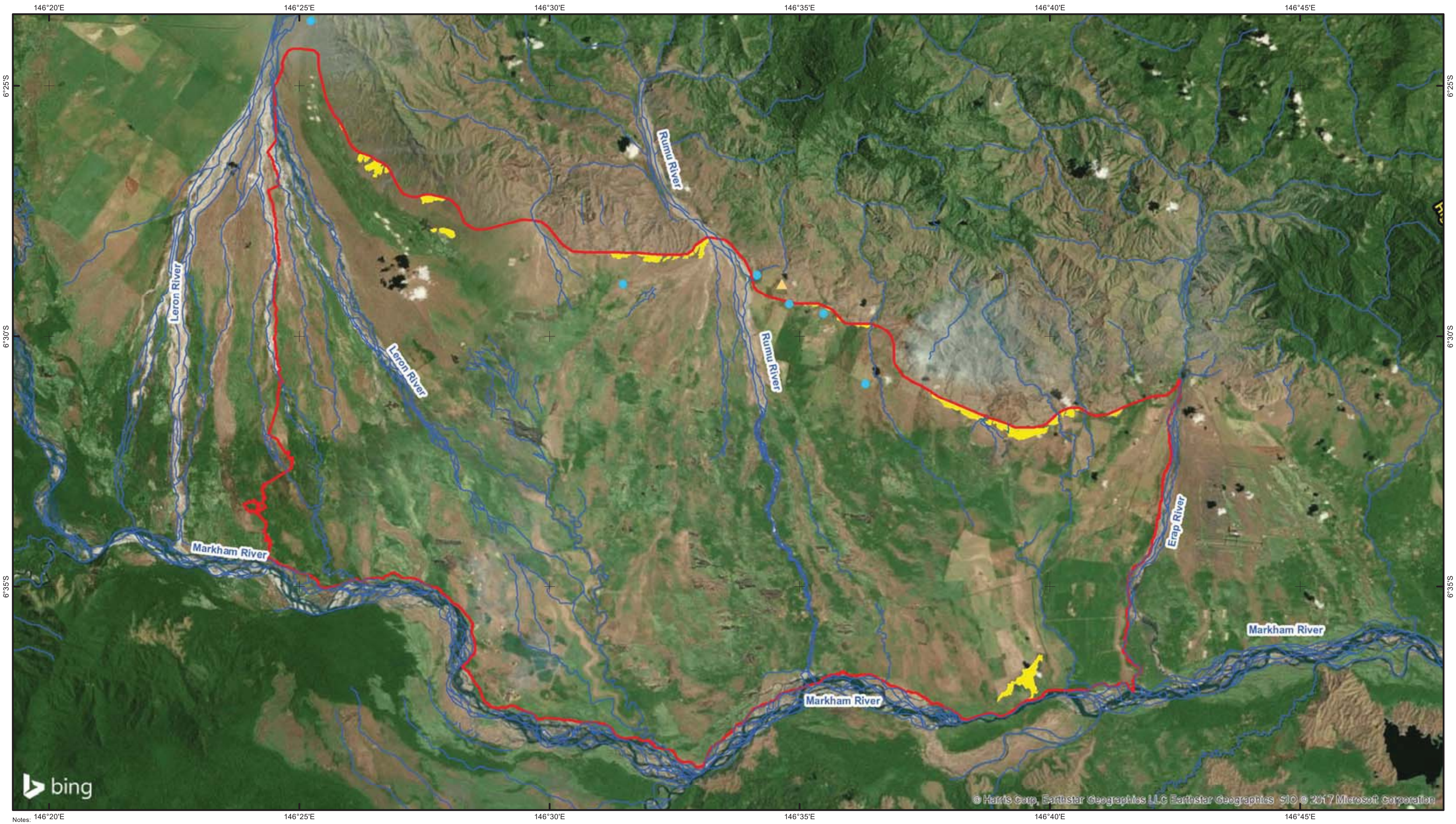
Photo 4.17 Immature *Intsia bijuga* (IUCN: Vulnerable) (the small tree in the centre of the photo) in degraded gully vegetation just outside the study area.

Photo 4.18 Locations of mature *Cycas schumanniana* (IUCN: Near Threatened) cycads (indicated by white circles) growing in typical grassland habitat on hill foot-slopes just outside the study area.

Table 4.3 Conservation significant flora species known or likely to occur within the study area and their threat status under the IUCN Red List.

Species	Record source	IUCN*	Habitat and distribution	Comments on records and likelihood of occurrence
Species known to occur in the study area – recorded in 2016 survey				
Intsia bijuga (Kwila)	Recorded during survey.	VU	A pan tropical species of lowland rainforest distributed throughout south-east Asia and Melanesia which produces one of the most valuable timbers of South East Asia (World Conservation Monitoring Centre 1998a).	Recorded during survey as a single small regrowth tree associated with degraded gully line forest in foothills behind Dinsu Village (outside the assessment area). A relatively rare regrowth tree with no adult trees noted. Historical timber extraction and forest clearing is likely responsible for the current rarity of this species in the study area.
Cycas schumanniana	Recorded during survey.	NT	Endemic to Papua New Guinea occurring on the northern side of the island along the foothills of the Bismarck Range, predominantly in the valleys of the Markham and Ramu Rivers extending south from Lae along the Bulolo River as far as Wau and Madang. Recorded from low to high elevations, up to 1,600 m asl in Kunai grassland habitats (Hill 2010).	A common species in native grasslands on hill foot-slopes throughout the study area with scattered individuals extending onto adjoining outwash plains. This species is associated with VC4b (Kunai grassland on foot-slopes and hill-slopes) in the study area.
Species possibly occurring in study area				
Pterocarpus indicus (New Guinea Rosewood)	Not recorded although known from area.	VU	A widespread tree found in lowland primary and some secondary forest, mainly along tidal creeks and rocky shores (World Conservation Monitoring Centre 1998b).	Known from primary and secondary forests along the Watut and Markham river. A widespread tree that is likely to be associated with both intact and disturbed native forest (VC1a in particular), but historical timber extraction is likely to have removed all adult trees.
Aglaia rimosa	Not recorded although known from area.	LR – NT	A widespread tree that is generally associated with secondary forests near rivers and streams (Pannel 1998).	Suitable habitat occurs in the study area, most likely in disturbed rainforest habitats (VC1a).

*IUCN status: LR- NT = Lower Risk – Near Threatened; NT = Near Threatened; VU = Vulnerable (facing a high risk of extinction in the wild in the medium-term future).



Notes:

Data Source: Image from ArcGIS Online Bing Maps data (c) 2010 Microsoft Corporation and its data suppliers.

Coordinate System: GCS GDA 1994
Datum: GDA 1994
Units: Degree

1:135,494 at A4
0 750 1,500 3,000 4,500 6,000 Meters

LEGEND

- *Intsia bijuga* (Kwila)
- *Cycas shumanniana*
- Watercourse
- Study Boundary
- Habitat suitable for *Cycas shumanniana*

Drawn By: MG Reviewed by: AC Date: 18-Jan-17

Figure:	4.3
Title:	Significant flora species records
Project:	PNG BIOMASS MARKHAM VALLEY TERRESTRIAL ECOLOGY ASSESSMENT
Client:	ERIAS Group Pty Ltd

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The majority of species listed under IUCN schedules are associated with intact habitats and hence are considered unlikely to occur in the study area. A full list of threatened species for Papua New Guinea, as per the IUCN Red List, together with a detailed assessment of their likelihood of occurrence within the study area is provided in **Appendix C**. *Acacia crassicarpa,* listed as Vulnerable, is considered unlikely to occur in natural habitats within the study area; however, it has been planted as a plantation tree in some stands of Project test plantings.

In addition to the IUCN species list, 263 taxa are listed in the CITES (appendices for Papua New Guinea (UNEP – WMC 2015)). The species presently listed for Papua New Guinea include five species of *Cyathea*, 10 species of *Cycas*, five taxa in the fern family Dicksoniaceae, four pitcher plants (genus *Nepenthes*), and 149 species of orchid. The CITES listing of orchids is, however, incomplete (as noted in the database explanatory notes) and export of all orchids collected from the wild was banned by the Papua New Guinea Department of Environment and Conservation in 1990 (Vantomme *et al*. 2002). Miller *et al*. (1994) also listed *Euphorbia* spp. as protected under CITES. *Cycas schumanniana* is the only species recorded within the study area that is listed under CITES.

4.7 Exotic Flora Species

One-hundred and thirty-six exotic flora species, or 36% of the flora, were recorded within the study area during the field assessment. The highest numbers of weeds are represented by grasses (Poaceae) followed by legumes (Fabaceae) and herbs within Asteraceae. Disturbed roadsides, garden and village areas were found to support the highest number of weed species (124 species) although a number of these are cultivated plants. High numbers of exotic species are also recorded in regrowth and disturbed grassland habitats.

There are 30 species that are considered to pose considerable risk to the integrity and function of both native habitats and agricultural and plantation systems within the study area. Details for those species considered to pose risk are provided in **Table 4.4**. This assessment of risk relies heavily upon on assessments and information provided within the Global Invasive Species Database (2016) and the Pacific Island Ecosystems at Risk Database (PIER 2013), supported by field observation. It does not include exotic garden food plants unless these spread readily into natural environments, nor a number of introduced species which are considered widespread and of low invasive potential. The weeds are listed in order of assessed risk to natural habitat values (PIER 2013) with nine species recorded in the study area listed in the '100 worst invasive alien species' (Global Invasive Species Database 2016) attributed the highest risk of impact to natural habitat values.

Throughout the broader study area, a dominant proportion of the landscape has been pervasively altered by growth and infestation of exotic weed species. Many of these are widespread herbaceous species and are not considered highly invasive nor a significant threat to native vegetation or agricultural land. However, several highly invasive weeds do also occur, and these are having significant landscape-scale impacts on the ecology of the area as well as reducing the productivity of grazing lands. The highly invasive weed species, which include Siam Weed (*Chromolaena odorata*), Leucaena (*Leucaena leucocephala*), Bamboo Piper (*Piper aduncum*), Giant Sensitive Plant (*Mimosa diplotricha*), Glyricidia (*Glyricidia sepium*), Cassia (*Senna* spp.), Neem Tree (*Azadirachta indica*) and Pigeon Bundle Flower (*Desmanthus pernambucanus*) plus the large woody Raintree, are creating major landscape-scale impacts on ecological values and land productivity. Other more aggressive species include Ceara Rubber (*Manihot glaviozi*), Bitter vine or Mile a Minute (*Mikania micrantha*), Belly Ache Bush (*Jatropha gossypiifolia*) and Castor Oil Bush (*Ricinus communis*).

The most significantly degraded areas are those that are, or have been, subject to heavy grazing regimes that have facilitated the spread of weeds throughout the landscape and diminished the potential for fire to act as an effective control agent. Riparian areas are almost universally impacted by monocultures of Raintree and Leucaena that inhibit the regeneration of native forest tree species. Further determination of weed control priorities at the project scale requires consideration of the potential significance of the impact of each weed present, the existing and future disturbance impacts to the local environment, and the feasibility of control.

Deleterious effects of exotic species may include direct displacement of native species through competition, smothering of canopy or ground layers or prevention or deflection of natural regeneration. They may also significantly impact agricultural productivity including orchard establishment and management as well as silviculture. Highly invasive woody species, particularly Leucaena and Raintree, have greatest potential to impact the establishment of eucalyptus plantation trees due to their rapid growth rates, the long-term persistence of their seeds in the soil and their capacity to shade out growing eucalypt seedlings if not managed. Weedy groundcover species will eventually be shaded by establishing plantation trees if early maintenance is practiced to ensure plantation seedlings are not smothered.

Table 4.4 Exotic species recorded during the survey and potential risks posed to agricultural systems and native habitats.

Species	Common name	Life form	Location and habitats recorded	Risk[1]	Major habitats at risk	Registered on GISD[2]
Chromolaena odorata	Siam Weed	Herb	Pervasive pest through heavily grazed grasslands, particularly VC4d.	High (28)	Disturbed habitats, riparian areas and savannah swamps and grasslands. This weed is a serious threat to garden productivity.	Yes (world's 100 most invasive pests)
Mikania micrantha	Mile a Minute	Vine	Most abundant in degraded habitats and garden areas along roadsides on river flats, and within regrowth-closed forests.	High (25)	This vine has potential to smother and penetrate tree crowns and choke plants. It reduces the growth and productivity of oil palm, rubber, citrus, cassava, tree plantations, pineapple, coconut and plantain. Invades native and exotic regrowth forests (Henty and Pritchard 1975).	Yes
Mimosa diplotricha	Giant Sensitive Plant	Herb	Widespread and aggressive weed of grazing lands and disturbed roadside margins and garden areas throughout the study area.	High (24)	Highly invasive coloniser of disturbed habitats and garden areas, wet areas and riparian areas. Most aggressive in lowland areas where it poses threat to gardens and other disturbed areas.	Yes

[1] From PIER (2013).
[2] From Global Invasive Species Database (2016).

Species	Common name	Life form	Location and habitats recorded	Risk[1]	Major habitats at risk	Registered on GISD[2]
Solanum torvum	Devils Fig	Shrub	Most abundant in degraded habitats and garden areas along roadsides and on river flats.	High (24)	Potential serious pest in lowland areas, particularly riparian fringes and wet savannah habitats where it has the potential to out-compete and displace native vegetation.	No
Bidens pilosa	Cobblers Pegs	Herb	Recorded from disturbed garden areas, access tracks and cleared easements throughout the study area.	High (23)	Mostly garden areas and disturbed margins of access tracks and roads.	Yes
Ricinus communis	Castor Oil Bush	Shrub	Grows in disturbed areas around villages, gardens and access tracks.	High (21)	May invade natural secondary forest margins, riparian areas and grasslands	Yes
Psidium guajava	Guava	Shrub	Grows in disturbed areas around villages, gardens and access tracks.	High (21)	Known to invade disturbed sites forming dense thickets.	Yes
Jatropha gossypiifolia	Belly Ache Bush	Shrub	Recorded along disturbed roadsides on track from 40 mile to Bismarck Ranch.	18 (High)	Disturbed grasslands and savannah woodlands. Able to form pure stands in open areas where the natural vegetation has been damaged or removed by cattle, man.	Yes
Piper aduncum	Bamboo Piper	Shrub	Pervasive pest of cleared forest areas forming dense thickets in abandoned garden areas and in secondary forests.	High (18)	Disturbed garden areas, secondary forests and cleared easements. Major impact is to prevent natural regenerative processes as well as impact agricultural production.	Yes
Mimosa pudica	Sensitive Weed	Herb	All disturbed areas, particularly along roadsides, cleared areas, gardens and grazed grasslands.	High (18)	Major impact is to grazing lands where it decreases productivity.	Yes
Megathyrsus maximus	Guinea Grass	Grass	Common on disturbed easements and roadsides.	High (17)	Rapidly occupies and tends to dominate disturbed habitats where it smothers native regeneration. Particularly aggressive along roadsides and riparian frontages.	Yes (referred to as *Urochloa maximum)*

Species	Common name	Life form	Location and habitats recorded	Risk[1]	Major habitats at risk	Registered on GISD[2]
Pennisetum purpureum	Elephant Grass	Grass	Common on disturbed easements and roadsides.	High (16)	Particularly aggressive along roadsides and riparian frontages.	No
Leucaena leucocephala	Leucaena	Shrub	Prominent in lowland habitats, particularly garden areas, degraded grassland habitats and as a dense regrowth shrub in disturbed grassland habitats. The species has been cultivated as fodder for cattle.	High (15)	Occupies and invades natural savannah habitats and grassland areas and pervasive through most secondary forest habitats.	Yes (world's 100 most invasive weeds)
Acacia farnesiana	Mimosa Bush	Shrub	A few scattered plants are located on heavily grazed lands in the vicinity of Dinsu Village.	High (14)	Has potential to invade and thicken in savannah habitats, particularly those areas subject to a heavy disturbance regime.	No
Ipomoea quamoclit	Cupid's Flower	Herb - Vine	Noted in disturbed garden habitats where it was smothering disturbed riparian vegetation.	High (14)	Has potential to invade early successional stages of tropical rainforest and compete with native vine species	No
Spathodea campanulata	African Tulip Tree	Tree	Only scattered trees occurring on the margins of secondary forest.	High (14)	Has significant potential to displace native species in regenerating forests. Currently outcompeted by Raintree.	Yes
Urochloa mutica	Para Grass	Grass	Dense patches observed in wetter localities within broader areas of native grassland.	High (14)	Rapidly occupies and tends to dominate disturbed habitats where it smothers grasses. Has potential to invade wetland habitats and river margins.	No
Desmanthus pernambucanus	Pigeon Bundleflower	Shrub	Thick infestations on roadside margins and in disturbed grazing lands where it grows in association with Leucaena.	High (12)	Has potential to thicken throughout all disturbed habitats reducing productivity of gardens and grazing lands.	No

Species	Common name	Life form	Location and habitats recorded	Risk[1]	Major habitats at risk	Registered on GISD[2]
Muntingia calabura	Japanese Strawberry	Small tree	Infestations on roadside margins where it is a typical pioneer species colonizing disturbed sites in tropical lowlands.	High (12)	May invade secondary forest margins and disturbed grasslands especially along tracks.	No
Centrosema molle	Butterfly Pea	Vine	Roadsides and disturbed grasslands.	High (11)	Native grasslands, savannah woodlands and gardens.	No
Cenchrus polystachios (syn. *Pennisetum polystachyon*)	Mission Grass	Grass	Roadsides and disturbed grasslands.	High (11)	Native grasslands and savannah woodlands.	No
Azadirachta indica	Neem Tree	Tree	Associated with degraded heavily grazed grassland habitats and spreading on margins of plantation or avenue trees.	High (10)	Potential to spread into savannah woodlands and invade degraded grassland and riparian areas.	No
Senna alata	Candle Bush	Shrub	Associated with overgrown gardens and adjacent to roadsides and access tracks as well as fringing habitats on the Markham River.	High (10)	Potential to spread into disturbed margins of regenerating forest and deflect establishment of native shrubs. Most aggressive in lowland areas.	No
Clitoria ternatea	Butterfly Pea	Vine	Associated with disturbed track margins and occurring throughout disturbed grazing lands where it forms a prominent groundcover.	High (9)	Potential to spread into disturbed margins of regenerating forest and deflect establishment of native groundcovers.	No
Tecoma stans var. *stans*	Yellow Bells	Shrub	Mostly grows in disturbed areas around villages, gardens and access tracks.	High (8)	Potential to grow in dense stands, inhibiting regeneration of other species in grasslands or savannah woodlands.	Yes
Manihot glaziovii	Rubber Tree	Shrub	Growing in older cultivated areas as a dense shrub where it was competing with cassava.	High (8)	High potential to be a serious pest in garden areas and a risk to garden productivity.	No

Species	Common name	Life form	Location and habitats recorded	Risk[1]	Major habitats at risk	Registered on GISD[2]
Albizia saman	Raintree	Tree	Pervasive tree weed throughout much of the study area forming dense monotypic forests and displacing native trees.	Low (4)	Established pest spread by cattle that is significantly reducing habitat complexity and diversity	No
Stachytarpheta jamaicensis, S. cayennensis	Snakeweeds	Herb	*S. cayennensis* is relatively common in disturbed areas, particularly on degraded grassland habitats adjacent to the Markham River.	NA*	Mostly grows in disturbed areas around villages, gardens and access tracks. May invade natural riparian areas (gravel beds and stream banks), wetlands and grasslands where there is a vector for spread (e.g. vehicles, pigs, cattle).	No
Macroptilium atropurpureum	Siratro	Herb	Generally associated with overgrown gardens where it forms a robust groundcover although also occurring as a dense cover in degraded grassland habitats.	NA*	Potential to spread into ground layers of gardens and regenerating forest and prevent establishment of native ground covers.	No
Hyptis capitata	Knob weed	Herb	Associated with degraded heavily grazed grassland habitats.	NA*	Degrades and reduces grassy cover in native grassland habitats. Readily spread by stock and is most aggressive in lowland areas.	No

[1] Risk assessment score reported in the Pacific Island Ecosystems at Risk Database (PIER 2013); * NA indicates that a risk assessment for the species has not been prepared for the Pacific Islands; [2] Registered as an invasive species on the Global Invasive Species Database (2016).

4.8 IFC Flora Habitat Type Assessment

The classification of floristic habitats against IFC Performance Standard 6 has previously been provided in **Section 1.5.5**. In summary, three habitat types are recognised under the IFC framework, namely:

- **Modified Habitat:** areas that may contain a large proportion of plant and/or animal species of non-native origin, and/or where human activity has substantially modified an area's primary ecological functions and species composition;
- **Natural Habitat:** areas composed of viable assemblages of plant and/or animal species of largely native origin, and/or where human activity has not essentially modified an area's primary ecological functions and species composition; and
- **Critical Habitat:** areas with especially high biodiversity value.

Mapping showing the distribution of habitat categories in accordance with the IFC framework across the study area is shown in **Figure 4.4**. No critical habitat occurs in the assessment area, which instead comprises 1,242 ha of natural habitat (2.6% of the study area) and 45,963 ha of modified habitat (97.4% of the study area). Further discussion relating to the classification of habitats in accordance with the IFC framework is provided in the following section.

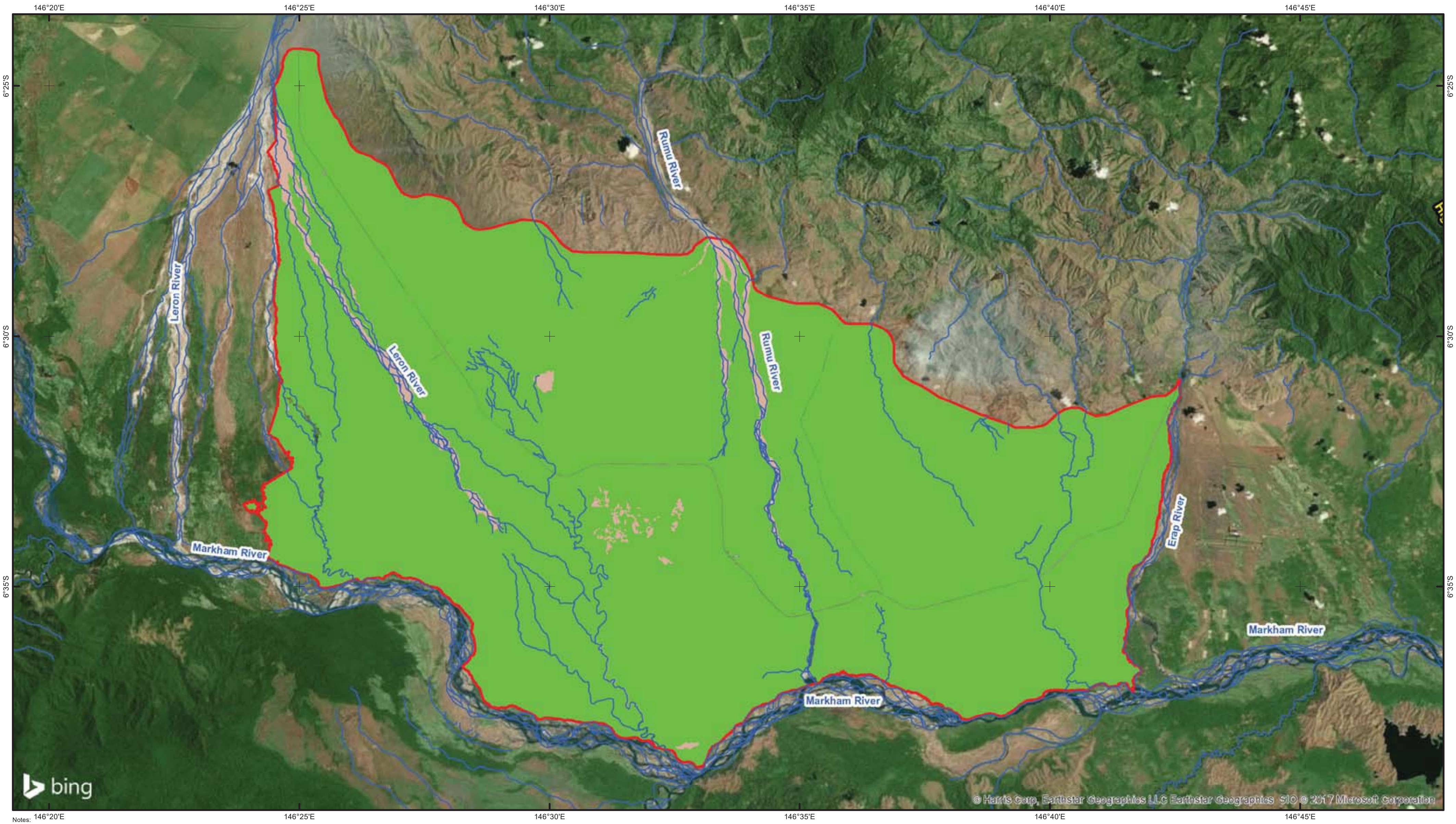
Modified Habitats: The majority of floristic communities within the study area fit within the definition of Modified habitat. Modified habitats comprise those vegetation communities that have been subject to considerable floristic and structural alteration due to anthropogenic influences, and include:

- habitats dominated entirely or mostly by exotic species, including: forests dominated by the invasive Raintree (VC5a and VC5b); shrublands dominated by exotic species (VC6a); areas of existing human occupation and garden areas (VC7a and VC11a); and plantation areas (VC8a, VC8b and VC9a);
- habitats that have been subject to long term alteration through anthropogenic application of fire to the landscape, including: native Kunai grassland habitats (VC4a and VC4b) in recognition of the role man has played in shaping such ecosystems with fire, and the role fire has played in substantially reducing the coverage of woody vegetation components and general floristic diversity; and variants of grassland and savannah habitats that have been degraded with exotic pest plants and partial clearing (VC3b, VC3c, VC4c, VC4d and VC4f); and
- habitats that have been subject to considerable structural alteration through either total or partial clearing of the original native forest canopy (VC2b and VC10a).

Natural Habitat: There are no habitats in the study area that have escaped extensive anthropogenic influence. A few small habitat vestiges have nevertheless retained aspects of their original undisturbed vegetation structure, composition and their primary ecological function and are considered consistent with the definition of natural habitat. Natural habitat areas include:

- a 14 ha patch of large to medium crowned forest (VC1a); although subject to selective logging and clearing, it has retained a portion of its original floristic composition and structure and its ecological function has not been entirely modified, and a considerable proportion of the retained canopy trees are characteristic canopy species in intact primary floodplain forest;
- several small patches of savannah woodland in natural condition (VC3a) that represent savannah habitats that have likely been relatively stable in the Markham Valley since the last glacial period (15,000 to 18,000 years ago) and have not been subject to clearing or severe degradation of the woody habitat component by repetitive hot burning;
- small vestiges of a developing rainforest community comprising predominantly native species (VC2a) that form a mosaic within broader areas of well-preserved savannah. This vegetation community type develops from the natural succession of savannah woodlands towards a more complex and diverse forest ecosystem in the absence of fire or human disturbance; and
- river gravel beds, although these are largely devoid of stable vegetation.

For the purposes of this assessment, natural grassland is defined as grassland composed of species of native provenance whose structure and distribution is controlled by soil and climatic conditions and has developed outside any substantial anthropogenic influence. No Kunai grassland habitats within the study area are considered to be in a natural condition due to the importance of anthropogenic influences in the origin and maintenance of Kunai grasslands. This concurs with descriptions of Paijmans (1976) and Henty (1982), who considered the extensive 'anthropogenic' grasslands within the Markham Valley as being derived through human modification.



Notes:

Data Source: Image from ArcGIS Online Bing Maps data (c) 2010 Microsoft Corporation and its data suppliers.

Coordinate System: GCS GDA 1994
Datum: GDA 1994
Units: Degree

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0 750 1,500 3,000 4,500 6,000 Meters

LEGEND

Watercourse
Study Boundary
Road

IFC Habitat Classification

Modified Habitat
Natural Habitat

Figure: 4.4
Title: IFC habitat classification
Project: PNG BIOMASS MARKHAM VALLEY TERRESTRIAL ECOLOGY ASSESSMENT
Client: ERIAS Group Pty Ltd

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Critical Habitat: No Critically Endangered or Endangered flora species were detected within the study area, and none are considered likely to occur. Furthermore no habitat areas of significant importance to endemic or restricted-range species were identified in the study area. Also, no evidence was found to suggest that habitats support key evolutionary processes, most of which have been substantially modified by repetitive anthropogenic disturbance. There is little evidence to suggest that native savannah habitats would qualify as a highly threatened or unique ecosystem due to the extensive, well preserved representations of savannah woodland associated with the Fly River Delta in southern Papua New Guinea (Paijmans 1976). There is evidence that large to medium-crowned forest in lowland localities is highly threatened, being subject to considerable anthropogenic pressure and extensive areas have been cleared for shifting cultivation and to develop commercial timber resources (Shearman *et al*. 2008). Based on clearing rates for commercially accessible forest calculated by Shearman *et al.* (2008) (1.41% between 1975 and 2002 increasing to 2.6% since 2002), large to medium crowned forest is predicted to have experienced > 50% reduction in habitat extent between 1975 and 2015, qualifying it as Endangered under IUCN criteria (see **Section 1.5.5**). However, the small area of this vegetation community within the study area is highly degraded and therefore does not have high biodiversity value. Consequently, the patch of large to medium crowned forest (VC1a) within the study area does not meet requirements for recognition as Critical Habitat. In summary, there are no habitats within the study area that qualify as Critical Habitat under IFC Performance Standard 6.

4.9 FSC Forest Type Assessment

The framework for assessment of habitat under the FSC National Forest Management Standard has been detailed in **Section 1.5.4**. This framework recognises two forest types of conservation significance, namely:

- High Conservation Value Forests; and
- natural forests.

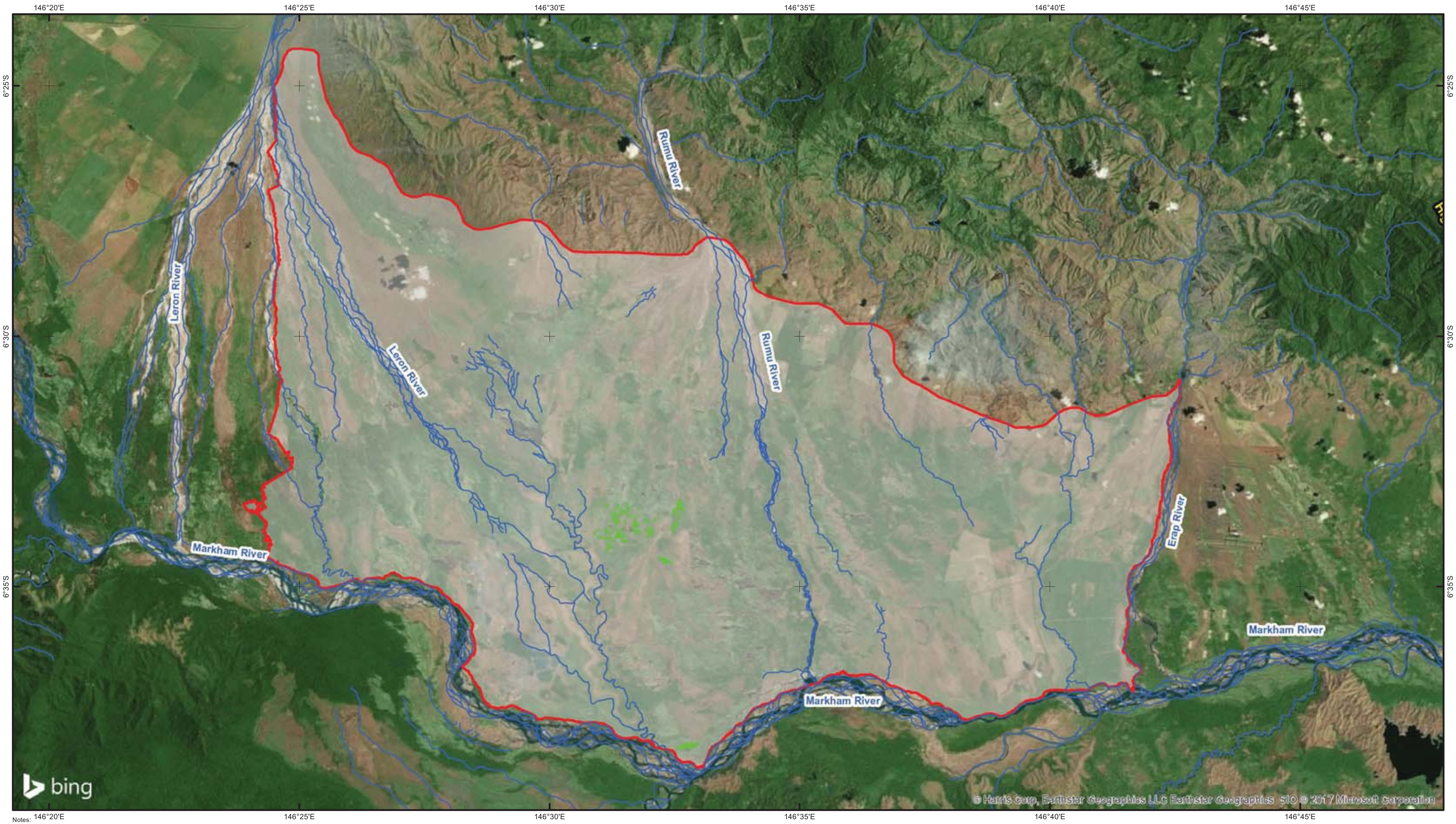
Two natural forest types occur within the study area, namely:

- large to medium crowned forest (VC1a); and
- small crowned forest / regrowth forest (VC2a).

Neither of these natural forest types qualifies as High Conservation Value Forest for the following reasons:

- no significant populations of endangered or endemic species occur within these forest types;
- neither is considered a threatened forest type of high biodiversity value due to the extent of habitat degradation experienced by these patches of forest, as discussed in more detail in **Section 4.8**;
- they do not provide any critical landscape function and contribute little to watershed protection or erosion control due to their landscape position i.e. on an alluvial plain close to the coast;
- the forests do not provide for > 50% of the basic needs of the local communities; food resources are largely obtained from cultivated garden areas, natural forests do not provide dietary staples, and timber resources are also obtained from a range of habitat types with no particular reliance on the very limited extent of natural forest areas within the study area; and
- there is no evidence that there is any particular cultural, ecological, economic or religious significance placed on these habitats by local communities.

Natural forests are fragmented and have limited coverage across the study area (see **Figure 4.5**). Total natural forest cover in the study area is 116 ha, which constitutes just 0.2% of the assessment area.



Notes:

Data Source: Image from ArcGIS Online Bing Maps data (c) 2010 Microsoft Corporation and its data suppliers.

Coordinate System: GCS GDA 1994
Datum: GDA 1994
Units: Degree

LEGEND

Watercourse

Study Boundary

FSC habitat classification

Not classified under FSC

Natural forest

Drawn By: MG   Reviewed by: AC   Date: 18-Jan-17

Figure: 4.5

Title: FSC habitat classification

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Other high conservation values within the study area are restricted to the occurrences of two conservation significant plant species (see **Section 4.6**). The study area does not support significant concentrations of biological diversity (see **Sections 4.5**, **4.6**, **5.3** and **5.6**), intact forest landscapes or other significant landscape-level ecosystems (see **Section 4.3**), or critical ecosystem services (see **Sections 4.10** and **5.7**).

4.10 Flora Resource Use

A total of 150 species of plants that are useful to local communities and other stakeholders were identified for the study area, making up 41% of the total flora recorded. **Appendix D** lists these species and includes details of plant life form, plant parts used, use categories, broad habitats and notes on abundance and distribution. These include:

- 34 species of food plants;
- 11 species that are used medicinally;
- 109 species that are used for a variety of material uses, including for timber;
- 6 species utilised for cultural purposes;
- 20 species that provide important habitat to culturally significant fauna; and
- 13 species that are used commercially.

Many species have multiple uses and occur across a number of habitats (see **Appendix D**). The dominant life forms of useful plants are trees and shrubs (85 species), with nine herbs, 20 vines, eight palms, 10 graminoids (two bamboo, eight grass) and two ferns. The highest numbers of plants were recorded from village gardens and disturbed areas, followed by secondary forests and degraded primary forests.

The most important species included material resources such as *Albizia procera* (Nginzib), Yellow Cheesewood (*Nauclea orientalis*, Ngempang), Galubia Palm (*Hydriastele costata*, Ompar) and *Ichnocarpus* sp. (Watag). *Albizia procera* is highly valued for house foundations and reported to be the best firewood available that was targeted during the cattle era for strainer posts which do not rot (K. Jim personal communication). The yellowish timber of Yellow Cheesewood is valued with high regard for furniture making and structural building purposes. The split outer trunk of the tall Galubia Palm, which has a restricted distribution in limited areas of lowland forest, is highly valued for flooring (where the material is called Ramid). The *Ichnocarpus* sp. vine is the most commonly used and highly valued rope used for house construction and all tying and binding purposes. Other highly valued timber species such as Taun (*Pometia pinnata*), Kwila (*Intsia bijuga*) and New Guinea Walnut (*Dracontomelon dao*, Mon) are very rare in the study area, although they are well known resources in the broader area. Reference by a senior elder to a number of timber trees that were not encountered in the study area indicates a knowledge base that extends outside the study area into surrounding landscapes where the timber species are likely to still occur more commonly.

The useful plants included 122 indigenous species and 28 introduced species (19% of the total). Exotic shrub and tree species introduced during cattle grazing enterprises, including Leucaena, Glyricidia and Senna are widespread throughout the landscape and are facilitating habitat transformation. These introduced resources are more readily available yet are considered by local informants as being of lower quality by comparison with indigenous species. The high numbers of useful plants within village and garden areas include many introduced species that are enriching or augmenting cultural traditions across a range of cultural and agricultural uses (Pfeiffer and Voeks 2008).

4.11 Ecosystem Services

Ecosystem services are the benefits provided to humans through the transformations of biological resources into a flow of essential goods and services such as clean air, water, food and materials (Costanza *et al*. 1997). Ecosystem services are characterised into the following four categories:

- provisioning services such as food, materials and clean water;
- regulating services such as flood and erosion control, and the regulation and stabilisation of climate;
- supporting services such as nutrient cycling, soil fertility and pollination; and
- cultural services such as spiritual, recreational and cultural benefits.

Local communities living within the study area are reliant on supporting services such as nutrient cycling, soil fertility and pollination to provide relatively fertile soils for growing food crops and cash crops. The rivers and clear-water streams running through the study area provide essential sources of water for drinking and washing. Native and introduced flora and fauna species provide supplementary sources of food and materials, as discussed in more detail in **Sections 4.10** and **5.7**. Vegetation in the study area contributes to regulating services that include flood control, erosion control and maintenance of water quality at the local scale. Due to the study area having limited forest cover, vegetation in the study area contributes little to the regulation of climate at a global scale.

4.12 INVASIVENESS ASSESSMENT

This section details the results of an assessment of the invasiveness of the plantation trees (three species and two hybrids) being trialled for the Project. An invasive species is an introduced species that spreads rapidly and often in large numbers without direct intervention by people, causing environmental or economic damage (Pyšek *et al*. 2004). The potential invasiveness of an introduced tree species is higher if it exhibits easy establishment, fast growth, good seed production and survival, efficient seed dispersal, an ability to germinate in a range of habitats, low shade tolerance, and it is not subject to herbivores or pathogens in its introduced environment (Booth 2012, Dodet and Collet 2012).

Tropical savannah habitats such as those found in the study area are susceptible to colonisation by invasive plantation trees because of high light availability and low species diversity (Dodet and Collet 2012). Two introduced woody species that have become invasive in the study area, *Albizia saman* and *Leucaena leucocephala* (see **Section 4.3.3**), provide a good example of successful invasion and naturalisation of alien species in savannah in the Markham Valley.

The ecological traits and biological attributes of the plantation tree species being trialled for the Project are summarised in **Table 4.5**.

Table 4.5 Ecological characteristics of *E. pellita*, *E. camaldulensis* and *A. crassicarpa*.

Ecological and biological attributes	*E. pellita*	*E. camaldulensis* subsp. *simulata*	*A. crassicarpa*
Distribution	In Papua New Guinea and the Indonesian province of Papua it occurs over a latitudinal range of between 7°30'–8°35’ S (Doran and Turnball 1997) north from the Muting area of Papua Province and 60 km northwest of Morehead in Western Province (Gunn *et al.,* 1992). In Queensland, Australia it extends from the Mcilwraith Range on Cape York Peninsula to Ingham north of Townsville over a latitudinal range from 12°45'–18°40' S (Doran and Turnbull 1997) and in disjunct populations. Also recorded from southern Queensland (Boland *et al.,* 1984, Chippendale 1988).	*E. camaldulensis* has a wide distribution in Australia, but *E. camaldulensis* subspecies *simulata* has a limited distribution, occurring in the Normanby – Laura – Mitchell River catchment areas on Cape York Peninsula in Queensland (Butcher *et al*. 2002).	Oriomo Plateau, Western Province, Papua New Guinea; Merauke Ridge, Indonesian Papua (Skelton, 1987); and in Australia from north east coast of Cape York Peninsula and along the east coast and coastal hinterland south to Townsville and Mackay (Turnbull 1986, Atlas of Living Australia 2016).

Ecological and biological attributes	*E. pellita*	*E. camaldulensis* subsp. *simulata*	*A. crassicarpa*
Climatic zone	In Papua New Guinea found in dry seasonal open forest or savannah-like vegetation on alluvial plains, hills and plateaus (Lamb *et al.* 1993). Mean annual rainfall 1,500-2,100 mm, January to May (Skelton 1987).	Seasonally dry zones, with mean annual rainfall of 900-1,000 mm (BoM 2016).	In Papua New Guinea it is found in dry seasonal open forest or savannah-like vegetation on alluvial plains, hills and plateaus (Skelton 1987; Lamb *et al.* 1993). Mean annual rainfall 1,500-2,100 mm, January to May (Skelton 1987). In tropical Queensland it occurs in coastal or sub coastal open forest and woodlands and littoral forests in sandy or rocky soils (Maslin 2001).
Sexual maturity	4-5 years for *E. globulus* (Calviño-Cancela and Rubido-Bará, 2013); no data for *E. pellita*.		Becomes reproductively active at 4-5 years of age (CAB International 2000).
Seed production	Good	Good	Good
Seed viability	Short term	Relatively short term	Long term in seed bank (Booth 2012)
Seed dispersal	Short distance, related to tree height and wind velocity (Booth 2012).	Short distance, related to tree height and wind velocity (Booth 2012).	Can be moved over longer distance, particularly by herbivores.
Seed germination	Requires bare earth and cannot establish in a grass sward or on organic mulch layers (Booth 2012).	Requires bare earth and cannot establish in a grass sward or on organic mulch layers (Booth 2012).	Can germinate and become established in grassland.
Shade tolerance	Intolerant	Intolerant	Intolerant
Cultivation	China, Indonesia, Australia, Brazil, Sabah, South Africa.	For *E. camaldulensis*: Australia, southern Africa, USA, SE Asia, China, Europe.	Trialled in Australia, SE Asia and China.
Invasiveness status	There are no records of it becoming invasive.	Has been recorded as an invasive species in South Africa (Forsyth *et al*. 2004) and USA (Gordon *et al.* 2011), particularly along rivers and riparian zones, and in South America (Booth 2012).	Invasive (Miller *et al.* 2011). Noted as a vigorous coloniser of degraded soils following slash-and-burn cultivation in Papua New Guinea (CAB International 2000). Also reported as invasive on other Pacific islands (Space *et al*. 2003).
Allelopathy	Yes, many *Eucalyptus* spp. have been shown to be allelopathic (Zhang and Fu 2009).	Yes (Ahmed *et al.* 2008).	Yes, *Acacia* spp. in general are allelopathic
Coppicing	Yes	Yes	No
Fire resistance	Good (Booth 2012)	Good (Booth 2012)	Probable

Using the information summarised in **Table 4.5**, the potential invasiveness of *Eucalyptus pellita*, *E. camaldulensis* and *Acacia crassicarpa* was assessed qualitatively (see **Appendix E** for details) using the weed risk assessment (WRA) model developed by Pheloung *et al*. (1999) and in accordance with guidelines and scoring system provided by Gordon *et al.* (2010) to develop a summary score of potential invasiveness for each species (**Table 4.6**). The two *Eucalyptus* hybrids (*E. pellita* x *E. tereticornis* and *E. pellita* x *E. camaldulensis*) are unlikely to produce viable seed when mature and are therefore unlikely to become invasive.

Table 4.6 Summary of Weed Risk Assessment (WRA) scores measuring potential invasiveness of *E. pellita, E. camaldulensis* and *A. crassicarpa*.

E. pellita	*E. camaldulensis*	*A. crassicarpa*
0	8	15

Based on the WRA, *E. pellita* has a low risk of becoming invasive, *E. camaldulensis* has a high risk of becoming invasive and should be evaluated further or controls should be implemented to mitigate the risk of it becoming invasive, and *A. crassicarpa* has a very high risk of becoming invasive. Although no weed risk assessment was carried out for the *E. pellita* x *E. tereticornis* and *E. pellita* x *E. camaldulensis* hybrids, there is little likelihood that the hybrids will become invasive. The higher score of eight for *E. camaldulensis* compared with zero for *E. pellita* is attributed to reports that this species has become invasive in South Africa (Forsyth *et al*. 2004) and USA (Gordon *et al.* 2011) and which had a heavy weighting in the scoring for the risk assessment. *E. camaldulensis* has the potential to become invasive if planted along streams within the Project area.

Generally, *Eucalyptus* species are not considered to be highly invasive (Booth 2012) as seed dispersal is restricted (Booth 2012, Larcombe *et al.* 2013). The apparent reason that *E. camaldulensis* has become a problem in southern Africa is its long history of introduction there, the species being planted widely on farms as well as in forestry trials (Richardson and Rejmánek 2011, Booth 2012). Furthermore this species seeds are dispersed down watercourses by running water, allowing it to establish on silt banks after flooding (Forsyth *et al*. 2004, Booth 2012).

While the Project intends to grow most plantation trees for biomass for the power plant, timber that is excess to power plant needs is likely to be ‘grown on’ to provide other products such as sawlogs. Consequently sawlog trees are expected to grow to sexual maturity and produce seeds that are capable of being dispersed. Furthermore, it is likely that local villagers will have access to, and establish plantation trees in their communities, providing an alternative pathway for naturalisation of plantation tree species.

It is relatively straight-forward to eradicate eucalypts as weeds through the removal of mature trees that have escaped, followed up by the removal of germinating seedlings before sexual maturity is reached (Booth 2012). However, weedy *Acacia* species are difficult to control as their seeds persist in the soil and keep germinating for many years (Booth 2012).

4.13 Forest Pathogens Assessment

The plantation tree species proposed to be used for the Project, *Eucalyptus pellita* and hybrids with *E. camaldulensis* and *E. tereticornis* are susceptible to a variety of pathogens that may attack the foliage, stems or roots of the plants. These potential pathogens are listed in **Table 4.7** under the three headings: foliage pathogens; stem cankers; and root rots. Information on these pathogens has been sourced largely from Ciesla *et al*. (1996) and Old *et al*. (2003), supplemented by other sources where relevant.

Table 4.7 Diseases and associated pathogens likely to occur in plantations of *Eucalyptus pellita* and its hybrids in the Project area.

Disease / Pathogens	Notes
Foliage pathogens	
Black Mildew: *Meliola amphitricha, M. densa* and *M. eucalypti*	Already present in Papua New Guinea, this pathogen may be common on foliage but does not cause serious damage, with little impact. Control measures not necessary.
Cryptosporiopsis leaf and shoot blight: *Cryptosporiopsis eucalypti*	Already present in Papua New Guinea, this pathogen is recorded only on *Eucalyptus* spp. It is easily confused with other leaf spot pathogens. May cause total defoliation of terminal shoots of young trees. Only feasible management option is selection of disease-resistant varieties.
Cylindrocladium foliar blight: *Cylindrocladium* spp.	Already present in Papua New Guinea, these are widespread and damaging pathogens of a very wide range of plant hosts including eucalypts. *E. pellita* is resistant to *C. reteaudii* (syn. *C. quinqueseptatum*) leaf blight in northern Queensland. Symptoms include the development of greyish water-soaked spots on young leaves which coalesce and develop into extensive necrotic areas. Particularly severe under conditions of high humidity and frequent rainfall and may result in death of trees. Only feasible management option is selection of disease-resistant species and varieties.
Mycosphaerella leaf diseases: *Mycosphaerella* spp. (over 30 species have been recognised on eucalypts.) Anamorphs (sexual stage) include *Phaeophleospora* spp. and *Pseudocercospora* spp.	Probably present in Papua New Guinea. Infected leaves develop spots and blotches, leaves crinkling in highly susceptible varieties. Can be severe under conditions of high rainfall and frequent rainfall. Affected trees suffer premature defoliation and may result in stunting. Only feasible management option is selection of disease-resistant species, varieties and hybrids.
Myrtle Rust or Eucalyptus rust: *Puccinia psidii*	Has not yet been recorded in Papua New Guinea. Infected leaves develop spots. *E. pellita* and *E. tereticornis* are relatively tolerant but not immune; *E. camaldulensis* subsp. *simulata* is less tolerant to infection (Zauza *et al.* 2010, Giblin 2013).
Stem Cankers	
Cryphonectria cankers: *Cryphonectria cubensis, C. gyrosa, C. eucalypti, Endothiella* sp (anamorph)	Widespread and important pathogens of eucalypts in the tropics. *Endothiella* and its teleomorph *C. cubensis* have been observed on cankers of *Terminalia brassii* grown in plantations near Lae (Arentz and Simpson 1988). Symptoms include basal cankers which, in severe cases can extend up the stem and trees can die if stems are girdled. However, *C. gyrosa* is a secondary pathogen of stressed trees (e.g. defoliated by *Cylindrocladium*), forming elongate stripe cankers which persist without killing the tree. Control is through selection of disease-resistant species, varieties and hybrids.
Pink Disease: *Erythricium salmonicolor* (syn. *Corticium salmonicolor*)	Common tropical pathogen with a wide host range including *E. tereticornis, E. camaldulensis* and *E. grandis* x *E. urophylla* hybrids as well as a wide range of horticultural tree crops. In Papua New Guinea, it is particularly a problem in high rainfall areas. Symptoms include crown dieback and stem breakage, with disease more prevalent within the stands rather than at edges. Not much can be done to prevent disease development in forest plantations and control has been through selection of resistant species, clones and varieties.
Stem and branch cankers: *Botryosphaeria* spp., *Valsa* spp. (anamorph *Cytospora* spp.)	Already present in Papua New Guinea, these cankers are a minor problem for trees planted on infertile soils or other unsuitable environments. May cause some crown dieback, especially on suppressed trees. Control is through matching species and provenance to climate and edaphic factors and avoiding stress through good silviculture practice.
Bacterial Wilt: *Ralstonia solanacearum*	A soil-borne organism with a pan-tropical distribution that has been recorded on agricultural crops in Papua New Guinea as *Pseudomonas solanacearum* (Shaw 1984). Wide host range, including *E. camaldulensis* and *E. pellita*. Trees affected shortly after planting, with scattered trees showing wilting, leaf drop, stem death and reduced growth rates. Eucalypt susceptibility to bacterial wilt is variable; with *E. pellita* and *E. urophylla* often susceptible. There is probably clonal variation to susceptibility but no control measures have been recommended.

Disease / Pathogens	Notes
Root and Stem Rots	
Woody root and stem rots: *Phellinus noxius, Rigidoporus* spp. and *Ganoderma* spp. (In Papua New Guinea *G. mastosporum, G. lauterbachii, G. lucidum, G. weberianum. G. australe* has been recorded as causing heart rot of living trees (Arentz and Simpson 1988)).	Wide host range including eucalypts and *Acacia* grown in forestry plantations. In Papua New Guinea, *Ganoderma* root rots have largely been a problem for *Acacia* plantations established on cleared rainforest sites in the lowlands (Arentz and Simpson 1988). Root rots caused by *P. noxius* and *Ganoderma* spp. were recorded in South Sumatra in *E. pellita* plantations grown on cleared *Acacia* plantations which had had a high incidence of root rot (Agustini *et al*. 2014). However, artificial inoculation *of E. pellita* roots with *G. philippii* indicated a high degree of resistance to infection (Gill *et al.* 2016). Infection of plantation trees is generally a result of the spread of inoculum from stumps and woody root masses left after clearing of the original forest cover. This should not be an issue for the Project, since plantations will be established on open grasslands. There is a possibility that root or butt rots may develop on eucalypt stumps after several coppicing cycles.
Phytophthora root rot: *Phytophthora* spp. incl. *P. cinnamomi, P. cryptogea* and *P. palmivora* (Arentz 1986).	*P. cinnamomi* is a major pathogen of eucalypt forests in Australia. However, this species does not occur in the Papua New Guinea lowlands (Arentz 2012) and is therefore unlikely to be a problem in the Project area. Furthermore, *E. pellita* and its hybrids are resistant to Phytophthora root rot.

Based on work in a number of lowland forest nurseries in Papua New Guinea (Arentz 1991), there are a number of pathogens that afflict seedlings and are likely to occur in the Project nursery; these pathogens are detailed in **Table 4.8**. Damping-off caused by *Rhizoctonia solani* is likely to be the most significant disease (Arentz 1991). A further pathogen that has yet to be recorded in Papua New Guinea but is likely to appear in the near future is Myrtle Rust, which is therefore also included in **Table 4.8**.

Table 4.8 Nursery disease pathogens and their control.

Disease and pathogens	Notes	Control
Pre- and post-emergent damping-off caused by *Rhizoctonia solani, Cylindrocladium* spp. (*C. scoparium, C. parvum* and *C. ilicola*), *Pythium* spp., *Fusarium* spp.	*Rhizoctonia* damping-off will be the most common disease problem in the Project forest nurseries. Seedlings are most susceptible when newly germinated and for the first two-three weeks of growth after which they become largely resistant to damping-off. The leaves and stems of affected seedlings will appear to be covered with a network of web-like hyphae, shortly followed by the collapse of the seedlings (Arentz 1991). The pathogen is soil-borne and is favoured by high humidity and temperatures. The absence of hyphae over the surface of collapsed seedlings may indicate that other damping-off pathogens may be responsible.	Soil sterilisation; spot treatment of affected seedlings with Azoxystrobin fungicide applied as a foliar spray (Kiewnick *et al*. 2001); other recommended treatments include combinations of captan, carbendazim, copperoxychloride and quintozene (Terraclor®) (Old *et al*. 2003). Alternatively cull affected seedlings to prevent spread of pathogens. *Rhizoctonia* may continue to be problem in older seedlings growing in stand-out beds. Although spot treatment with fungicides can be effective, it may be more effective to cull diseased seedlings.
Leaf spots and blights; pathogens include *Colletotrichum gloeosporioides, Cylindrocladium reteaudii* (syn. *C. quinqueseptatum*).	Development of spots on leaves; significant defoliation of tubed seedling stock may occur (Arentz 1991).	*Cylindrocladium* infections in nurseries can be readily controlled using carbendazim fungicide as a foliar spray or soil drench (Old *et al*. 2003).
Powdery Mildew *Oidium* spp. (asexual stage of *Erysiphe* and *Sphaerotheca*)	The pathogen attacks leaves and young shoots of *Eucalyptus*, producing a thick layer of densely inter-woven white mycelium on the surface of leaves and shoots sometimes causing spotting and	Chemical treatments are seldom necessary although fungicides such as benomyl, chlorothalonil, triademefon, maneb or zineb have been used as foliar sprays

Disease and pathogens	Notes	Control
	malformation of older growth. There are no reports of it being a significant problem in forestry nurseries in Papua New Guinea.	(Old *et al*. 2003).
Myrtle Rust: *Puccinia psidii*	Myrtle Rust, which attacks young, soft, actively-growing leaves, shoot tips and young stems, has not yet been recorded in Papua New Guinea. The first signs of rust infection are tiny spots or pustules which can appear 2-4 days after infection. Symptoms can vary depending on the host species, susceptibility level within a host species, and age of the host leaf. After a few days, the pustules erupt with the production of distinctive, yellow spores. The infected area spreads radially outwards and multiple pustules eventually merge and coalesce with age. Secondary infections can occur within days but are usually confined to new young tissue, shoots and expanding foliage. Left untreated, the disease can cause deformed leaves, heavy defoliation of branches, dieback, stunted growth and even plant death. *E. pellita* is largely resistant to myrtle rust but is not immune (Giblin 2013).	*Eucalyptus* seedlings 0 to 2 years old are highly susceptible to myrtle rust (*Puccinia psidii*) (Coutinho *et al*. 1998). A range of fungicides are available for use in the nursery. These include triadimenol (250g/L active ingredients (ai)), triforine (190g/L ai), mancozeb (750-800 g/kg ai), azoxystrobin (250 g/L ai), copper oxychloride (500 g/kg ai) and propiconazole (250g/kg ai) (Giblin 2013). Other management measures are discussed below.
Nematodes	Stunting and chlorosis of seedlings (Arentz 1991),	Sterilisation of tubing soil.
Phytophthora root rot: *Phytophthora* spp., particularly *P. cinnamomi*	Stunting, chlorosis and sudden collapse of seedlings.	Root rots associated with *P. cinnamomi* are highly unlikely in the Project nurseries as this species of *Phytophthora* does not occur in the lowlands of Papua New Guinea (Arentz 2012). Other *Phytophthora* spp. found in the lowlands of Papua New Guinea are not known to be pathogenic on *Eucalyptus* spp.

The most effective control of pathogens in the nursery is prevention. This can be achieved through the elimination of pathogens by heat sterilisation of soil and by preventing the reintroduction of pathogens through the use of pathogen-free water, ensuring equipment and benches are pathogen free, and implementing nursery hygiene protocols. Sterilisation of soil to be used for seed trays using heat is possible although care must be taken to prevent over-heating as this may change the chemical properties of the soil resulting in toxicity issues (Arentz 1991). A better option therefore is to sterilise soil using steam.

Given the large number of seedlings to be raised for the Project, it may not be practicable to steam sterilise soil to be used for the tubing of seedlings. Consequently, tubing soil should be sourced from sites that have been shown to be free of any significant pathogens.

Despite all precautions, damping-off may still occur, often as a result of splash dispersal of inoculum during heavy rain or through the re-introduction of the pathogen(s) from unclean working surfaces, tools or water used for irrigation. This may require spot treatment of affected seedlings with fungicides (**Table 4.8**). Raising tubed stock in racks about 1 m above the ground will reduce the chance of recontamination (Old *et al*. 2003).

Most of the pathogens listed in **Table 4.7** and **Table 4.8** are already present in Papua New Guinea and are probably widespread in the natural vegetation. Therefore, they are unlikely to pose a new threat to the native vegetation growing in the vicinity of the Project. The majority of the disease management recommendations relate to the selection of resistant tree species, clones or varieties, since little can be done to control disease outbreaks in plantations.

The most significant exception is Myrtle Rust, caused by *Puccinia psidii*, a major pathogen of plants in the Myrtaceae family that has not yet been detected in Papua New Guinea. This pathogen, first recorded in Australia in 2010 (Carnegie *et al*. 2010), has subsequently been recorded in China, Japan and New Caledonia (Giblin 2013).

Twenty seven genera of Myrtaceae occur in Papua New Guinea (Johns 1976), a significant number of which are potentially susceptible to Myrtle Rust (**Table 4.9**).

Table 4.9 Genera of Myrtaceae present in Papua New Guinea (Johns 1976) and their susceptibility to Myrtle Rust (Zauza *et al*. 2010, Pegg *et al.* 2014).

Genus	Habit and distribution	Susceptibility to Myrtle Rust
Syzygium	*S. australe*, a common species in lower montane forests; *S. buettnerianum*, common throughout lowland rainforests in New Guinea and Solomon Islands.	*S. australe* – moderately susceptible; other spp. relatively tolerant (Pegg *et al*. 2014).
Acmena;	Occurs in lowland rainforests, often associated with *Castanopsis*, *Lithocarpus* and *Elmerillia*.	Tolerant (Pegg *et al*. 2014).
Eucalyptus	*E. deglupta*, mainly found naturally on New Britain; small natural stands occur in Oro, Milne Bay and Central Provinces. This species has been planted extensively in New Britain, Madang and Morobe Provinces. Other native species include *E. papuana, E. brassiana, E. tereticornis* and *E. pellita.*	*E. deglupta* – susceptible; *E. pellita, E. tereticornis,* and *E. brassiana* – resistant (Zauza *et al.* 2010).
Eucalyptopsis	*E. papuana*; dominant in stands of lower montane rainforest on Upper Fly and Sepik Rivers and on ridges in the Kui-Buso- Lasanga region, Morobe Province.	Not tested.
Tristania	*T. suveolens*, in dry forests in Western Province; *T. longivalis; T. ferrunginea.*	Moderately susceptible (Pegg *et al*. 2014).
Melaleuca	*M. leucadendra*, in almost pure stands on seasonally wet flats in Central and Western Provinces; other species include *M. cajuputi* subsp. *platyphylla* and *M.* quinquenervia (Zauza *et al*. 2010).	All three species listed have been shown to be highly susceptible (Zauza *et al*. 2010).
Metrosideros	*M. petiolate*, common on dry ridges.	Tolerant (Pegg *et al*. 2014)
Shrubs or trees occurring largely in mid-montane forests, thus remote from the Project site.	*Basisperma, Kania, Leptospermum, Fenzlia, Kjellbergiodendron, Osbornia, Octamyrtus, Mearnsia, Syncarpia, Backhousia, Myrtella, Psidium* (introduced guava)*, Myrtus, Aphanomyrtus, Cleistocalyx, Eugenia, Decaspermum, Rhodamnia, Xanthomyrtus, Rhodomyrtus, Xanthostemon, Agonis, Baeckea.*	Variable, but majority of these genera are moderately to highly susceptible (Pegg *et al*. 2014).

Although a species or genus may have been found to be resistant or relatively tolerant to myrtle rust, infection of leaves can still occur, albeit at very low levels (Pegg *et al.* 2014). Thus most species of Myrtaceae will be a host for the pathogen, including resistant species such as *E. pellita, E. camaldulensis* and *E. tereticornis*, thus providing a source of inoculum that can be carried into surrounding vegetation.

While Myrtle Rust has not yet been detected in Papua New Guinea, there is a high probability that it will enter the country. There is a precedent with the introduction of Poplar Rust (*Melampsora* spp.) to Papua New Guinea in the mid-1970s, probably from Australia (Heather and Sharma 1977), which spread quickly throughout the Highlands where poplars were grown (Arentz and Simpson, unpubl. data). When Myrtle Rust does arrive in Papua New Guinea, it is likely to spread as quickly as it has done in Australia. In the study area it is likely to become established initially on exotic guava found in disturbed areas around villages, gardens and access tracks. The pathogen cannot be eradicated as rust spores are naturally wind- and animal-borne. Long-distance spread of Myrtle Rust in Australia was most probably facilitated by human movement of infected plant material (Makison 2014).

The most likely entry point for Myrtle Rust to the Markham Valley is Nadzab airport, only a short distance from the Project plantations. Thus, it is likely to be only a matter of time before the pathogen arrives on-site. Only once Myrtle Rust is confirmed to occur in Papua New Guinea will special management measures in the plantation nurseries be required.

Following the introduction of Myrtle Rust to New Caledonia, Giblin (2013) recommended a series of management strategies to limit the spread and impact of the pathogen. These strategies are also appropriate for the Project and consist of the following:

- Provide Myrtle Rust training and education so that the community can become involved in providing feedback on the impact of the rust within their community.
- Introduce hygiene measures, including:
  - reducing direct vehicle movement from plantations to natural forest habitats including riparian buffer zones and in remnant forest stands
  - limiting the movement of people from known infected areas into natural forests and into the nurseries;
  - cleaning equipment, clothing, gloves and footwear after returning from infected sites;
  - do not remove myrtaceous plants from natural forests; and
  - ensuring clothing, vehicles, equipment and machinery is clean and free of plant debris before starting work in new areas.
- If Myrtle Rust does become established in the nursery, there is a range of fungicides (see **Table 4.8**) that can be used as a preventative or curative measure. Giblin (2013) does stress that fungicides should be rotated to maintain their usefulness. The use of fungicides to treat rust infections in hedges used to provide clonal cutting material is particularly important, particularly as young foliage is more susceptible to infection than mature leaves. Fungicide application is not appropriate for mature trees or bushland.
- Remove and dispose of seriously infected plants.

Should Myrtle Rust become introduced to Papua New Guinea, it may be appropriate to survey the Project area for the presence of Myrtle Rust prior to the establishment of the Project nurseries as this will inform the steps that should be taken to manage this pathogen.

5.0 TERRESTRIAL FAUNA RESULTS AND DISCUSSION

5.1 OVERVIEW OF PAPUA NEW GUINEA'S TERRESTRIAL VERTEBRATE FAUNA

New Guinea is the world's largest tropical island. Vegetated mostly with rainforest, it supports the third largest expanse of tropical forest after the rainforests of the Amazon and Congo (Brooks *et al.* 2006). Its tropical location coupled with the island's diverse topography, with elevations ranging from sea level to over 5,000m, diverse habitat types and complex geological history have resulted in an extraordinarily rich biodiversity; while it occupies less than 1% of the global land area, between 5% and 7% of the world's biodiversity is found on the island (UNEP 2010).

The mammal fauna of Papua New Guinea includes at least 245 recognised species, nearly 40% of which are bats (IUCN 2015). The New Guinea mammal fauna has affinities with that of Australia due to a period of contact between the two land masses that ended in the early Miocene about 25 million years ago, and includes groups such as the monotremes (represented by echidnas in the family Tachyglossidae), eight families of marsupials, rodents and six families of bats (Flannery 1995). The bats are divided into two main groups, the family Pteropodidae that live on a diet of fruit, nectar and flowers and have well developed eyes to find their way around at night using vision, and several families of bats (generally termed micro-bats) that are primarily insectivorous and use sophisticated echo-location to find their way around and forage.

A total of 744 bird species are known to occur in Papua New Guinea, of which 113 are endemic to Papua New Guinea and 43 species are globally threatened (BirdLife International 2016a). BirdLife International considers the most important places for habitat-based conservation of birds to be Endemic Bird Areas (EBAs), which are regions of the world where the distributions of two or more restricted-range species (species that occupy ranges smaller than 50,000 km^2) overlap (BirdLife International 2016a). The study area does not fall within the range of any EBA, meaning that the local region is not located within a priority area for the habitat-based conservation of birds.

The herpetofauna (reptiles and amphibians) of the Papuan region, which comprises New Guinea, the Admiralty and Bismarck Archipelagos and the Solomon Islands, is considered to be extremely diverse but remains relatively poorly surveyed and described, with the geographic ranges of known species often poorly understood and hundreds of species likely still to be discovered or formally named (Allison 1993, Kraus 2010). In 2011, the herpetofauna of the Papuan region comprised 424 reptile species (266 lizard, 138 snake, 18 turtle and two crocodile species) and 408 frog species (Allison and Kraus 2011), but these totals have since expanded with increasing taxonomic work and field survey. For example, recent expeditions to previously unstudied localities have described many new species of frogs (e.g. Günther and Richards 2011, Günther *et al.* 2012, Kraus 2013a,b).

The desktop assessment identified a total of 392 terrestrial vertebrate fauna species with potential to occur in the study area should suitable habitat occur, including 253 bird species, 75 mammal species, 36 reptile species and 28 amphibian (frog) species (**Appendix F**).

5.2 SURVEY COVERAGE OF THE STUDY AREA

5.2.1 Previous surveys

One previous survey of the study area, a rapid environmental and socio-economic assessment undertaken over one week (10 to 16 October 2012), recorded 12 bird species and four mammal species (ECO Care Engineering Limited 2013). The mammal species that were recorded included two bat species, namely the Common Tube-nosed Fruit Bat (*Nyctimene albiventer*) and Variable Flying-fox (*Pteropus hypomelanus*), one bandicoot species (*Echymipera kaluba*) and one rat species (*Melomys lutillus*).

5.2.2 2016 survey

The survey coverage of the study area during the 2016 is shown in **Figure 5.1**, including the locations of survey tracks and trapping sites.

5.3 SURVEY RESULTS

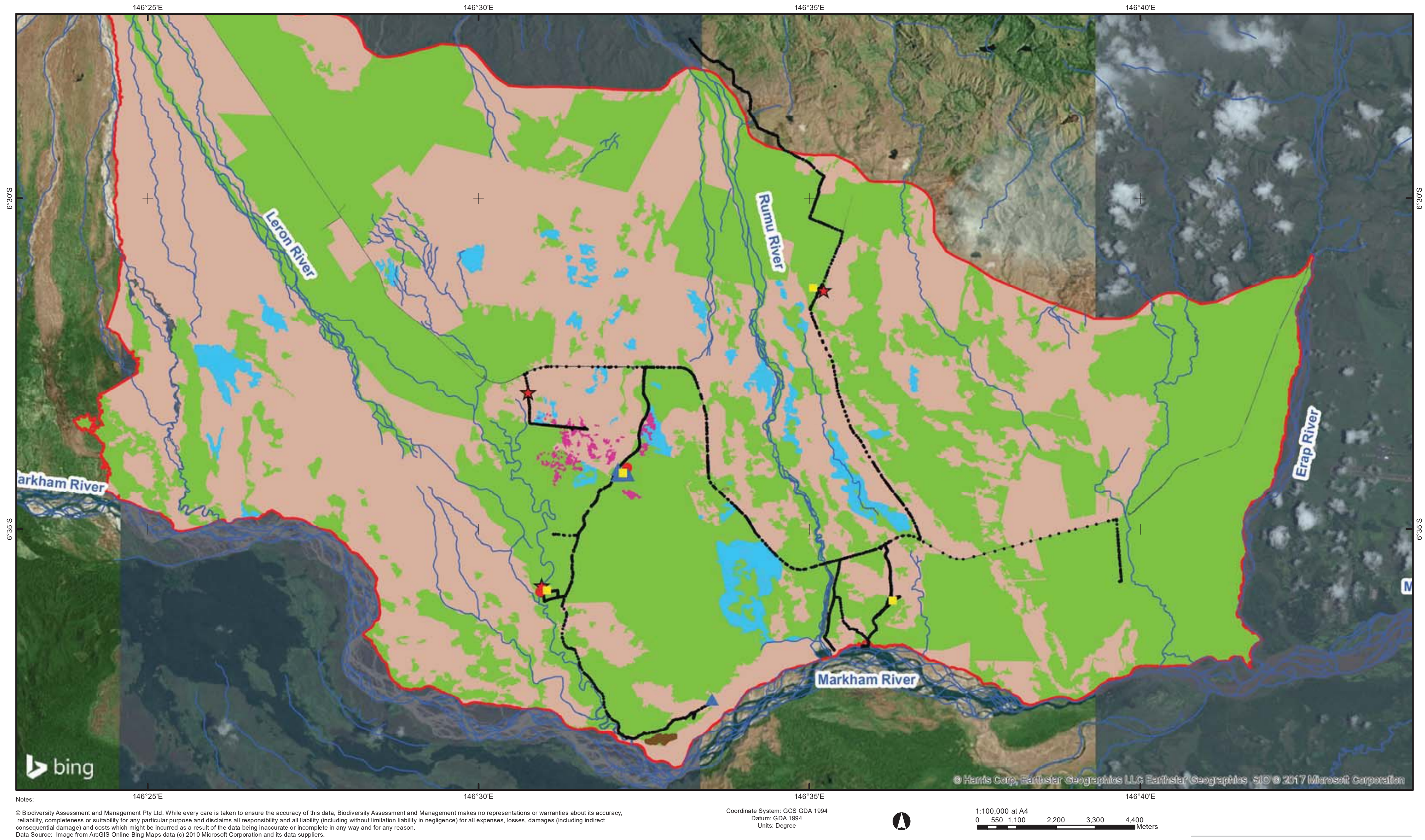
The field survey recorded a total of 89 terrestrial vertebrate fauna species, including 68 bird species, eight mammal species, two reptile species and two frog species (**Appendix G**). Discussions with reliable local informants identified at least a further 10 mammal species, eight bird species and five reptile species that are likely to occur in the study area (**Appendix G**). The Anabat detectors identified the presence of eight microbat species (**Appendix H**). No small mammals were trapped during the trapping survey; the only species captured by the traps were two introduced fauna pest species: Giant African Snail (*Achatina fulica*); and Cane Toad (*Bufo marinus*, **Photo 5.1**). The remote cameras photographed New Guinea Scrubfowl (*Megapodius decollatus*, **Photo 5.2**) at two locations, and nest mounds of this species (**Photo 5.3**) were detected at a number of locations (**Appendix G**, **Figure 5.1**). There was surprisingly little reptile activity, and few reptile species were detected in the study area. As nocturnal surveys were not feasible, only two frog species were detected despite good rainfall falling during the survey period.

Photo 5.1 Cane Toad, an introduced pest, was common throughout the study area.

Photo 5.2 New Guinea Scrubfowl photographed by remote camera.

Photo 5.3 Large New Guinea Scrubfowl nest mound in a forest patch disturbed by gardening.

Photo 5.4 View over the central portion of the study area, showing generally modified habitats.



Notes:

Data Source: Image from ArcGIS Online Bing Maps data (c) 2010 Microsoft Corporation and its data suppliers.

LEGEND

- Anabat
- Camera
- Scrubfowl nest mound
- Trapping site
- survey track
- Watercourse
- Study Boundary

Vegetation Communities

- **G** - Grassland
- **O** - Other non-vegetation and areas dominated by land use
- **PL** - Large to medium crowned forest
- **PS** - Small crowned forest / regrowth forest
- **SA** - Savannah

Figure: 5.1

Title: Location of fauna survey sites and tracks

Project: PNG BIOMASS MARKHAM VALLEY TERRESTRIAL ECOLOGY ASSESSMENT

Client: ERIAS Group Pty Ltd

BAAM ECOLOGICAL CONSULTANTS

Drawn By: MG Reviewed by: AC Date: 17-Jan-17

Document Location: C:\Users\Owner\Documents\Clients\3D Environmental\PNG\BAAM_PNG\BAAM_A3_Landscape_PNG_17117.mxdDate: 17-Jan-17 5:59:09 PM

Most bird species recorded in the study area are species associated with forest or woodland habitats that are also tolerant of forest fragmentation and disturbance. Bird species that were most frequently encountered across the study area included New Guinea Friarbird (*Philemon novaeguineae*), Hooded Butcherbird (*Cracticus cassicus*), Yellow-faced Mynah (*Mino dumontii*), Red-cheeked Parrot (*Geoffroyus geoffroyi*), Eclectus Parrot (*Eclectus roratus*), Coconut Lorikeet (*Trichoglossus haematodus*), Black Kite (*Milvus migrans*) and Torresian Crow (*Corvus orru*). A large number of lowland forest species that are known to occur commonly in intact lowland forests on the southern side of the Markham River were notably absent from the study area, including common forest interior species such as Stephan's Emerald Dove (*Chalcophaps stephani*), Buff-faced Pygmy-Parrot (*Micropsitta pusio*), Tawny-breasted Honeyeater (*Xanthotis flaviventer*), Black-sided Robin (*Poecilodryas hypoleuca*), Raggiana Bird-of-paradise (*Paradisaea raggiana*), King Bird-of-paradise (*Cicinnurus regius*), Boyer's Cuckooshrike (*Coracina boyeri*), Brown-headed Jewel-babbler (*Ptilorrhoa geislerorum*), Grey Whistler (*Pachycephala simplex*) and several species of monarch. Consequently, the forest bird species community was substantially less diverse and abundant than that typical of intact lowland rainforest (Bell 1982a,b 1983). Small birds that feed on insects were notably sparse in the regrowth forest habitats in the study area, a feature that appears to be typical of lowland secondary forests in PNG (Bell 1982c).

5.4 FAUNA HABITATS

Four main terrestrial fauna habitat types were characterised within the study area: (1) alluvial forest and woodland; (2) grassland; (3) watercourses and wetlands; and (4) highly disturbed anthropogenic habitats. These broad habitat types and their characteristic terrestrial fauna assemblages are described in more detail in the sections below.

5.4.1 Alluvial forest and woodland

Patches of disturbed and degraded alluvial forest occur across the southern half of the study area, and include a small patch of large to medium crowned forest near the Markham River, scattered small patches of small crowned forest and secondary forests dominated by Sago Palm, and more extensive areas of mixed regrowth forests and shrublands dominated by exotic species, particularly the invasive Raintree. Detailed descriptions of these habitat types are provided in **Sections 4.3.1**, **4.3.2**, **4.3.5** and **4.3.6**. Despite the highly fragmented and degraded condition of these forest patches in the study area, they still supported a reasonably diverse bird community, including species associated with rainforest habitats such as a variety of fruit-eating doves and pigeons, and several species of parrot. Small patches of savannah woodland in the central portion of the study area (see **Section 4.3.3** for a detailed description) had a similar structure to fragmented alluvial forest and therefore supported a similar bird community.

5.4.2 Grassland

Extensive areas of native grassland occur particularly on the hill-slopes of the northern half of the study area, extending onto the alluvial plain in scattered areas throughout the rest of the study area, often forming a complex mosaic with fragmented forest and woodland. As described in more detail in **Section 4.3.4**, these native grasslands have developed as a consequence of a long history of human use of fire for clearing and hunting. Native grasslands are generally dominated by the native grass *Imperata cylindrica* (Kunai), and are typically referred to as kunai grassland.

By comparison with adjoining forests and wetland habitats, grassland supports a relatively species poor but distinct vertebrate fauna. Mammals associated with this habitat include a number of rodent species, particularly Grassland Melomys (*Melomys lutillus*). The bird community is a little more diverse, including species such as Eastern Barn Owl (*Tyto delicatula*), Pheasant Coucal (*Centropus phasianinus*), Horsfield's Bushlark (*Mirafra javanica*) and Golden-headed Cisticola (*Cisticola exilis*).

5.4.3 Watercourses and wetlands

The study area is dissected by three moderate-sized rivers and bounded in the south by the floodplain of the large and generally turbid Markham River. All these rivers are relatively high energy, and expose extensive areas of shingle, sand and mud sediments when not in flood. A number of smaller, clear-water streams also occur across the study area. Heavy rainfall also results in seasonally swampy areas in particularly flat portions of the local landscape. Waterbirds are more prominent on the larger rivers, including four species of egret and heron, and the migratory Common Sandpiper (*Actitis hypoleucos*) that frequent areas of exposed sediments along the river's edge, as well as Pacific Black Duck (*Anas superciliosa*) and Little Black Cormorant (*Phalacrocorax sulcirostris*) on open waters. The floristic and structural characteristics of these wetland communities are described in more detail in **Section 4.3.7**. The apparent lack of oxbow lakes in the study area reflects the high energy of the rivers that result in a rapidly evolving planform.

5.4.4 Highly disturbed anthropogenic habitats

Highly disturbed habitats largely cleared of forest are most abundant close to villages and other settled areas, and on properties with more intensive management for cattle grazing, palm oil and coconut production, and plantation forestry. Areas on richer, alluvial soils are under long-term cultivation of food plants and cash crops such as cocoa. Areas of untended garden or swidden agriculture are vegetated with young regrowth forest, as described in more detail in **Section 4.10**. Due to the juxtaposition of highly disturbed anthropogenic habitats (particularly areas under swidden agriculture) with surrounding forest patches, bird species richness is still moderate, at least at the edges of these habitats.

5.5 CONSERVATION PRIORITY SPECIES

5.5.1 Threatened and near threatened species

The desktop assessment identified eight threatened or near threatened vertebrate fauna species with potential to occur in the study area, including three mammal species and five bird species (**Table 5.1**). No threatened or near threatened terrestrial vertebrate fauna species were detected in the study area during the field survey. Based on an assessment of habitat suitability and the nature of threatening processes at a broader landscape scale (relatively high human population density resulting in heavy hunting pressure and extensive rainforest habitat fragmentation and degradation), no threatened or near threatened species are considered likely to occur in the study area (see **Table 5.1** for details).

Table 5.1 Assessment of the likelihood of occurrence in the study area of threatened and near threatened vertebrate fauna species that the desktop assessment identified as having potential to occur.

Scientific name	Common name	Status[1]		Likelihood of occurrence in the study area
		IUCN	PNG	
Mammals				
Dasyurus albopunctatus	New Guinea Quoll	NT		**Unlikely to occur**. The study area occurs within the historical range of the species. However, this species was not recognized by community interview participants. The forest-dwelling species is sensitive to habitat loss and hunting by dogs (Woolley *et al.* 2016), so is likely to have been extirpated from the study area historically due to extensive habitat transformation and high hunting pressure.

Scientific name	Common name	Status[1]		Likelihood of occurrence in the study area
		IUCN	PNG	
Thylogale browni	New Guinea Pademelon	VU		**Unlikely to occur.** New Guinea Pademelon inhabits primary and secondary tropical moist forest, with an apparent preference for disturbed areas. The main threat to the species is subsistence hunting by local people (hunting with dogs) for food; hunting has heavily depleted populations over parts of its range, where it is now restricted to remote mountainous interior areas (Heinsohn 2005, Leary *et al*. 2016a). The study area occurs within the range of the species. However, community interview participants recognized the species and reported that while it used to occur in the area, it no longer occurs. This species is likely to have been extirpated by extensive habitat transformation and heavy hunting pressure.
Spilocuscus rufoniger	Black-spotted Cuscus	CR	P	**Unlikely to occur**. This rare species has been extirpated from parts of its range through overhunting and its intolerance of human disturbance. Within the local region it is known only from mountainous rainforest areas north of Lae (Leary *et al*. 2016b), and it was not recognized by community interview participants; therefore it is unlikely to occur in the study area.
Birds				
Psittrichas fulgidus	Pesquet's Parrot	VU	P	**Unlikely to occur**. This species is restricted to hill and lower montane forest, mostly at elevations of 500 to1,800m asl (Mack and Wright 1998). The species is sensitive to hunting pressure and has been historically and recently extirpated from large areas in Papua New Guinea (BirdLife International 2016b). The species is therefore unlikely to occur in the study area due to the relatively low elevations, lack of hill forest and extensive forest fragmentation and degradation.
Megatriorchis doriae	Doria's Goshawk	NT		**Unlikely to occur.** This unobtrusive and therefore cryptic species occurs only in the interiors of intact lowland forest and adjoining hill forest foothills (BirdLife International 2016c). While it has been reported in lowland forest habitat northwest of Lae (Eastwood 1995), it is unlikely to occur in the study area due to the absence of intact rainforest habitat and extensive forest fragmentation and degradation.
Harpyopsis novaeguineae	Papuan Eagle	VU	P	**Unlikely to occur**. Papuan Eagle inhabits intact rainforest landscapes and is most common in undisturbed forest at elevations from sea level to 3,700m (BirdLife International 2016d). In suitable habitat of extensive, old-growth forest, pairs occupy large home ranges that average 13 km^2 (Watson and Aysoma 2001). While the species is known to occur in extensive hill forest on the southern side of the Markham River, it is unlikely to occur in the study area due to the absence of intact rainforest habitat and extensive forest fragmentation and degradation.
Aquila gurneyi	Gurney's Eagle	NT	R	**Unlikely to occur**. Gurney's Eagle inhabits a variety of rainforest habitats to 1,000m elevation, but seems to prefer primary, relatively undisturbed rainforest (BirdLife International 2016e). While the species is known to occur in extensive hill forest on the southern side of the Markham River, it is unlikely to occur in the study area due to the absence of intact rainforest habitat and extensive forest fragmentation and degradation.
Zonerodius heliosylus	Forest Bittern	NT		**Unlikely to occur**. Forest Bittern occurs in association with streams, pools and swamps in lowland alluvial and hill rainforest at elevations up to 1,430m (BirdLife International 2016f). It is unlikely to occur in the study area due to the absence of intact rainforest habitat and extensive forest fragmentation and degradation.

[1] Extinction risk status under the IUCN Red List (IUCN) and protection status under the Papua New Guinea Fauna Act (PNG): CR = Critically Endangered; EN = Endangered; VU = Vulnerable; NT = Near Threatened; P = protected; R = restricted.

5.5.2 Species protected under the Papua New Guinea Fauna Act

A total of four species declared protected and a further two species declared restricted under the Papua New Guinea Fauna Act, all of which are birds, have been recorded within the study area (**Table 5.2**). All these species occupy wide ranges across Papua New Guinea and none of these species is of particular conservation concern.

Table 5.2 Summary of terrestrial vertebrate species declared protected (P) or restricted (R) under the Papua New Guinea Fauna Act that have been confirmed as occurring within the study area.

Scientific name	Common name	Status[1]	
		IUCN	PNG
Ardea modesta (listed *A. alba*)	Great Egret	LC	P
Ardea intermedia (listed *Egretta intermedia*)	Intermediate Egret	LC	P
Rhyticeros plicatus (listed *Aceros plicatus*)	Blyth's Hornbill	LC	P
Probosciger aterrimus	Palm Cockatoo	LC	P
Cacatua galerita	Sulphur-crested Cockatoo	LC	R
Circus spilothorax	Papuan Harrier	LC	R

[1] Conservation status under the IUCN Red List (IUCN): LC = Least Concern; and Papua New Guinea Fauna Act (PNG): P = protected; R = restricted.

5.5.3 Exotic Fauna Species

Two introduced fauna pest species, the Giant African Snail (*Achatina fulica*) and Cane Toad (*Bufo marinus*) were common throughout the area surveyed and were the only fauna species trapped during the trapping survey. While local informants reported that feral pigs were still hunted in the area, no clear evidence of feral pig diggings were encountered during the field survey, suggesting that feral pigs likely occur at low density as a consequence of high hunting pressure.

5.6 CRITICAL FAUNA HABITAT

No terrestrial vertebrate species listed as Critically Endangered or Endangered under the IUCN Red List are considered likely to occur in the study area. Furthermore, there are no sites supporting globally significant concentrations of migratory species and/or congregatory species (e.g. cave-dwelling bats) or habitats of significant importance to endemic and/or restricted-range species within the study area. Consequently, no critical fauna habitat, as defined by the IFC Performance Standard 6 guidelines, is assessed as occurring within the study area.

5.7 FAUNA RESOURCE USE

The Wampar names for fauna species recorded in the study area are listed in **Appendix G**. Local informants reported that the main terrestrial fauna species that were still hunted in the study area included bandicoots (Siri), cuscus and feral pigs, and young boys hunted a variety of birds (particularly doves and pigeons) opportunistically with sling-shots. Within the study area, bandicoots and rats are hunted mainly when kunai grassland is burned. Rats with rufous fur (Maziaz, *Melomys/Paramelomys* spp.) are eaten, but rats with grey fur (Moangom, *Rattus* spp.) and the Giant White-tailed Rat (Ngayar) are not eaten. Freshly-laid eggs of New Guinea Scrubfowl (Kerong) are also periodically harvested from their nest mounds in areas where this species still occurs.

6.0 PROTECTED AND SPECIAL PURPOSE AREAS

Papua New Guinea currently has three areas that are formally protected as national parks, namely: 1) Lake Kutubu; 2) Varirata National Park; and 3) McAdam National Park. Only McAdam National Park is located in Morobe Province, situated at least 40km from the study area in the upper reaches of the Watut River catchment system. As the Project is unlikely to impact on any national park, no aspects of the *Conservation and Environment Protection Authority Act 2014 specific to national parks* will be triggered by the Project.

Two Conservation Areas are located in Morobe Province: Labu Tali Conservation Area; and Yus Conservation Area. The Labu Tali Turtle Conservation Area is located along several kilometres of sandy beach immediately south of the Markham River mouth and protects the nesting sites of Leatherback Turtle that visit between late November and early February to lay eggs. Yus Conservation Area is located on the Huon Peninsula, outside the zone of influence of the Project. As the Project is unlikely to impact on any conservation area, no specific aspects of the *Conservation Areas Act 1978* will be triggered by the Project.

The only Wildlife Management Area in Morobe Province is the Kamiali Wildlife Management Area located in the Salamaua District (at 07º 23’ 24’’ S; 147° 09’ 39’’ E), about 80km south along the coast from the city of Lae. The Project will not impact on any Wildlife Management Area and will therefore not trigger aspects of the *Fauna (Protection and Control) Act 1966* specific to Wildlife Management Areas.

Papua New Guinea’s two wetlands listed under the Ramsar Convention, Lake Kutubu in the Southern Highlands, and Tonda Wildlife Management Area in Western Province, are both remote from the study area. The Project will therefore have no implications for Papua New Guinea’s commitments under the Ramsar Convention.

7.0 IMPACT ASSESSMENT

7.1 IMPACT ASSESSMENT FRAMEWORK

The assessment of the impacts of the Project on terrestrial ecology values was based on assessing the significance of the impacts taking into account the impact magnitude and the sensitivity of the value being affected, following a standardised framework adopted by ERIAS Group Pty Ltd for the Project. The residual impacts of the Project were assessed assuming the successful application of the recommended impact avoidance or management measures. As defined in the *Environment Act 2000*, a beneficial value is:

> *a quality or characteristic of the environment or any element or segment of the environment, which (a) is conducive to ecological health, public benefit, welfare, safety, health or aesthetic enjoyment and which requires protection from environmental harm; or (b) is declared in an Environment Policy or permit to be a beneficial value*

The term 'value' is hereafter used to encompass this definition with reference to terrestrial ecology beneficial values.

7.1.1 Magnitude of impact

The magnitude of an impact reflects the size and nature of change based on its severity, geographical extent and duration. These elements are defined below.

- Severity: the scale or degree of change (both positive and negative) from the existing condition as a result of the impact.
- Geographical extent: the spatial extent of the impact where this is defined as site, local, regional or widespread (provincial, national or trans-boundary).
- Duration: the timescale of the effect, such as short, medium or long term (i.e., effectively permanent), and takes into account the reversibility of the impact.

The magnitude of impact was ranked as high, moderate, low or negligible, as described in **Table 7.1**, with positive impacts (or benefits) also being included but not ranked. In situations where the magnitude of impact was ranked as negligible, the overall impact significance was also ranked as negligible regardless of the sensitivity of the value being impacted.

Table 7.1 Criteria for magnitude of impact.

Magnitude	Description
High	An impact that is long lasting, widespread, and leads to substantial and possibly irreversible change to the value
Moderate	An impact that is short term and is contained within the region where the project is being developed, but that extends beyond the area of disturbance to the surrounding area
Low	An impact that is temporary or short term and localised, and where the change is barely detectable with respect to natural variability
Negligible	An impact that is highly transient or very short term, highly localised, and easily remediated, and where the change is unlikely to be detectable with respect to natural variability
Positive	A beneficial impact on the value

7.1.2 Sensitivity of a value

The sensitivity of a terrestrial ecology value was determined on the basis of a range of factors such as its:

- conservation status under the IUCN Red List;
- rarity or uniqueness within and beyond the immediate area of interest; and

- capacity to adapt to change without adverse effects on its attributes, i.e. its resilience.

Sensitivity was ranked as high, moderate or low, as described in **Table 7.2**.

Table 7.2 Criteria for sensitivity of a value.

Sensitivity	Description
High	• The value is intact and retains its intrinsic attributes. • The value is listed as being of conservation significance under the IUCN Red List. • The value is endemic to the affected area or system, and is poorly represented in the region. • The value has not been exposed to threatening processes, or there has not been a noticeable impact on its integrity. • Project activities would have an adverse effect on the value. • Potentially affected communities are highly reliant on the value, e.g., it may be the primary or only source of food or income (i.e., the primary provisioning or regulating ecosystem service) for the community. • The value is highly important from a cultural heritage perspective.
Moderate	• The value is recognised as being important at a regional level. • The value is in a moderate to good condition and retains many of its key characteristics and structural elements. • The value is relatively well represented in the areas/systems in which it occurs, but its distribution and abundance are limited by threatening processes. • Threatening processes have reduced the environmental value's resilience to change. As such, changes resulting from project activities may lead to degradation. • Due to the abundance and distribution of the value, replacement of unavoidable losses is possible. • Potentially affected communities are somewhat reliant on the value, resource or receptor. The environmental value is one of a number of food sources or income streams and is not the primary or only provisioning or regulating ecosystem service available to the community. • The value is moderately important from a cultural heritage perspective.
Low	• The value is not listed on any recognised or statutory register, but may be recognised locally by relevant and suitably qualified experts or organisations. • The value is in a poor to moderate condition. • The value is not rare or unique, and numerous representative examples exist throughout the area/system. • The value is widely distributed and abundant throughout the host area or system. • Change is not expected to result in further degradation of the value, or there is no detectable response to change. • Replacement of unavoidable losses is assured due to the abundance and wide distribution of the value. • Potentially affected communities are not reliant on the value, resource or receptor. The value is not an important or regularly used source of food or income (it is an occasional ecosystem service) for the community. • The value is not important from a cultural heritage perspective.

Not all of the attributes listed in **Table 7.1** and **Table 7.2** may be applicable to a specific impact or value, or may be contradictory, with the application of these criteria sometimes leading to inconsistent outcomes. For example, impacts that are widespread (with a high magnitude of impact as described in **Table 7.1**) may also be barely detectable (with a low magnitude of impact). Where this occurs, professional judgement was used to determine the criteria of most relevance and the overall impact significance.

7.1.3 Impact significance

The significance of an impact on a value was determined by combining the likely magnitude of the impact on that value with its sensitivity via a matrix based on the above criteria, as shown in **Table 7.3**.

Table 7.3 Matrix for assessing the significance of impacts.

Magnitude of impact	Sensitivity of value		
	High	Moderate	Low
High	Major	High	Moderate
Moderate	High	Moderate	Low
Low	Moderate	Low	Low
Negligible	Negligible	Negligible	Negligible
Positive	Positive	Positive	Positive

7.2 POTENTIAL IMPACTS ON TERRESTRIAL ECOLOGY

This section sets out the impact mechanisms predicted to affect terrestrial flora and fauna in the study area during the vegetation clearing, construction and plantations establishment, and operation phases of the Project. In general, impacts on terrestrial ecology receptors can be considered in terms of direct and indirect effects, both short-term and long-term.

7.2.1 Direct impacts

Direct impacts occur through the direct interaction of a Project activity with an ecological receptor. The potential direct impact mechanisms of Project activities are outlined below.

Land clearing

The clearing of land for the development of Project infrastructure, including the power plant, plantation nursery and access tracks, as well as for establishing plantations is expected to result in the loss of existing vegetation and natural habitats from the impacted areas. Land clearing may cause direct mortality to individual plants and animals during the clearing process. However, the primary impact of land clearing results from habitat loss, since land clearing will reduce the extent of habitat for native terrestrial flora and fauna species in proportion to the total surface area cleared, disturbed or transformed to a different land cover such as *Eucalyptus* plantation. Mobile species such as birds and bats will be able to escape to adjoining uncleared habitat and are, therefore, unlikely to experience direct mortality. However, slower moving species such as reptiles and amphibians sheltering in areas being cleared will have a greater likelihood of being killed during clearing, and bird nests active at the time of clearing will be destroyed. The movement of mobile species out of the cleared area will increase population densities in retained refuge habitat beyond the Project footprint, thereby increasing competition for resources within those retained habitats. As fauna demography in tropical environments is generally regulated by density dependence, population densities of fauna species in the refuge habitat will likely reduce over time back to pre-disturbance levels (Debinski and Holt 2000), leading to an overall reduction in local population sizes in proportion to the reduction in habitat extent and condition.

Areas converted to plantation forest will offer relatively minor habitat values to terrestrial biodiversity. Land clearing and herbicide treatment will remove most native flora species and natural vegetation from the plantation areas. The plantation trees will likely offer minimal habitat values for most terrestrial vertebrate species, due to the paucity of groundcover (see **Photo 7.1** and **Photo 7.2**), refuge sites and foraging resources in plantation areas. The Project will therefore result in substantial habitat transformation with a long-term impact on the areas directly affected.

Introduction or spread of invasive weeds, pest fauna and diseases

The construction and operation of the Project, including the establishment of plantations, will increase traffic and the transport of machinery and introduce a variety of materials into the Project area. Propagules (seeds and self-reproducing plant parts, many of which are very small) of weeds and vectors of disease may be transported to the site (e.g. by being attached to soil/grease on vehicles, machinery or materials). The Project will also introduce and establish plantings of several plantation tree species and hybrids, some of which may be potentially invasive (detailed in **Section 4.11**). Once released on site, weeds may establish on disturbed ground and subsequently invade the vegetation bordering the Project infrastructure, thereby compromising the ecological integrity of the terrestrial ecosystems. The study area already contains a large variety of introduced plant species, including invasive weeds that have already heavily impacted habitats in the study area (detailed in **Section 4.7**).

Photo 7.1 New plantings of *Eucalyptus pellita*, showing preparation to minimise vegetation cover around plantings.

Photo 7.2 Stand of young *Eucalyptus pellita* trees, showing open ground layer.

The open ground layer in the plantation areas will be attractive to Cane Toads, an introduced pest fauna species. The facilitation of Cane Toad movement in the plantation areas may reduce insect pest damage to inter-cropped food plants, thereby providing a potential socio-economic benefit, since Cane Toads can be effective in the control of insect pest species of crops (Dexter 1932, Bailey 1976). Cane Toad tadpoles can also potentially reduce the abundance of mosquitoes (Zug et al. 1975, Hagman and Shine 2007). Cane Toads have well-documented negative effects on native fauna, particularly frogs, reptiles and carnivorous marsupials (Doody *et al.* 2009, Shine 2010). However, as Cane Toads are already abundant throughout the study area, the contribution of the Project to the spread of this species will be minor.

<u>Chemical contamination and waste</u>

The use of chemicals in Project activities may impact on flora, fauna and vegetation in the event that uncontrolled releases of such chemicals to the environment occur, or if the chemicals should enter the environment, particularly waterways, through spills, seepage or stormwater flows. Hazardous waste, including batteries, spent reagents and waste oil may be generated during construction and operation of the power station. Non-hazardous waste arising during construction and operations will include both construction-related waste streams (e.g. timber, scrap metal, paper, plastic) and putrescible waste. Potential impacts associated with inappropriate hazardous waste management may include water and land contamination, emissions from incineration, and increased feral animal populations, all of which may affect terrestrial ecology if not appropriately managed.

Commercially applied forms of glyphosate, the primary herbicide to be used by the Project, can cause very high mortality of larval frogs (i.e. tadpoles) and juvenile frogs if the herbicide is sprayed over wetland areas in which larval frogs reside or over the frogs themselves (Relyea 2005). Surfactants that are mixed with the herbicide before spraying appear to be the main cause of toxicity rather than the herbicide itself, with the polyethoxylated tallowamine surfactant (POEA) being especially toxic (Howe *et al*. 2004). Formulations of glyphosate that include the surfactant POEA at environmentally relevant concentrations found in ponds after field applications can be toxic to the tadpole stages of frogs, whereas glyphosate alone and recently developed formulations lacking POEA are less toxic (Howe *et al*. 2004). The Project proposes to use Grasskill CT450 with addition of the Apparent Buffer 700 surfactant, which does not include POEA. The active ingredients of the surfactant are soyal phospholipids and propionic acid, which are unlikely to have significant impacts on frogs at the concentrations that will be applied based on ecotoxicology study results (Toxnet 2017).

Fauna mortality from vehicle strike, cables, fences and trenches

The construction and operation of the Project will increase road traffic in the local region, which will, in turn, increase the risk of direct mortality of slow-moving fauna through vehicle strike. Frogs and reptiles are more susceptible to vehicle strike, whereas birds are generally only impacted at relatively fast vehicle speeds. However, most traffic will occur during the day, whereas many frog and reptile species are more active at night. Furthermore, the paucity of roads in the local region means that the rate of vehicle strike mortality is likely to be very low in the broader context.

During Project construction, fauna (especially frogs and reptiles) may fall into and become trapped in open, steep-sided trenches unless escape options are provided. However, no conservation significant species will be affected since none are expected to occur in the Project area.

Fences with top strands of wire, barbed wire or razor wire may lead to a small increase in the incidence of mortality of certain fauna, particularly pteropodid bats that may become entangled in wire fencing. In addition, powerlines associated with the Project may present a potential electrocution hazard to flying-foxes should there be insufficient separation distance between powerline cables thereby allowing flying-foxes to reach between cables. However, these potential impacts can largely be managed through safe design of fences and powerlines.

Air emissions (dust, sulphur dioxide and nitrogen oxides)

During construction and operation of the Project, air emissions that may impact on terrestrial biodiversity will include fugitive dust, sulphur dioxide (SO_2) and nitrogen oxides. Dust will likely be generated by earthmoving machinery during site clearing, construction activities and vehicle traffic. Sulphur dioxide and nitrogen oxides will be emitted as a product of biomass combustion in the power plant and equipment such as trucks, excavators, bulldozers and transport vehicles.

Fugitive dust has the potential to reduce the photosynthetic efficiency of adjoining vegetation by blocking leaf stomata or smothering leaf surfaces, and reducing fruit yields through reduced pollination success of dust-affected flowers (McCrea 1984, Saralabai *et al*. 1997). Dust effects on photosynthetic efficiency can compromise vegetation condition and even cause dieback if severe enough. However, the regular rainfall experienced in the study area will likely mitigate the effects of dust on vegetation given that the rain will regularly and frequently wash away dust from leaves. Furthermore, the low wind speeds characteristic of the area will minimise the area potentially affected as the majority of dust particles will not travel far before settling out of the air. Impacts of dust on vegetation will therefore be localised, limited to less than a few hundred metres from active work areas, and will be only of short duration. The impacts of dust on terrestrial vertebrate fauna will manifest through highly localised impacts on habitat condition.

Sulfur dioxide and nitrogen oxides can have negative direct and indirect impacts on plants. Direct impacts include inhibition of photosynthesis by disrupting the photosynthetic mechanism, while indirect impacts result from acid rain that leaches out nutrients from plant canopy and soil (Varshney *et al*. 2009). Plants vary widely in their tolerance to SO_2, with lichens and bryophytes being particularly sensitive. However, the power plant will be designed and operated such that emissions to air will (at a minimum) comply with the Equator Principles and the IFC/World Bank environmental, health and safety (EHS) guidelines for thermal power plants (IFC 2008).

Lighting and noise

Temporary and permanent sources of light at the power plant may affect the behaviour of animals, both for diurnal and nocturnal species. Lights can interfere with nocturnal birds and birds that migrate at night, alter reproductive behaviour of frogs, focus the foraging activities of insectivores such as micro-bats, increase the likelihood of predation for some species (e.g. insects attracted to lights) and affect foraging activities of prey species (Longcore and Rich 2004). The impacts of extended periods of lighting are not detrimental to all species and some, particularly insectivorous predators (e.g., micro-bats that feed on insects attracted to lights), may derive a benefit. Lighting impacts will be localised, largely restricted to the vicinity of the power plant that is located within a highly modified landscape with relatively limited fauna biodiversity.

Project-related construction and operations activities will generate noise from a number of sources including:

- vegetation clearance and earthworks;
- vehicle and equipment operations;
- concrete batch plant operation; and
- power plant operation.

Excessive noise emissions have the potential to adversely affect some fauna species. The severity of the impact will vary depending on proximity to project activities, individual species sensitivity (and their ability to habituate), and the efficacy of avoidance and management measures. There is limited documentation of the effects of noise on fauna assemblages or populations. While noise can cause increase stress hormones and interfere with breeding communications and predator avoidance (Rabin *et al.* 2003; Dooling and Popper 2007; Barber *et al.* 2010, Kight and Swaddle 2011), many species habituate to noise (Bomford and O'Brien 1990, Kight and Swaddle 2011). Noise levels in excess of 100 dB(A), over extensive periods, may cause physical damage or injury, so it is unlikely that any terrestrial fauna would remain in any area affected by noise levels of this order.

However, construction and operation of the Project will not include plant and equipment capable of generating noise levels required to cause such damage, even in very close vicinity to the plant and equipment. The power plant, which will emit the greatest noise levels, will be designed and operated such that near-field noise emissions (within 1 m of equipment) will be limited to 85 dB(A). Far-field noise levels of the overall facility (including start up and shutdown) will be limited to 70 dB(A) at the site boundary (assuming that this is at least 150 m from the highest noise emitter). While some sensitive fauna species can be expected to be displaced from areas in close proximity to the power plant, this impact will be relatively minor since the power plant will be located within a highly modified landscape with relatively limited fauna biodiversity.

7.2.2 Indirect impacts

Indirect impacts are secondary effects that are not a direct result of Project activities but occur away from direct spatial impacts or as a delayed result of a complex impact pathway. The potential indirect impact mechanisms of Project activities are outlined below.

Habitat fragmentation and edge effects

Land clearing and habitat transformation for the Project is expected to have additional indirect impacts (i.e. beyond the direct impact of the surface area cleared) on habitat quality for terrestrial flora and fauna through habitat fragmentation (including loss of connectivity) and the consequences of what are known as 'edge effects' (Saunders *et al.* 1991). Land clearing fragments previously intact natural habitat, potentially isolating some areas of natural habitat from other areas, and creates numerous hard edges. The magnitude of edge effects is strongly correlated with the degree of contrast in physical and structural condition between retained vegetation and the surrounding matrix; edge effects are more severe in fragmented rainforest than more open habitats. The Project is expected to have a relatively minor contribution to edge effects due to the already substantially degraded and fragmented nature of habitats throughout the study area (detailed in **Section 4.4**). Furthermore, the plantations that form the great majority of the Project footprint will provide a vegetated edge to retained habitats, and this 'softer' edge is expected to have less indirect impact.

Erosion leading to habitat degradation

The exposure, disturbance and stockpiling of soil during land clearing and other construction activities, combined with heavy rainfall events that can be experienced in the Project area, may cause increased soil erosion, leading to reduced freshwater quality and subsequent sedimentation of creek channels.

7.3 AVOIDANCE AND MITIGATION MEASURES

This section outlines the avoidance, mitigation and management measures that have been developed to minimise the potential impacts described under **Section 7.2**. The avoidance, mitigation and management measures, which are recommended for implementation under the Environmental Management Plan (EMP) for the Project, are described below.

7.3.1 Avoidance measures

Planning for the Project has been informed by the identification and mapping of relevant terrestrial ecology receptors to the extent that the direct impacts of vegetation clearing (for plantations, power plant and plant nursery) on terrestrial ecology receptors of higher sensitivity have been avoided as far as possible.

7.3.2 Mitigation and management measures

A small population of the conservation priority plant species *Cycas schumanniana* occurs on the boundary of one of the proposed plantation areas (see **Figure 7.5**). To avoid direct impacts on this species, the plants should be protected with a buffer of at least 20 m, with no Project activities to occur inside the buffer zone. Should it not be possible to avoid direct impacts, then to avoid no net loss of individuals, the plants should be translocated to suitable habitat outside of the Project area, or used in rehabilitation landscaping where they will be protected from fire and herbicide treatments; translocated plants should be re-planted as a single cluster of plants. Cycads, including *Cycas* species, can be successfully translocated (Boyd 1995, Rowe and Rowe 1995, Forster 2014).

It is understood that the Project will implement the following buffers to riparian zones throughout the Project area, which will assist in mitigating the relatively minor impact of the Project on habitat fragmentation and landscape connectivity:

- riparian buffer zones of 100 m from the banks of the Markham River;
- riparian buffer zones 60 m from the banks of the Erap and Leron rivers, and also from the edges of lakes, lagoons and swamps;
- riparian buffer zones of 30 m from the banks of the Rumu River and on all sides of permanent watercourses with bed widths greater than 5 m;
- riparian buffer zones at least 20 m wide on all sides of all bodies of water and watercourses with an average width greater than 1m; and
- riparian buffer zones at least 5 m wide on all sides of all bodies of water and watercourses with an average width less than 1 m.

The Project will exclude the following activities from occurring within the riparian buffer zones:

- felling of plantation trees or Raintree into the buffers, or clearing of vegetation except where required for bridges or stream crossings;
- establishment of plantations;
- storing of logs; and

- crossing of harvesting machinery, with the exception of appropriately constructed permanent crossing points (bridges) or at designated temporary crossings for dry watercourses; harvesting machinery can cross watercourses where log crossings or culverts are provided.

Since most of the larger watercourses cross the entire width of the Project area, draining from the mountain foothills in the north to empty into the Markham River in the south (see **Figure 1.1**), the implementation of these riparian buffer zones will maintain connectivity of habitats along riparian corridors at a landscape scale across the study area. The maintenance of riparian corridors can be important for the maintenance of general biodiversity at landscape scales (Naiman *et al*. 1993, Sabo *et al*. 2005).

To mitigate the potential for the Project to introduce or facilitate the spread of invasive weeds, pest fauna and diseases, the following management measures are recommended:

- due to the very high invasiveness potential of *Acacia crassicarpa*, it is recommended that: (a) where practicable, do not burn nearly cleared plots of *A. crassicarpa* before replanting with plantation species (to minimise seed germination of *A. crassicarpa* since germination of acacia seeds is promoted by fire); (b) monitor whether spread of *A. crassicarpa* occurs outside the plantation planting areas, especially downstream of the planting areas; and (c) control any recruitment of *A. crassicarpa* from seed or suckering outside plantation areas using an appropriate herbicide;
- implement the proposed riparian buffer zones, within which no plantations will be established to mitigate the potential for the plantation tree species *Eucalyptus camaldulensis* to establish and spread along riparian zones, and control any plants that establish in riparian zones downstream of the plantation areas using an appropriate herbicide before they reach sexual maturity;
- follow Papua New Guinea quarantine requirements for soil or other plant material;
- implement wash down protocols, including inspections to ensure that machinery and equipment brought into the Project area are free of soil, seeds and other plant parts;
- monitor regularly for the presence of invasive weeds, pathogens (particularly Myrtle Rust) and pest animals in areas disturbed by the Project;
- control invasive weeds using species-appropriate methods wherever their presence is detected in areas disturbed by the Project; and
- control pest rodents including Black Rat (*Rattus rattus*) and House Mouse (*Mus musculus*) wherever they are detected by monitoring in Project infrastructure areas.

The implementation of riparian buffer zones will mitigate the potential impacts of glyphosate herbicide application on native frogs, assuming the herbicide will not be sprayed over buffer zones or wetlands. The negative impacts of glyphosate application on frogs can be further minimised if formulations of glyphosate that do not include POEA surfactant are used. To minimise impacts from chemical spills and waste on terrestrial ecology, the following management measures are recommended:

- store all fuels and chemicals in appropriate bunded storage sites at below the maximum allowable storage quantities;
- provide spill response procedures and equipment to reduce the risk of pollution in the event of a spill;
- store all hazardous and non-hazardous waste in appropriate receptacles and dispose of at appropriate waste receiving facilities; and
- store all putrescible waste in a manner that excludes pest animals such as rodents, dispose of it by incineration, transporting it to an urban waste disposal facility or burying it on-site in a manner that prevents pest animals from accessing putrescible waste as a food supply.

To minimise soil erosion, it is recommended that an Erosion and Sediment Control Plan be developed for the Project that includes measures to stabilise disturbance areas and utilise erosion and sediment control measures to minimise the release of sediment into watercourses.

To minimise impacts to terrestrial ecology from dust, water spraying during periods of heavy on-site activity is recommended to minimise dust emissions from heavy vehicle traffic, excavation and clearing.

To minimise impacts to terrestrial ecology from noise and artificial lighting, the following mitigation and management measures should be implemented through the construction and operational phases of the Project:

- shield external lights and direct lights onto work areas wherever practicable to minimise light spill to the sky and to adjoining natural habitats; and
- conduct regular maintenance of plant and machinery used for the Project to minimise noise emissions.

To minimise fauna mortality from Project activities, the following mitigation and management measures are recommended:

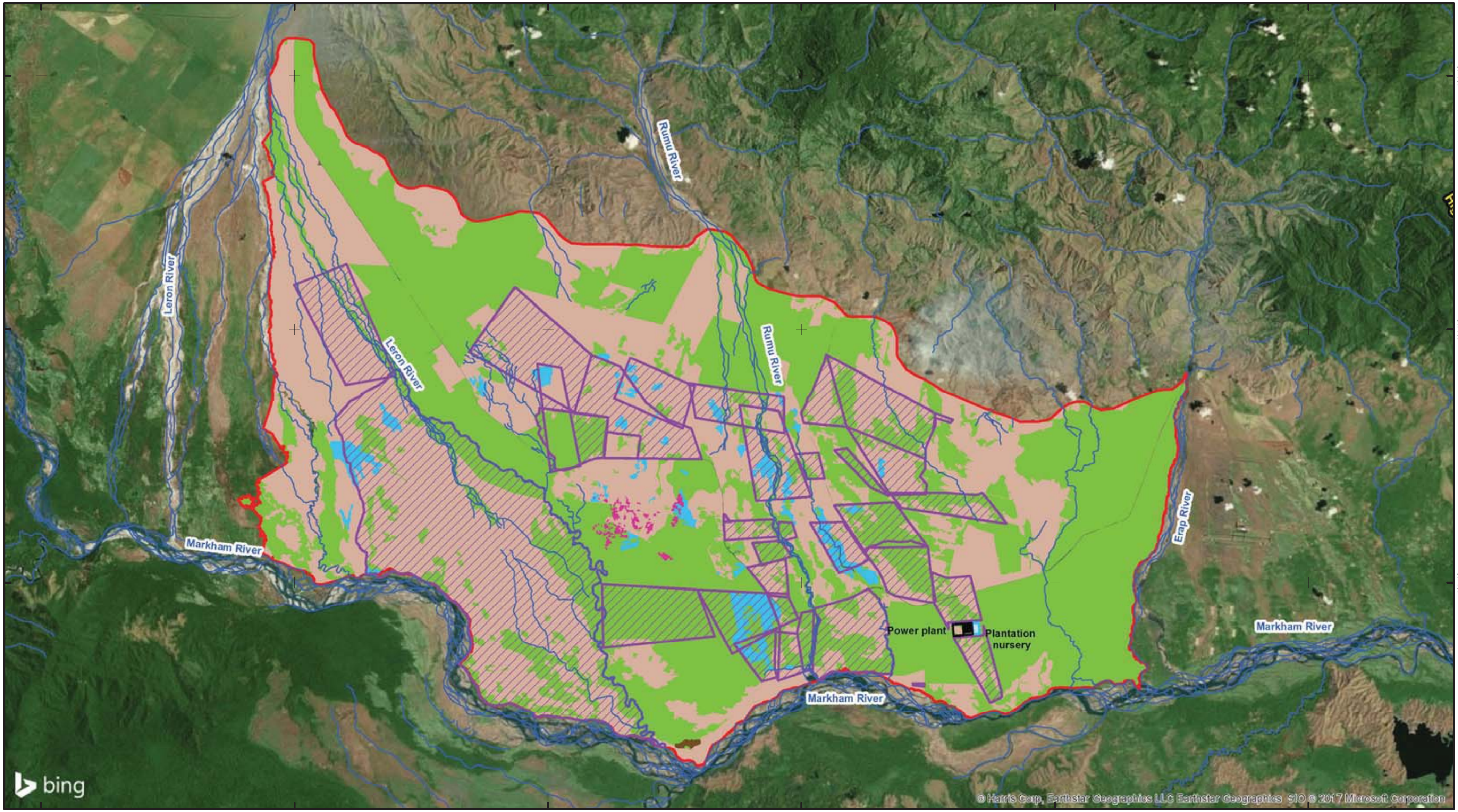
- implement a traffic management plan including appropriate speed limits on project roads and vehicle crossings to minimise the risk of vehicle strike on fauna;
- minimise the period of time that trenches are left open;
- ensure that open trenches have trench plugs installed with slopes less than 45° (to provide exit ramps for fauna) or patrol on a daily basis to check for and rescue trapped fauna while open trenches are present;
- use small-gauge mesh fencing and avoid topping the fence with barbed wire or razor wire where practicable, to minimise mortality of pteropodid bats that can get caught in the top strands of fences; and
- where possible, ensure that powerline designs have a horizontal separation of at least 1.5 m and a vertical separation of at least 1.2 m between adjacent powerline cables (to minimise electrocution of flying-foxes and other pteropodid bats).

7.4 Residual Impacts of the Project on Terrestrial Ecology Values

The direct impact of the Project on terrestrial ecology receptors was calculated as the area of the respective terrestrial ecology receptor that intersected the Project footprint shown in **Figure 1.1**, which comprises all areas subject to Memoranda of Understanding (MOUs) with land owners. Due to the already modified or degraded condition of vegetation within the broader study area (see under **Section 7.4.1** below), indirect impacts are considered to be of negligible importance. The residual impact of the project on various ecological values was calculated as the total area of that value that intersected with the total area under MOUs. However, this residual impact area will be reduced once buffers to waterways and wetlands (as outlined in **Section 7.3.2**) are accounted for and villages and other sensitive areas are avoided. While the total area under MOUs is 16,097 ha, up to 16,000 ha is proposed to be used for plantations.

7.4.1 Residual impacts on terrestrial vegetation communities

The residual impact areas of the Project footprint on terrestrial vegetation communities (see **Figure 7.1**) are summarised in **Table 7.4** and compared with the total area of the corresponding vegetation community within the study area. The study area is the area of assessment of terrestrial ecology values, whereas the Project area is a subset of the study area that comprises the areas under MOUs within which the plantations, power plant, plantation nursery and associated infrastructure will be developed.



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LEGEND

- Power Plant
- Watercourse
- Plantation nursery
- Potential plantation area under MOU
- Study Boundary

Vegetation Communities

- **G** - Grassland
- **O** - Other non-vegetation and areas dominated by land use
- **PL** - Large to medium crowned forest
- **PS** - Small crowned forest / regrowth forest
- **SA** - Savannah

Figure:	7.1
Title:	Project footprint in relation to vegetation communities
Project:	PNG BIOMASS MARKHAM VALLEY TERRESTRIAL ECOLOGY ASSESSMENT
Client:	ERIAS Group Pty Ltd

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Drawn By: MG Reviewed by: AC Date: 19-Jan-17

Table 7.4 Residual impact areas of the Project (areas under MOUs) on terrestrial vegetation communities compared with their total areas within the study area.

Vegetation community code	Vegetation community description[1]	FIM equivalent[2]	Total area (ha)[3]	Area under MOUs (ha)	% under MOUs
Vegetation communities with minimal to moderate present-day disturbance					
1a	Large to medium crowned forest (disturbed).	PL: Large to medium crowned forest	13.6	0.0	0.0
2a	Small crowned forest / regrowth forest	PS: Small crowned forest	102.5	0.0	0.0
3a	*Nauclea orientalis / Albizia procera* savannah	SA: Savannah	53.8	8.4	15.7
4a	Kunai grassland on riverine alluvium	G: Grassland	907.3	146.3	16.1
4b	Kunai grassland on footslopes and hillslopes	G: Grassland	390.3	0.0	0.0
Vegetation communities with moderate to high levels of disturbance					
3b	*Nauclea orientalis / Albizia procera* savannah - moderately degraded	SA: Savannah	937.7	657.7	70.1
4c	Kunai grassland on riverine alluvium -moderately /patchily degraded with weeds	G: Grassland	19,322.6	9,278.6	48.0
12a	Active river channels	O: Other non-vegetation and areas dominated by landuse[4]	1,072.3	347.2	32.4
Vegetation communities that are highly degraded					
2b	Mixed native/exotic secondary forest	O: Non-vegetation and areas dominated by landuse[4]	1,148.5	678.5	59.2
3c	Native savannah woodland with severely degraded ground cover	SA: Savannah	59.5	17.7	29.7
4d	Kunai grassland on riverine alluvium - heavily modified and degraded with weeds and pasture plants	G: Grassland	10,424.6	1,407.5	13.5
4e	Mixed native/exotic grassland, shrubland and woodland on river alluvium.	G: Grassland	553.7	89.9	16.2
4f	*Saccharum robustum, Leucaena leucocephala* grassland/shrubland on recent river deposits	G: Grassland	469.2	118.3	25.2
5a	*Albizia saman* dominated savannah	G: Grassland	210.9	96.4	45.7
10a	Sago swamp - regrowth/degraded forest	O: Non-vegetation and areas dominated by landuse[4]	92.9	46.4	49.9
Vegetation communities resulting from complete habitat modification					
5b	*Albizia saman* dominated open forest	O: Non-vegetation and areas dominated by landuse[4]	7,430.2	2,681.8	36.1

Vegetation community code	Vegetation community description[1]	FIM equivalent[2]	Total area (ha)[3]	Area under MOUs (ha)	% under MOUs
6a	*Leucaena leucocephala, Albizia sp., Albizia saman* dominant shrubland	O: Non-vegetation and areas dominated by landuse[4]	206.1	29.6	14.4
7a	Village area	O: Non-vegetation and areas dominated by landuse[4]	397.3	60.2	15.2
8a	Plantation areas/leucaena/palm oil	O: Non-vegetation and areas dominated by landuse[4]	936.7	0.3	0.0
8b	Plantation areas: *Pinus* and *Araucaria*	O: Non-vegetation and areas dominated by landuse[4]	25.8	0.0	0.0
9a	Former gardens/coconut plantations	O: Non-vegetation and areas dominated by landuse[4]	2,155.4	430.7	20.0
11a	Garden areas with evidence of recent modification	O: Non-vegetation and areas dominated by landuse[4]	294.1	0.0	0.0
Total			**47,205.0**	**16,097.0**	

[1] Description derived from Paijmans (1976), applied to natural vegetation communities only.
[2] Classification derived from Hammermaster and Saunders (1995).
[3] Total area of the vegetation community within the study area.
[4] Referring to areas utilised by humans for agriculture, settlement or other industrial or extractive activity.

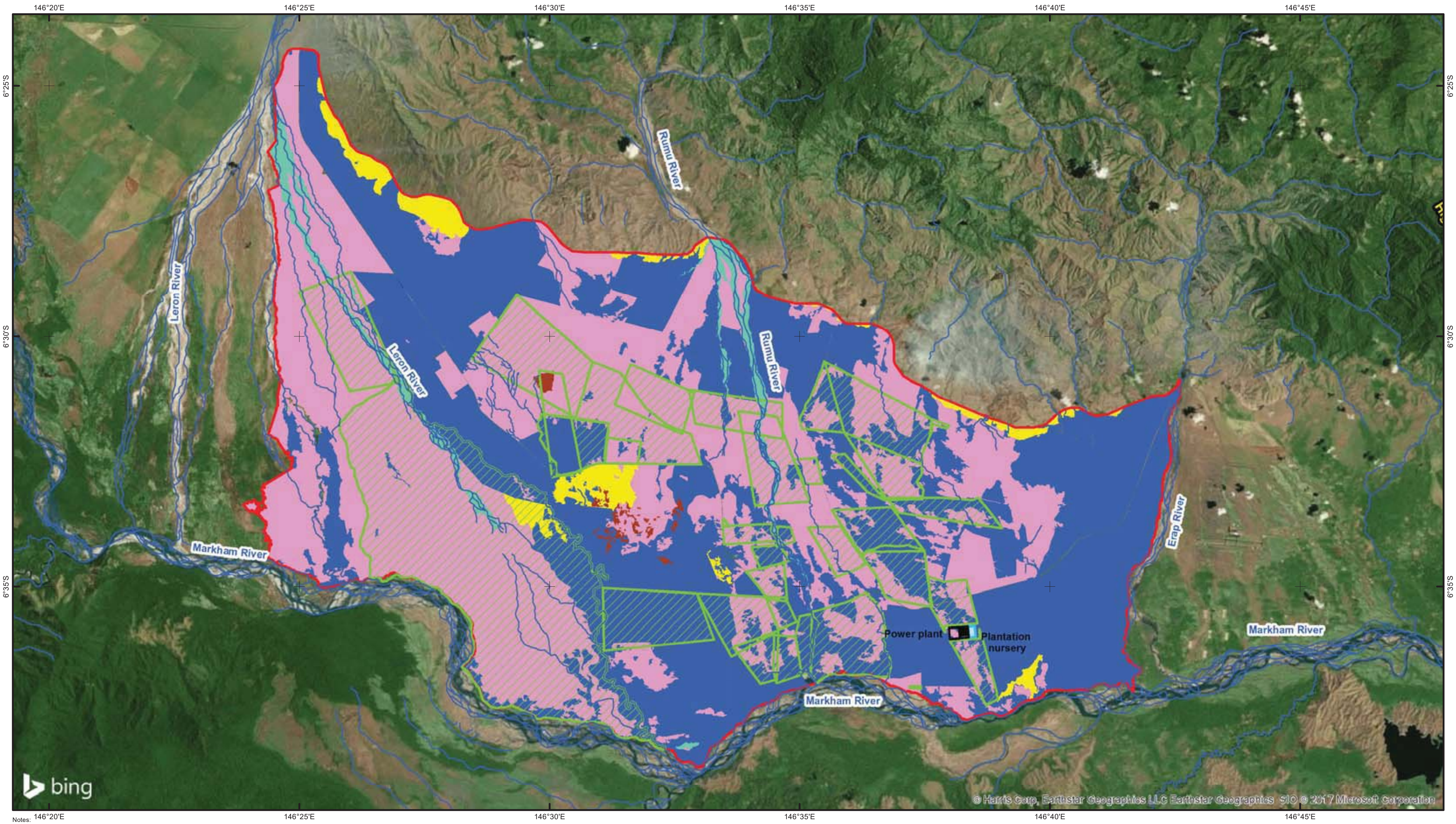
The residual impact areas of the Project footprint by vegetation condition category (see **Figure 7.2**) are summarised in **Table 7.5** and compared with the total area of the corresponding condition category within the study area.

Table 7.5 Residual impact areas of the Project (areas under MOUs) by vegetation condition category compared with their total areas within the study area.

Condition category code	Condition category description	Total area (ha)[1]	Area under MOUs (ha)	% under MOUs
2b	Moderately disturbed (stable or regenerating)	156.2	8.4	5.4
2a	Moderately disturbed (stable to declining)	1,085.9	347.2	32.0
3	Modified (cultural)	1,297.5	146.3	11.3
4	Degraded	21,970.9	10,780.9	49.1
5	Highly degraded	22,694.4	4,814.1	21.2
Total		**47,205.0**	**16,097.0**	

[1] Total area of the condition category within the study area.

Of the 16,097 ha under MOUs, 2.2% is moderately disturbed (condition category 2a and 2b), 0.9% is modified (cultural) (condition category 3), 67.0% is degraded (condition category 4) and 30.0% is highly degraded (condition category 5). Therefore, the great majority of the residual impact of the Project (approximately 97% of the areas under MOUs) comprises degraded or highly degraded vegetation communities.



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Datum: GDA 1994
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LEGEND

- Power Plant
- Watercourse
- Plantation nursery
- Potential plantation area under MOU
- Study Boundary

Vegetation Condition

- Moderately Disturbed (Stable or Regenerating)
- Moderately Disturbed (Stable to declining)
- Modified (Cultural)
- Degraded
- Highly Degraded

Figure:	7.2
Title:	Project footprint in relation to vegetation condition
Project:	PNG BIOMASS MARKHAM VALLEY TERRESTRIAL ECOLOGY ASSESSMENT
Client:	ERIAS Group Pty Ltd

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7.4.2 Residual impacts on IFC habitat types

The residual impact areas of the Project footprint on IFC habitat types (see **Figure 7.3**) are summarised in **Table 7.6** and compared with the total area of the corresponding habitat type within the study area.

Table 7.6 Residual impact areas of the Project on IFC habitat types compared with their total areas within the study area.

Habitat category	Total area (ha)[1]	Area under MOUs (ha)	% under MOUs
Modified habitat	45,962.9	15,741.4	34.2
Natural habitat	1,242.1	355.6	28.6
Total	**47,205.0**	**16,097.0**	

[1] Total area of the habitat category within the study area.

The Project will have a potential impact on up to 355.6 ha of natural habitat under the IFC habitat classification, comprising 347.2 ha of active river channels (VC12a) that will likely be protected by implementation of the watercourse buffers and 8.4 ha of savannah (VC3a). Compliance with IFC Performance Standard 6 requires that the Project should not significantly convert or degrade natural habitats, unless all of the following are demonstrated:

- no other viable alternatives within the region exist for development of the Project on modified habitat;
- consultation has established the views of stakeholders, including affected communities, with respect to the extent of conversion and degradation; and
- any conversion or degradation is mitigated according to the mitigation hierarchy designed to achieve no net loss of the natural habitats affected, for example through habitat restoration or implementation of biodiversity offsets.

7.4.3 Residual impacts on FSC forest types

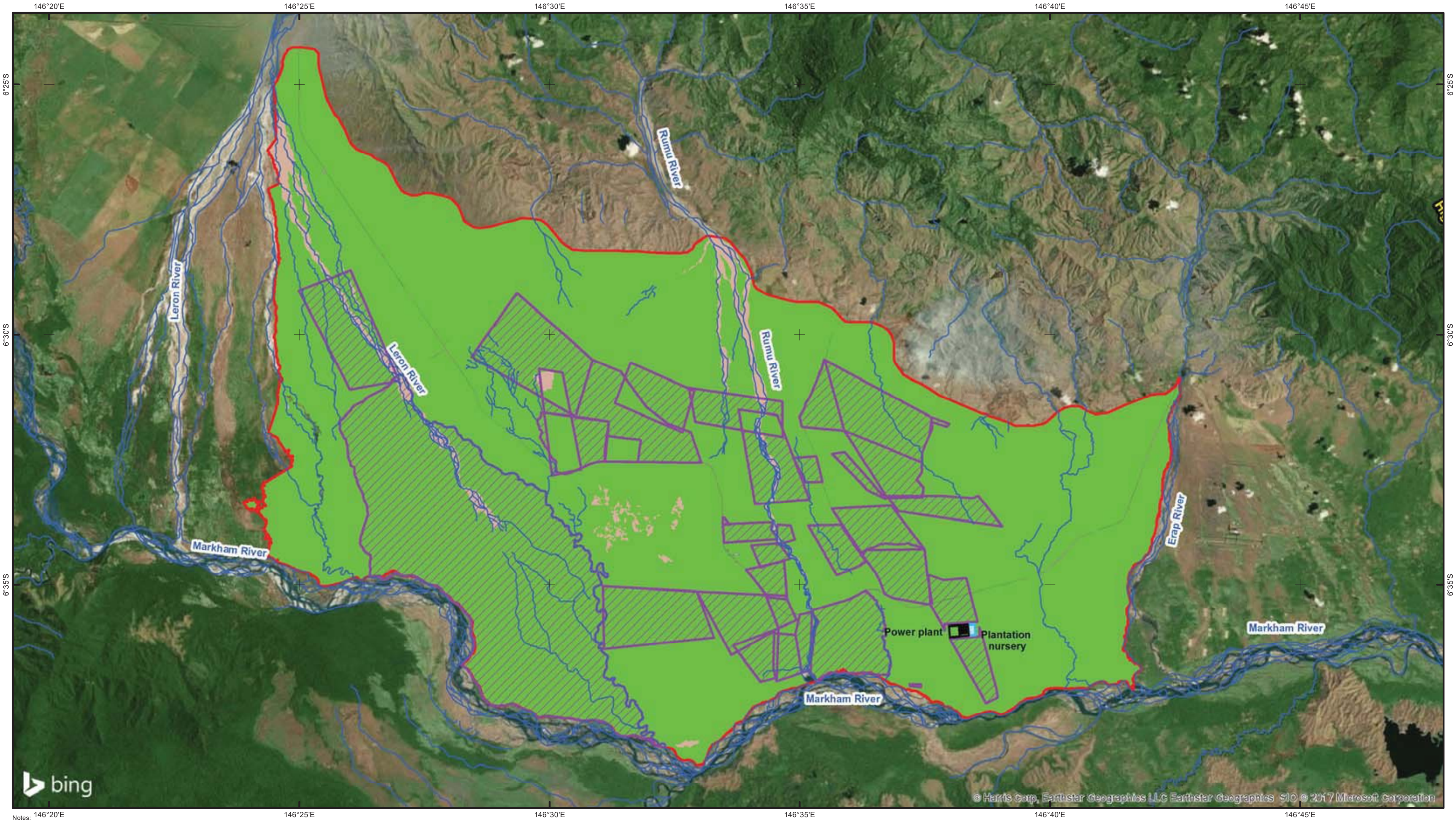
The residual impact areas of the Project footprint on FSC forest types (see **Figure 7.4**) are summarised in **Table 7.7** and compared with the total area of the corresponding forest type within the study area.

Table 7.7 Residual impact areas of the Project on FSC forest types compared with their total areas within the study area.

Habitat category	Total area (ha)[1]	Area under MOUs (ha)	% under MOUs
Natural forest	116.0		0.0
Not classified under FSC	47,089.0	16,097.0	34.2
Total	**47,205.0**	**16,097.0**	

[1] Total area of the habitat category within the study area.

Compliance with Principle 6 of the FSC National Forest Management Standard for Papua New Guinea in both the current (PNG FSC National Working Group 2010) and revised draft versions (FSC 2016) requires that no areas of natural forest be converted to plantations or non-forest land use. The Project will have no impact on natural forest under the FSC forest classification, since all areas of natural forest within the study area occur outside of the areas under MOUs; therefore the Project will avoid impacts on natural forest. Should the proponent with to apply for FSC certification under the revised draft FSC National Forest Management Standard for Papua New Guinea (FSC 2016), which is not currently in force, then compliance with Management Indictor A1 under Principle 5, Annexe C requires that wetlands, peatlands, savannahs or natural grasslands are not converted to plantations or any other land use except where:



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LEGEND

- Power Plant
- Watercourse
- Plantation nursery
- Potential plantation area under MOU
- Study Boundary
- Road

IFC Habitat Classification

- Modified Habitat
- Natural Habitat

Figure:	7.3
Title:	Project footprint in relation to IFC habitat types
Project:	PNG BIOMASS MARKHAM VALLEY TERRESTRIAL ECOLOGY ASSESSMENT
Client:	ERIAS Group Pty Ltd

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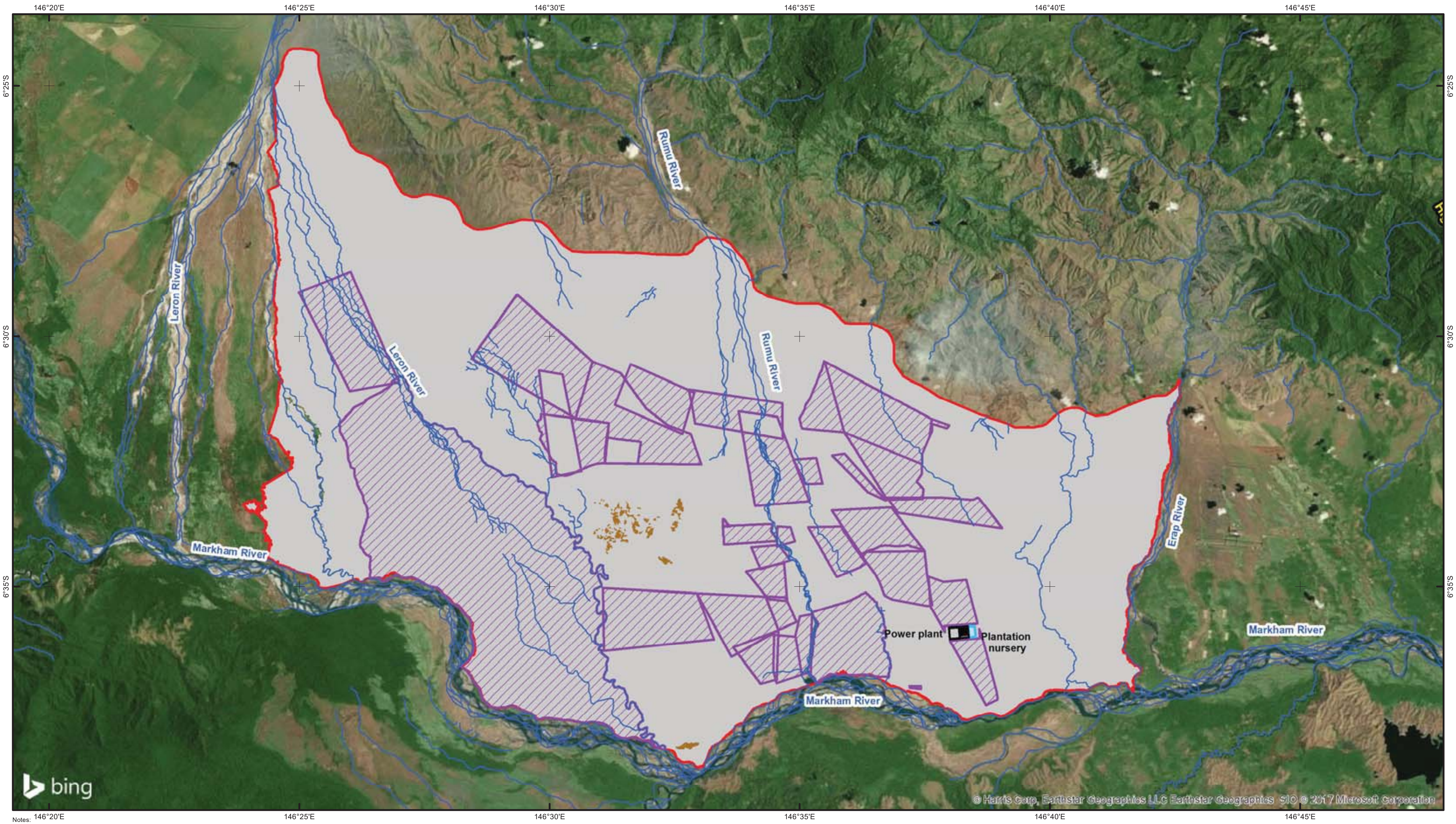

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LEGEND

- Power Plant
- Watercourse
- Plantation nursery
- Potential plantation area under MOU
- Study Boundary

FSC habitat classification

- Not classified under FSC
- Natural forest

Figure: 7.4
Title: Project footprint in relation to FSC forest types
Project: PNG BIOMASS MARKHAM VALLEY TERRESTRIAL ECOLOGY ASSESSMENT
Client: ERIAS Group Pty Ltd

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- the conversion is producing clear, substantial, additional, secure, long-term conservation benefits in the management unit; and
- the total area of plantation on sites converted is less than 5% of the total area of the management unit.

The implementation of buffers to wetlands will ensure no wetlands in the Project area will be converted to plantations or any other land use. No peatlands or natural grasslands were identified within the Project area (see discussion of 'natural grasslands' in **Section 4.8**). The Project may have a residual impact on up to 8.4 ha of natural savannah (VC3a) unless these areas of savannah are avoided. While conversion of 8.4 ha of savannah would constitute less than 0.1% of the management unit, the conversion is not expected to produce a conservation benefit.

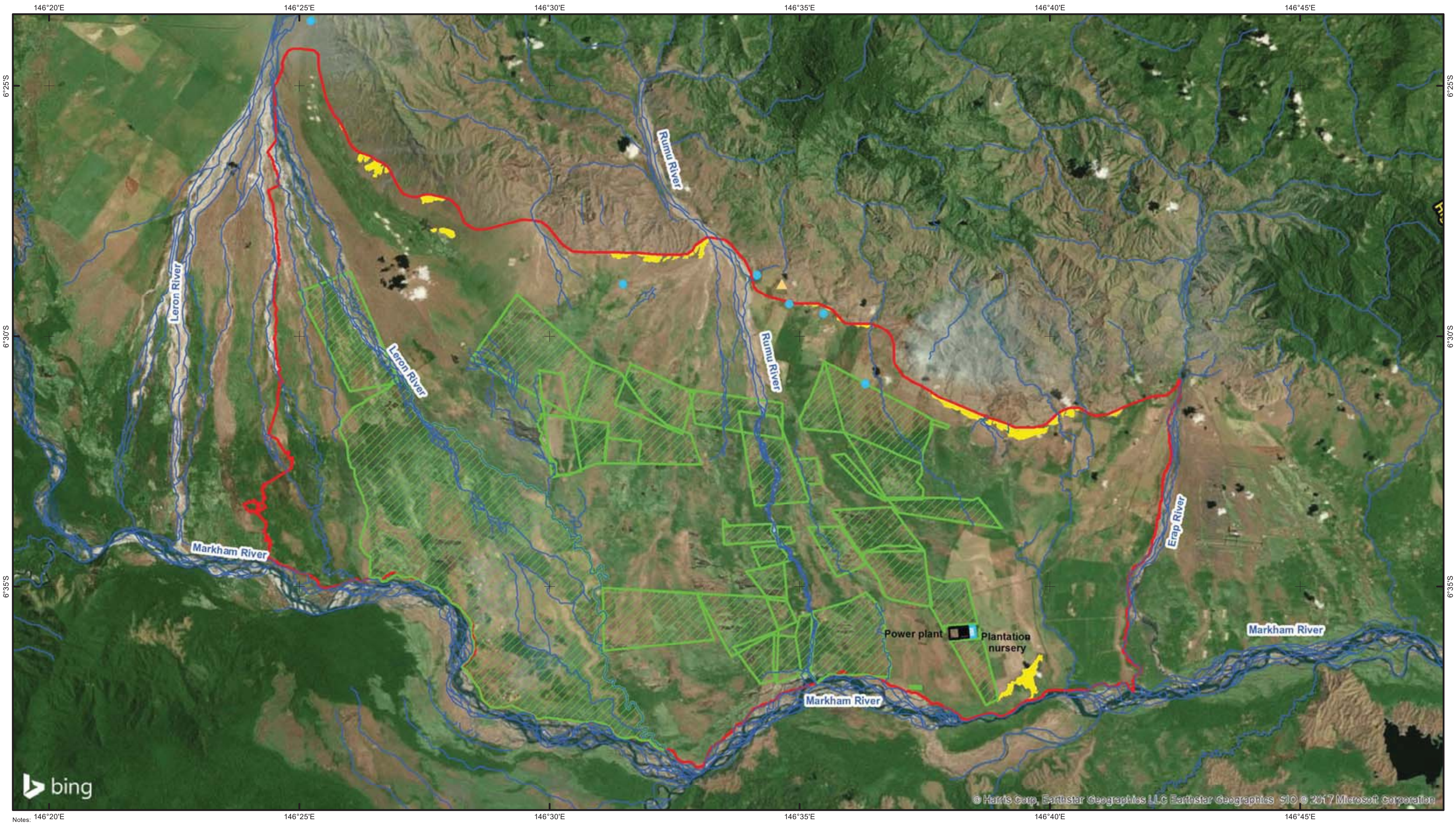
7.4.4 Residual impacts on conservation priority flora and fauna species

Two conservation priority species are known to occur in the study area, both of which are plant species, namely *Intsia bijuga* (Kwila) and *Cycas schumanniana*. Kwila was not detected within the areas under MOUs (see **Figure 7.5**); therefore the Project is expected to have no residual impact on this species. While all occurrences of habitat most suitable for *Cycas schumanniana* occur outside of the areas under MOUs that will be potentially directly impacted by the Project, a single occurrence of the species was detected on the boundary of an area under MOU (see **Figure 7.5**). At this location, the species occurs as a single, mature seed-producing plant, 1.5 m tall surrounded by up to 20 immature plants over a radius of 10 to 20 m from the mature plant, growing in recently burnt grassland on an outwash plain (VC4c) that was variably degraded through invasion of woody weeds, mostly Leucaena (**Photo 7.3** and **Photo 7.4**).

Photo 7.3 Immature *Cycas schumanniana* cycads (visible as short black trunks) in burnt grassland on the boundary of an area under MOU.

Photo 7.4 Single mature *Cycas schumanniana* cycad with burnt leaf fronds on the boundary of an area under MOU.

Successful implementation of the recommended avoidance or mitigation measures (conservation buffer to avoid impacts or translocation to mitigate impacts, as outlined in **Section 7.3.2**) is likely to result in no net loss of individuals of the species due to the Project. If these individuals were lost instead of translocated, the loss of the relatively small number of plants involved is unlikely to significantly increase the risk of extinction of the species. However, were this type of loss to be repeated at other locations across the range of this near threatened species, then it is possible the status of the species would change to it having a high risk of extinction in the wild.



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LEGEND

- *Intsia bijuga* (Kwila)
- *Cycas shumanniana*
- Power Plant
- Watercourse
- Plantation nursery
- Potential plantation area under MOU
- Study Boundary
- Habitat suitable for *Cycas shumanniana*

Figure: 7.5
Title: Project footprint in relation to significant flora species
Project: PNG BIOMASS MARKHAM VALLEY TERRESTRIAL ECOLOGY ASSESSMENT
Client: ERIAS Group Pty Ltd

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7.4.5 Significance of residual impacts

The significance of the residual impacts of the Project on terrestrial ecology receptors, assuming the successful implementation of recommended avoidance and mitigation measures, was assessed in accordance with the significance level matrix outlined in **Section 7.1** (see **Table 7.3**), which combines assessment of the magnitude of the impact, including the scale and duration of the impact should it occur, and assessment of the sensitivity of the terrestrial ecological receptor that is impacted. The significance of the residual impacts of the Project were assessed against the following terrestrial ecology beneficial values that are known to occur in the study area, listed in order of relative importance or sensitivity:

- *Intsia bijuga* (Kwila, listed as vulnerable by the IUCN Red List) and its habitat;
- *Cycas schumanniana* (listed as near threatened by the IUCN Red List) and its habitat;
- Natural forest habitats, which are not considered threatened but support greater biodiversity and provide relatively more resources for potentially affected communities; and
- Modified habitats, other natural habitats and general flora and fauna biodiversity, which are not considered threatened but provide some resources for potentially affected communities.

The results of this assessment are summarised in **Table 7.8** below.

Table 7.8 Significance of the residual impacts of the Project on terrestrial ecology receptors.

Ecological receptor	Magnitude of impact	Sensitivity	Significance	Justification
Intsia bijuga (Kwila)	Negligible	High	Negligible	Kwila is widespread along the coastal fringes and foothills of Papua New Guinea and forms extensive stands on lowland footslopes and coastal fringes throughout the Madang, East Sepik, East and West New Britain, Milne Bay and New Britain Provinces. The Markham Valley is not considered a habitat stronghold for the species although well-developed stands of Kwila are known from the Watut Valley to the south of the study area. Kwila produces seed profusely and has been observed as an active coloniser on the margins of fire disturbed habitats, most likely due the resistance of the hard seed to fire. The species is known to colonise in disturbed / secondary habitats. On this basis, the species is considered to have moderate sensitivity to project related impacts. However, the species is listed as being of conservation significance (vulnerable) under the IUCN Red List, and is therefore categorised as having high sensitivity in accordance with criteria outlined in Table 7.2. The species was not detected in the areas under MOUs, the great majority of which is in degraded or highly degraded condition and unlikely to support the species. On account of the widespread distribution and limited extent of the species in the study area, the magnitude of impact is considered to be negligible. The significance of residual impacts of the Project on this species is therefore categorised as negligible.

Ecological receptor	Magnitude of impact	Sensitivity	Significance	Justification
Cycas schumanniana	Negligible	High	Negligible	*Cycas schumanniana* is endemic to Papua New Guinea, where it occupies a fairly restricted range on the northern side of the island along the foothills of the Bismarck Range, predominantly in the valleys of the Markham and Ramu Rivers, and extending south from Lae along the Bulolo River as far as Wau and Madang. While it is a locally abundant species, annual burning of its habitat inhibits seedling regeneration and habitat conversion for agriculture is expanding. If this continues, the species may decline further and qualify for threatened status. Since the species is listed as being of conservation significance (near threatened) under the IUCN Red List, it is categorised as having high sensitivity in accordance with criteria outlined in Table 7.2. The species was detected as a single cluster of plants on the boundary of the areas under MOUs. Due to the restricted occurrence of the species in the Project area, successful implementation of the recommended avoidance or mitigation measures is likely to ensure that the Project will have negligible impact on this near threatened species. The significance of residual impacts of the Project on this species is therefore categorised as negligible.
Natural forest habitats	Negligible	Moderate	Negligible	Natural forest habitats in the study area are too degraded and fragmented to provide habitat for conservation priority flora and fauna species. Nevertheless, local (human) communities are somewhat reliant on natural forest habitats for food and timber, but this is not the primary or only provisioning or regulating ecosystem service available to these communities. Consequently, natural forest habitats are ascribed moderate sensitivity. No natural forest habitats occur within the areas under MOUs. The Project will therefore have negligible impact on natural forest habitats. The significance of residual impacts of the Project on these habitats is therefore categorised as negligible.
Modified habitats, other natural habitats and general flora and fauna biodiversity	Moderate	Low	Low	While the majority of the areas under MOUs are degraded or highly degraded, they still support moderate levels of flora and fauna biodiversity of low sensitivity (no rare or threatened species), components of which are used by communities. With the exception of areas that are used for food gardens and growing cash crops (which will be avoided by the Project), communities are not reliant on these habitats, which provide occasional ecosystem services for the community. Therefore, these habitats are ascribed low sensitivity to Project impacts. Due to the degraded condition of these habitats, conversion of these habitats to plantations will have a moderate impact on flora and fauna biodiversity in the areas directly affected. Assuming that the Project will avoid areas used for food gardens and growing cash crops (which communities are highly reliant on for food and income streams), the Project will have a moderate impact on community use of the areas directly affected. Consequently, the significance of residual impacts of the Project on these habitats is categorised as low.

7.5 CUMULATIVE IMPACTS

7.5.1 Introduction

The IFC provides guidance regarding cumulative impact assessment and management in its Good Practice Handbook: Cumulative Impact Assessment and Management: Guidance for the Private Sector in Emerging Markets (IFC 2013), which defines cumulative impacts as:

"Those that result from the successive, incremental, and/or combined effects of an action, project, or activity when added to other existing, planned, and/or reasonably anticipated future ones".

Cumulative impacts therefore comprise the combined impacts of the Project together with other projects in the region causing related impacts.

7.5.2 Assessment approach

The Good Practice Handbook (IFC 2013) describes a six-step rapid cumulative impact assessment approach, summarised as follows:

- determine the spatial and temporal boundaries of assessment;
- identify relevant valued environmental and social components, and all developments and potential stressors affecting these valued components;
- determine the baseline condition of the valued components;
- assess the contribution of the Project to the predicted cumulative impacts;
- evaluate the significance of the predicted cumulative impacts to the viability or sustainability of the affected valued components; and
- design and implement mitigation measures to manage the Project's contribution to the cumulative impacts and risks.

This approach was applied to the cumulative impact assessment for the Project.

7.5.3 Project selection rationale

Within a 50 km radius of the Project, five recently approved or proposed projects and activities that could contribute to cumulative impacts on terrestrial ecology receptors in a lowland context were identified. The details of these projects are summarized in **Table 7.9**.

Table 7.9 Projects and activities considered in cumulative impact assessment for the Project.

Activity and proponent	Description	Relationship to project	Cumulative impact
Lae Port Development Project (PNG Ports Corporation)	Existing and planned operations involving dredging, reclamation and port development. Phase 1 was completed in 2014 and Phase 2 is ongoing.	Located in the Port of Lae, adjacent to the mouth of the Markham River.	Located in a highly disturbed area in the city of Lae; therefore assessed as having negligible cumulative impact on terrestrial ecology receptors.
New ANGAU hospital (Australian and PNG Governments)	Proposed new hospital supported by the PNG and Australian Governments.	Located in Lae.	Located in what is presumed to be a highly disturbed area in the city of Lae; therefore assessed as having negligible cumulative impact on terrestrial ecology receptors.

Activity and proponent	Description	Relationship to project	Cumulative impact
Palm oil industry (Ramu Agri-Industries Limited)	Expansion of the existing industries.	Located in the Markham Valley.	No information available on the impact of the proposed development on terrestrial ecology receptors.
Small agricultural initiatives (Trukai Industries and the Morobe Provincial Government)	Partnership to generate small agricultural initiatives such as livestock and a peanut butter factory.	Located in the Markham Valley.	No information available on the impact of the proposed development on terrestrial ecology receptors.
Wafi-Golpu copper-gold mine (Wafi-Golpu Joint Venture)	An advanced exploration project investigating the proposed construction of a large underground mine and associated infrastructure, including access roads, pipelines and tailings management facilities.	Located in the Watut and Markham river valleys and adjacent foothills.	No information available on the impact of the proposed development on terrestrial ecology receptors.

The Lae Port Development Project and ANGAU hospital re-development are proposed to be located in highly disturbed areas in the city of Lae and were therefore assessed as having negligible cumulative impacts on terrestrial ecology receptors. Insufficient information was available via desktop research to enable quantification of potential cumulative impacts associated with the execution of the other projects and activities identified in **Table 7.9**. The expanding palm oil industry and other agricultural initiatives in the Markham Valley may have similar potential impacts to the Project since they are likely to be undertaken in similar habitats, although their impacts may be greater if mitigation and management measures are not investigated and implemented as part of a formal environmental assessment. Parts of the Wafi-Golpu Project are expected to be undertaken in intact lowland rainforest, and can therefore be expected to have greater impacts on terrestrial biodiversity than the Project. As outlined in **Section 7.4**, the residual impacts of the Project on terrestrial biodiversity are low to negligible; therefore the Project's contribution to cumulative impacts in the region will similarly be low to negligible.

8.0 ENVIRONMENTAL MANAGEMENT PLAN

This section outlines the terrestrial ecology components recommended to be included in the overall Environmental Management Plan (EMP) to be developed for the Project.

8.1 MITIGATION AND MANAGEMENT MEASURES

Mitigation and management measures are detailed in **Section 7.3**, and summarised in **Table 8.1** below.

8.2 Monitoring

Recommended monitoring of the impacts of the Project on terrestrial ecology components and the success of the mitigation and management measures includes the following:

- Monitor annually for the presence of invasive weeds and pest animals in areas disturbed by the Project. Monitoring for invasive weeds should be undertaken by a botanist or silviculturist familiar with the species listed in **Table 4.4** of **Section 4.7**. A pest animal problem should be identified if damage from pest animals becomes apparent to Project staff or local communities living adjacent to the Project area.
- Monitor annually for recruitment of *Acacia crassicarpa* plants from seed or suckering in the test planting areas. Monitoring should be undertaken by a botanist or silviculturist or a staff member trained to identify the species.
- Monitor once every five years for recruitment of *Eucalyptus camaldulensis* in riparian areas downstream of plantations planted with *E. camaldulensis*. Monitoring should be undertaken by a botanist or silviculturist or a staff member trained to identify the species.

The results of monitoring should be reported to the Project Manager and included in the annual environmental reporting framework of the Environmental Management Plan for the Project.

Table 8.1 Summary of potential impacts, management objectives and mitigation and management measures for the EMP for the Project.

Source of impact	Potential impact	Management objective	Mitigation and management measures
Land clearing for plantations and project infrastructure.	Loss of natural habitat for terrestrial flora and fauna.	Minimise the area of natural habitat, particularly natural forest habitat, to be cleared.	Limit clearing to the minimum areas required to accommodate the Project footprint, as outlined in the Project design, and locate plantations and infrastructure in already disturbed habitats as far as possible.
	Edge effects and habitat fragmentation.	Minimise edge effects and habitat fragmentation.	Co-locate linear infrastructure such as powerlines and access roads where possible and practical.
			Locate Project facilities in already disturbed areas as far as practicable to minimise the area of intact forest to be cleared.
			Control the establishment of invasive weeds and pest animals at the edges of cleared or disturbed areas.
	Loss of individuals of conservation significant flora species, particularly the near threatened cycad *Cycas schumanniana.*	Avoid the clearing of conservation significant flora species as far as possible.	Avoid clearing habitat for *Cycas schumanniana* (VC4a: Kunai grassland on footslopes and hillslopes) as far as possible. Implement a buffer of at least 20 m around plants, with no Project activities to occur within the buffer.
		No net loss of conservation significant flora species.	Should avoidance not be possible, translocate the affected plants to suitable habitat.
	Damage to retained natural habitats.	Minimise damage to natural habitats outside the designated clearing footprint.	Employ directional felling methods to ensure that trees are felled into areas marked to be cleared and not into adjoining areas marked not to be cleared.
	Erosion of soil in disturbance areas, leading to reduced water quality and sedimentation of water courses.	Minimise soil erosion.	Develop an Erosion and Sediment Control Plan for the Project. Stabilise disturbance areas and utilise erosion and sediment control measures, and schedule work appropriately (i.e. not during heavy rainfall) where feasible to minimise the release of sediment into watercourses.
	Disturbance leading to the facilitation of the spread and establishment of invasive weed and pest animal species.	Minimise the potential for the establishment and spread of invasive weed and pest animal species.	Monitor annually for the presence of invasive weeds and pest animal damage in areas disturbed by the Project and implement weed and pest animal control in disturbed areas as required.
Introduced plantation tree species.	Introduction of a species (*Acacia crassicarpa*) with very high potential for invasiveness.	Removal of a potentially invasive plantation species.	After harvesting of *A. crassicarpa* plantings, where practicable do not burn the newly cleared sites before replanting with plantation species (to minimise seed germination of *A. crassicarpa* since germination of acacia seeds is promoted by fire). Monitor annually whether spread of *A. crassicarpa* occurs outside the plantation planting areas, especially downstream of the planting areas. Control any recruitment of *A. crassicarpa* from seed or suckering outside plantation areas using an appropriate herbicide.

Source of impact	Potential impact	Management objective	Mitigation and management measures
	Introduction of a species (*Eucalyptus camaldulensis*) with high potential for invasiveness if planted along streams.	Minimise potential for invasiveness.	Implement riparian buffer zones as outlined in **Section 7.3.2**, with no plantations to be established within the buffers.
		Control any plants that establish in riparian areas.	Monitor riparian areas downstream of plantations planted with *E. camaldulensis* every five years and control (via application of an appropriate herbicide) any plants that establish outside of plantation areas.
	Accidental introduction of plant pathogens and diseases on introduced nursery stock.	Minimise the risk of accidental introduction of plant pathogens and diseases.	Follow PNG quarantine requirements for importation of any plant materials. Source nursery stock from pathogen/disease free sources, and screen any introduced nursery stock for potential plant pathogens and diseases, particularly Myrtle Rust.
Transportation of construction materials, vehicles and machinery into the Project area.	Introduction and spread of invasive weed species.	Minimise the introduction and spread of invasive weeds.	Follow PNG quarantine requirements for importation of construction materials, soil or other plant material to the Project area.
			Implement washdown protocols for all equipment brought into the Project area from external sites, including inspection to ensure that it is free of soil, seeds and other plant parts.
Increased vehicular traffic.	Mortality and injury to native fauna from vehicle strike.	Minimise vehicle strike impacts to native fauna.	Implement a night-time speed limit of 40 km/hr to minimise the risk of vehicle strike on nocturnal fauna.
Open trenches, fencing and powerlines.	Mortality of native fauna from entrapment in open trenches.	Minimise fauna mortality.	Minimise the period of time that trenches are left open, to minimise the risk of fauna entrapment in open trenches.
			Ensure that open trenches have trench plugs installed with slopes less than 45° (to provide exit ramps for fauna) or patrol on a daily basis to check for and rescue trapped fauna while open trenches are present.
	Electrocution of flying-foxes on powerlines.	Minimise fauna mortality.	Powerline designs to ensure a horizontal separation of at least 1.5m and a vertical separation of at least 1.2m between adjacent powerline cables to minimise electrocution of flying-foxes and other pteropodid bats.
	Entanglement of flying-foxes in fencing.	Minimise fauna mortality.	Small-gauge mesh fencing to be used and fencing to avoid topping the fence with barbed wire or razor wire where practicable, to minimise mortality of pteropodid bats that can get caught in the top strands of fences.
Putrescible waste.	Increased populations of feral animals that may feed on putrescible waste.	Minimise the accessibility of putrescible waste to feral animals	Implement a waste management plan that ensures all putrescible waste is stored in a manner that excludes pest animals such as rodents, and is disposed of by either transporting it to an urban waste disposal facility, incineration or burying it on-site in a manner that does not allow pest animals to access the putrescible waste as a food supply.

Source of impact	Potential impact	Management objective	Mitigation and management measures
Glyphosate herbicide use.	Toxicity to frogs.	Minimise toxicity of herbicide to frogs.	Implement riparian buffer zones, with no herbicide spraying to occur within the riparian buffer zones. Use formulations of glyphosate that do not include polyethoxylated tallowamine surfactant (POEA).
Chemical spills.	Contamination leading to habitat degradation.	Minimise the potential for chemical spills and implement effective spill management plans.	Implement measures for the safe storage and use of chemicals, and develop a spill management plan that is capable of rapidly responding to a chemical spill to minimise contamination of the environment. Store all fuels and chemicals in appropriate bunded storage sites at below the maximum allowable storage quantities. Provide spill response procedures and equipment to reduce the risk of pollution in the event of a spill. Store all hazardous and non-hazardous waste in appropriate receptacles and dispose of at appropriate waste receiving facilities.
Air emissions of sulphur dioxide and nitrous oxides by the power plant.	Inhibition of plant photosynthesis and indirect impacts from acid rain that leaches out nutrients from plant canopy and soil.	Minimise sulphur dioxide and nitrous oxides emissions	Design and operate the power plant such that emissions to air comply (at a minimum) with the Equator Principles and the IFC/World Bank environmental, health and safety (EHS) guidelines for thermal power plants (IFC 2008).
Dust from vehicles and machinery.	Reduced photosynthetic ability of plants in adjacent natural habitats, compromising vegetation condition.	Minimise fugitive dust.	Dust suppression water tankers to apply water to road surfaces and other disturbed areas, as appropriate to the conditions, to reduce dust.
Noise from the power plant and working plant and machinery.	Disturbance to terrestrial fauna, particularly nocturnal mammals.	Minimise noise disturbance to terrestrial fauna.	Conduct regular maintenance of plant and machinery used for the Project to minimise noise emissions.
Artificial lighting.	Effects on behaviour of native fauna.	Minimise light spill to the sky and to adjoining natural habitats.	Shield external lights and direct lights onto work areas wherever practicable.

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Appendix A

Terrestrial flora field site data

APPENDIX A: Terrestrial Flora Field Site Data

Site	Date	Latitude	Longitude	Locality	Landform	Structure	Characteristic floristics	Map unit
1	04/09/16	-6.6128	146.59986	40 Mile	River terrace	Secondary forest	Emergents: *Cocos nucifera.* Canopy: *Albizia* sp., *Atrocarpus altilis, Ficus nodosa, Commersonia bartramia, Dysoxylum gaudichaudianum, Albiza procera, Sterculia shillinglawii*. Shrub: *Glyricidia sepium.*	2b
2	04/09/16	-6.6078	146.59289	40 Mile	River terrace	Kunai grassland	Ground cover: *Imperata cylindrica* dominant. Emergent: *Nauclea orientalis, Albizia procera.*	3a
3	04/09/16	-6.6126	146.58852	40 Mile	River terrace	Kunai grassland	Ground cover: *Imperata cylindrica, Polytocca monophyla.* Emergent: *Nauclea orientalis, Albizia procera.*	3a
4	04/09/16	-6.6011	146.58945	40 Mile	Alluvial flood plain	Coconut garden / open forest	Canopy: *Cocus nucifera*.* Sub-canopy: *Ficus* sp., *Artocarpus altilis, Theobroma cacao*, Glyricidia sepium*.*	9a
5	04/09/16	-6.5787	146.52773	Markham Ranch	Alluvial flood plain	Degraded grassland	Shrub layer: *Chromolaena odorata*. Ground cover: Poaceae sp.(exotic) *Imperata cylindrica.*	4d
6	04/09/16	-6.5507	146.54305	Markham Ranch	Alluvial flood plain	Degraded grassland	Shrub layer: *Chromolaena odorata**. Ground cover: exotic grass species, *Imperata cylindrica.*	4d
7	05/09/16	-6.3951	146.42053	Leron River	Alluvial Plain	Grassland dominated by *Themeda triandra* with scattered ***Cycas shumanniana***.	Emergent shrubs: *Albizia procera, Antidesma ghaesembilla,* ***Cycas schumanniana***, *Clerodendrum tomentosum, Leucaena leucocephala**. Groundcover: *Alliopteris semiulata, Capillipedium parviflorum, Chromoleana odorata*, Cyanthillium cinereum,* ***Cycas schumanniana***, *Desmodium sp., Macroptilium atropurpureum*, Ophiuros exaltatus, Passiflora foetida*, Phyllanthus virgata, Themeda arguens, Themda triandra, Uraria picta*.	3b
8	05/09/16	-6.4025	146.41763	Leron River	Alluvial Plain	Grassland of *Themeda arguens* and *Imperata cylindrica.*	Emergent shrubs: *Albizia procera*. Groundcover: *Bothriochloa bladhii, Capillipedium parviflorum, Cyanthileum cinereum, Desmodium rhytidiophyllum, Euphorbia hirta*, Fimbristylis sp., Melinus repens*, Mnethisea rothboellioides, Pennisetum polystachyon*, Phyllanthus virgata, Sida acuta*, Stylosanthes hamata*, Themeda arguens, Themda triandra, Tridax procumbens*.*	4a
9	05/09/16	-6.4317	146.41768		Alluvial Plain	Exotic dominated grassland/herbland dominated by *Mimosa invisa* with *Passiflora foetida*, Sida cordifolia*, Macroptilium atropurpureum** and *Hyptis suaveolens**.	Groundcover: *Desmanthus pernambucanus*, Hyptis suaveolens*, Leucaena leucocephala*, Macroptilium atropurpureum*, Mimosa diplotricha*, Passiflora foetida*, Sida acuta*, Sida cordifolia*, Stylosanthes hamata*.*	6a
10	05/09/16	-6.5041	146.45650		Alluvial Plain	Forestry Plantation	Dominated by *Araucaria cunninghamii*.	11a

Site	Date	Latitude	Longitude	Locality	Landform	Structure	Characteristic floristics	Map unit
11	05/09/16	-6.5033	146.45835		Alluvial Plain	Tall exotic dominated shrubland (5-7m) of *Luecaena leucocephala** with an understorey of *Azadirachta indica**.	Upper: *Luecaena luecacephala**. Mid: *Azadirachta indica*, Desmanthus pernambucanus*, Hyptis suaveolens*, Leucaena leucocephala*, Macroptilium atropurpureum*, Mimosa diplotricha*, Passiflora foetida**. Groundcover: *Stylosanthes hamata**.	6a
12	05/09/16	-6.6128	146.59986		Alluvial Plain	Native grassland of *Themeda arguens.*	Emergent shrubs: *Clerodendrum tomentosum*. Groundcover: *Alliopteris semiulata, Capillipedium parviflorum, Chromoleana odorata*, Cyanthileum cinereum, Passiflora foetida*, Phyllanthus virgata, Stylosanthes humilis*, Themeda arguens, Tridax procumbens*, Uraria picta, Urochloa decumbens**.	4a
13	05/09/16	-6.5273	146.47987		Alluvia plain	Native grassland with emergent pandanus	Emergents: *Pandanus* sp., *Albizia procera.* Ground: *Imperata cylindrica*.	4a
14	05/09/16	-6.5464	146.50384		Alluvial plain	Exotic closed forest	Canopy: *Albizia saman**, *Ficus* sp.	5b
15	05/09/16	-6.5452	146.50861		Alluvial Plain	Closed forest (15-20m) of *Albizia saman**	Upper: *Albizia saman*, Litsea guppyi, Melanolepis multiglandulosa, Senna sp.*, Dysoxylum gaudichaudianum, Epipremum amplissimum*. Mid/Understorey: *Alstonia scholaris, Antidesma* sp., *Asplenium nidus, Buchanania macrocarpa, Carica papaya*, Clerodendrum tomentosum, Cynanchum sp., Endospermum medullosum, Ficus adenosperma, Ficus copiiosa, Ficus septica, Ficus wassa, Glochidion novoguineensis, Ipomoea obscura*, Leea novoguineensis, Mikania micrantha*, Myristica fatua, Passiflora edulis*, Piper aduncum*, Pometia pinnata, Passiflora subpeltata*, Trophis scandens subsp. scandens*. Groundcover: *Achyranthes aspera, Alpinea* sp., *Asystasia gangetica*, Dioscorea sp., Hornesteadia schottiana, Mormochodia charanta, Nephrolepis bisserata, Oplismenus compositus**, *Sida* sp., *Stephania japonica var. timorensis, Urena lobata**.	5b
16	05/09/16	-6.5470	146.51233		Alluvial Plain	Grassland dominated by *Imperata cylindrica* with *Phragmites velatorius*.	Groundcover: *Brachiaria repens, Centrosema molle*, Coleus argentea*, Crotalaria calycina, Euphorbia hirta*, Hyptis suaveolens*, Imperata cylindrica*, Ipomoea hederifolia*, Ipomoea obsura*, Macroptilium atropurpureum *, Mimosa diplotricha*, Mimosa pudica*, Mukia maderaspatata, Phragmites velatorius, Physalis peruviana*, Pterocaulon sphacelata, Pueraria lobata* var. *lobata, Sesbania cannabina, Sporobolus* sp.*, *Rynchnosia* sp., *Tribulus cistoides, Stachytarpheta cayennensis*.*	4a
17	05/09/16	-6.5568	146.51475		Alluvial Plain	Savannah woodland	Canopy: *Nauclea orientalis*. Ground cover: *Imperata cylindrica, Phragmites karka.*	4a

Site	Date	Latitude	Longitude	Locality	Landform	Structure	Characteristic floristics	Map unit
18	05/09/16	-6.5556	146.51528		Alluvial Plain	Closed broad crowned forest	Upper: *Tristiropsis acutangula, Celtis latifolia, Terminalia complanata, Dysoxylum gaudichaudianum, Litsea guppyi, Nauclea orientalis, Albizia saman** (margins). Mid/Understorey: *Melanopsis multiglandulosa, Endospermum medullosum, Morinda citrifolia, Myristica spp., Calamus longipinna, Ficus septica, F. adenosperma, Pandanus* sp.*, Sterculia shillinglawii, Mallotus paniculatus, Allophyllus cobbe, Breynia cernua, Flagellaria indica, Stephania japonica var. timorensis, Leea novoguineensis, Pometia pinnata, Senna hirsuta** (margins). Groundcover: *Passiflora foetida*, Momordica charantia *, Asclepias curassavica*, Hyptis capitata*.*	2a
19	05/09/16	-6.5577	146.52155		Alluvial Plain	Open forest (10-15m) dominated by *Albizia procera* with scattered *Albizia saman**.	Upper: *Albizia procera, Albizia saman*, Timonius timon*. Mid/Understorey: *Barringtonia acutangula, Dysoxylum parasiticum, Melanopsis multiglandulosa, Endospermum medullosum, Morinda citrifolia, Myristica* spp.*, Planchonia papuana, Calamus longipinna, Ficus septica, F. adenosperma, Glochidion novoguineensis, Macaranga* sp.*, Carica papaya*, Sterculia shillinglawii, Mallotus paniculatus, Allophyllus cobbe, Breynia cernua, Flagellaria indica, Stephania japonica var. timorensis, Leea novoguineensis, Mikania micrantha*, Piper aduncum*.* Groundcover: *Cyanthileum cinereum, Persicaria lapathifolia, Oplismenus compositis, Alpinia* sp.*, Passiflora foetida*, Solanum torvum*, Momordica charantia*, Arthraxon* sp.	2a
20	05/09/16	-6.5580	146.52416			Open / closed forest (10-15m) dominated by *Albizia procera* with scattered *Albizia saman**.	Upper: *Albizia procera, Buchanania microcarpa, Hydriastele costata, Trichospermum pleiostychya, Albizia saman*, Timonius timon*. Mid/Understorey: *Barringtonia acutangula, Dysoxylum parasiticum, Melanopsis multiglandulosa, Endospermum medullosum, Morinda citrifolia, Myristica* spp.*, Premna odorata, Planchonia papuana, Calamus longipinna, Ficus septica, F. adenosperma, Glochidion novoguineensis, Macaranga involucrata var. mallotoides, Carica papaya*, Sterculia shillinglawii, Mallotus paniculatus, Allophyllus cobbe, Breynia cernua, Flagellaria indica, Stephania japonica* var. *timorensis, Leea novoguineensis, Mikania micrantha*.* Groundcover: *Cyanthileum cinereum, Oplismenus compositis, Alpinia* sp.*, Passiflora foetida*, Solanum torvum.*	2a
21	06/9/16	-6.5552	146.51363			Exotic savannah woodland	Canopy: *Albizia saman**. Ground: *Imperata cylindrica*.	5a

Site	Date	Latitude	Longitude	Locality	Landform	Structure	Characteristic floristics	Map unit
22	06/9/16	-6.5550	146.51254		Dissected drainage line on alluvial plain	Closed forest (10-20m) of *Pandanus* sp., *Neonauclea* sp.	Upper: *Pandanus* sp., *Glochidion novoguineensis, Neonauclea* sp.*, Nauclea orientalis, Trichospermum pleiostigma, Albizia saman*, Timonius timon.* Mid/Understorey: *Antidesma ghaesembilla, Barringtonia acutangula, Melanopsis multiglandulosa, Premna odorata, Calamus longipinna, Ficus wassa, Glochidion novoguineensis, Macaranga involucrata var. mallotoides, Macaranga tanarius, Carica papaya*, Allophyllus cobbe, Breynia cernua, Flagellaria indica, Stephania japonica var. timorensis, Leea novoguineensis, Psidium guajava*, Piper aduncum*, Adenia heterophylla.* Groundcover: *Cyanthileum cinereum, Oplismenus compositis, Alpinia* sp.*, Passiflora foetida*, Solanum torvum.*	2a
23	06/9/16	-6.5425	146.52462		Alluvial flat	Kunai grassland	Ground cover: *Imperata cylindrica* dominant. Emergent: *Pandanus* sp., *Nauclea orientalis, Albizia procera*.	4c
24	06/9/16	-6.5515	146.54269	Markham Ranch	Alluvial flood plain	Degraded grassland	Shrub layer: *Chromolaena odorata**. Ground cover: Exotic grass species, *Imperata cylindrica*.	4d
25	06/9/16	-6.5555	146.54380		Alluvial plain	Disturbed open/closed forest of *Dysoxylum gaudichaudianum, Nauclea orientalis, Berrya cordifolia, Alstonia scholaris*.	Upper: *Dysoxylum gaudichaudianum, Litsea guppyi, Berrya cordifolia, Alstonia scholaris, Planchonia papuana, Glochidion novoguineensis, Nauclea orientalis, Trichospermum pleiostigma, Timonius timon, Hydriastele costata, Caryota rumphiana, Ganophyllum falcatum*. Mid/Understorey: *Antidesma ghaesembilla, Barringtonia acutangula, Melanopsis multiglandulosa, Calamus longipinna, Ficus wassa, Ficus sp., Leucaena leucocephala*, Glochidion novoguineensis, Macaranga involucrata* var. *mallotoides, Macaranga tanarius, Carica papaya*, Allophyllus cobbe, Breynia cernua, Flagellaria indica, Stephania japonica var. timorensis, Leea novoguineensis, Adenia heterophylla, Gnetum gnemon, Ptychosperma spp., Clerodendrum tomentosum, Cissus* sp., *Abrus precatorius, Pachygone* sp. Groundcover: *Oplismenus compositis, Alpinia* sp., *Passiflora foetida**.	2a
26	06/9/16	-6.5551	146.54438		Alluvial plain	Savannah woodland	Emergent: *Nauclea orientalis, Albizia procera*. Ground: *Imperata cylindrica, Hyptus capitate, Chromolaena odorata**.	3b
27	06/9/16	-6.5692	146.53593		Alluvial plain	Closed forest dominated by *Dysoxylum gaudichaudianum, Trichosperma pleiostigma, Melanopsis multiglandulosa*.	Upper: *Dysoxylum gaudichaudianum, Trichospermum pleiostigma, Melanopsis multiglandulosa, Sterculia sp., Litsea guppyi, Berrya cordifolia, Alstonia scholaris, Bombax ceiba* var. *leiocarpa, Glochidion novoguineensis, Timonius timon, Hydriastele costata, Caryota rumphiana, Melicope elleryana, Ganophyllum falcatum, Mangifera odorata, Senna* sp.* Mid/Understorey: *Antidesma ghaesembilla, Melanopsis*	2a

Site	Date	Latitude	Longitude	Locality	Landform	Structure	Characteristic floristics	Map unit
							multiglandulosa, Premna odorata, Piper aduncum, Calamus longipinna, Ficus wassa, Ficus* sp., *Leucaena leucocephala*, Glochidion novoguineensis, Macaranga involucrata var. mallotoides, Carica papaya*, Allophyllus cobbe, Breynia cernua, Flagellaria indica, Leea novoguineensis, Adenia heterophylla, Gnetum gnemon, Cissus* sp., *Muntingia calabura*, Morinda citrifolia*. Groundcover: *Oplismenus compositus, Alpinia* sp., *Passiflora foetida*, Albizia saman**.	
27a	06/9/16	-6.5686	146.53483		Alluvial plain	Exotic dominated low closed forest with *Albizia saman** and *Senna* sp.*, *Glycricidia sepium** and *Leucaena leucocephala*.*	Upper: *Albizia saman*, Senna* sp.*, *Glycricidia sepium*, Leucaena leucocephala**. Mid/Understorey: *Piper aduncum*, Ficus* sp., *Leucaena leucocephala*, Carica papaya*, Breynia cernua, Flagellaria indica, Cissus* sp., *Muntingia calabura*, Passiflora foetida*, Albizia saman*, Glycricidia sepium*, Macroptilium atropurpureum*, Mimosa diplotricha**.	5a
27b	06/9/16	-6.5906	146.52347		Alluvial plain	Exotic shrubland	Shrubs: *Albizia saman,* Leucaena leucocephala*, Glyricidia sepium**.	6a
27c	06/9/16	-6.5996	146.52222		Alluvial plain	Exotic shrubland	Shrubs: *Albizia saman,* Leucaena leucocephala*.*	6a
28	06/9/16	-6.6404	146.54603	Junction of Markham and Watut	Alluvial plain (river bank)	Savannah woodland / open woodland dominated by *Albizia procera* and *Nauclea orientalis* with exotic dominated shrub layer.	Upper: *Naucela orientalis, Albizia procera, Glochidion novoguineensis*. Understorey: *Albizia saman*, Leucaena leucocephala*, Chromolaena odorata*, Sida* spp., *Solanum torvum**. Groundcover: *Impertata cylindrica, Senna alata*, Centrosema molle*, Sesbania cannabina, Passiflora foetida**.	3c
29	06/9/16	-6.6374	146.54239		Closed forest 15-25 with emergents to 35m		Upper: *Dysoxylum gaudichaudianum, Trichospermum pleiostigma, Melanopsis multiglandulosa, Sterculia sp., Litsea guppyi, Alstonia scholaris, Glochidion novoguineensis, Trema orientalis, Timonius timon, Hydriastele costata, Caryota rumphiana, Melicope bonwickii, Ganophyllum falcatum, Ailanthus integrifolia, Artocarpus altilis*. Mid/Understorey: *Melochia umbellata, Piper aduncum*, Melicope elleryana, Homolanthus novoguineensis, Ficus wassa, Melanopsis multiglandulosa, Myristica* sp., *Premna odorata, Piper aduncum*, Calamus longipinna, Ficus wassa, Glochidion novoguineensis, Macaranga involucrata* var. *mallotoides, Allophyllus cobbe, Flagellaria indica, Leea novoguineensis, Gnetum gnemon*. Groundcover: *Oplismenus compositus, Alpinia* sp., *Passiflora foetida*, Pueraria lobata*.	1a
30	06/9/16	-6.6305	146.53293		Alluvial Plain	Exotic dominant secondary riparian forest	Canopy: *Albizia saman*, Nauclea orientalis, Alstonia scholaris, Cocos nucifera**.	2b

Site	Date	Latitude	Longitude	Locality	Landform	Structure	Characteristic floristics	Map unit
31	06/9/16	-6.6228	146.52938		Alluvial Plain	Open forest dominated by *Albizia saman**.	Canopy: *Albizia saman**.	5b
32	06/9/16	-6.5967	146.54917		Alluvial Plain	Degraded savannah woodland dominated by *Albizia saman*.*	Upper: *Albizia saman**.	5a
33	06/9/16	-6.5888	146.55597			Open savannah woodland dominated by *Albizia procera* with occasional *Albizia saman**. Disturbed understorey.	Upper: *Albizia procera*. Understorey: *Albizia saman*, Melia azederach, Muntingia calabura*, Piper aduncum *, Leucaena leucocephala*, Chromolaena odorata*, Sida spp., Solanum torvum**. Groundcover: *Impertata cylindrica, Centrosema molle*, Passiflora foetida**.	3c
34	06/9/16	-6.5821	146.55920		Swampy drainage line on alluvial plain	Closed forest (10-20m).	Upper: *Metroxylom sagu, Glochidion novoguineensis, Neonauclea sp., Trichospermum pleiostigma, Pandanus* sp., *Timonius timon, Albizia procera*. Mid/Understorey: *Barringtonia acutangula, Melanopsis multiglandulosa, Calamus longipinna, Ficus wassa, Glochidion novoguineensis, Macaranga involucrata var. mallotoides, Macaranga tanarius, Piper aduncum **.	10a
35	06/9/16	-6.5821	146.55904		Alluvial plain	Open kunai grassland	Ground: *Imperata cylindrica*.	4a
36	06/9/16	-6.5815	146.55988		Alluvial plain	Open kunai grassland	Ground: *Imperata cylindrica*.	4a
37	07/09/16	-6.5388	146.58582		Alluvial plain	*Imperata cylindrica* dominated grassland with scattered emergents of *Albizia procera* and *Nauclea orientalis*.	Emergents: Albizia *procera, Nauclea orientalis.* Groundcover: *Impertata cylindrica, Passiflora foetida*, Capillipedium parviflora, Clerodendrum tomentosum, Phragmites vellatorius, Bothriochloa bladhii, Antidesma ghaesembilla, Tridax procumbens*, Boerhavia erecta, Macroptilium atropurpureum*, Albizia saman**.	
38	07/09/16	-6.5386	146.58207		Dissected drainage line on alluvial plain	Closed forest (10-20m)	Upper: *Glochidion novoguineensis, Neonauclea sp., Bombax ceiba, Litsea guppyi, Trichospermum pleiostigma, Timonius timon, Horsefieldia sp, Mangifera odorata*. Mid/Understorey: *Antidesma ghaesembilla, Melanopsis multiglandulosa, Calamus longipinna, Ficus wassa, Glochidion novoguineensis, Macaranga involucrata var. mallotoides, Allophyllus cobbe, Flagellaria indica.*	
39	07/09/16	-6.5750	146.60513					
40	07/09/16	-6.5769	146.60660					
41	07/09/16	-6.5730	146.60366					
42	07/09/16	-6.4925	146.59120		Alluvial plain	Grassland	Emergent shrubs: ***Cycas schumanniana***, *Clerodendrum tomentosum.* Groundcover: *Imperata cylindrica, Capillipedium parviflorum, Cyanthileum cinereum,* ***Cycas schummania***, *Desmodium* sp., *Passiflora foetida*, Crotalaria* sp., *Pychnospora lutescens, Tridax procumbens*, Stylosanthes* spp.*.	

Site	Date	Latitude	Longitude	Locality	Landform	Structure	Characteristic floristics	Map unit
43	07/09/16	-6.4894	146.57976		Footslope on unconsolidated volcanics	Open grassland	Ground: *Themeda triandra, Imperata cylindrica,* ***Cycas schumanniana***.	4b
44	07/09/16	-6.4840	146.57446		Colluvial outwash	Degraded grassland	Shrub layer: *Vachellia farnesiana.* Ground: Indeterminate grass species plus exotic herbs.	4d
45	07/09/16	-6.4797	146.56906		Footslopes	Grassland	Emergent shrubs: ***Cycas schumanniana***, *Clerodendrum tomentosum, Mussaenda* sp. Groundcover: *Imperata cylindrica,* ***Cycas schumanniana***, *Desmodium sp., Passiflora foetida**, Crotalaria sp., Tridax procumbens**.	4b
46	07/09/16	-6.4730	146.56639		Footslope gully line	Exotic shrubby thicket	Canopy: *Leucaena leucocephala** and *Albizia saman*.*	6a
47	07/09/16	-6.4678	146.56390		Footslope gully line/ Footslope	Low exotic forest	Canopy: *Albizia saman*, Ficus nodosa*. Shrubs: *Leucaena leucocephala**.	6a
48	07/09/16	-6.4663	146.56118		Footslope gully line/ Footslope	Exotic dominant open forest	Canopy: *Albizia saman*, Ficus nodosa.* Shrubs: *Leucaena leucocephala*, Macaranga involucrata, Melanolepsis sp*. Ground: *Megathyrsus maximus**.	5b
49	07/09/16	-6.4710	146.56418		Foothills	Grassland dominated by *Imperata cylindrica* with emergent shrubs.	Emergent shrubs: *Antidesma ghaesembilla, Timonius timon, Clerodendrum tomentosum, Muessanda* sp. Groundcover: *Imperata cylindrica, Desmodium* sp., *Passiflora foetida*, Crotalaria* sp., *Tridax procumbens*, Vitex* sp., *Pueraria lobata*, Euphorbia schumanniana, Bothriochloa bladhii*.	4b
50	07/09/16	-6.4725	146.56603		Footslope gully line	Exotic shrubby thicket	Canopy: *Leucaena leucocephala** and *Albizia saman*.*	6a
51	07/09/16	-6.4881	146.57767		Colluvial outwash plain	Disturbed / exotic grassland	Indeterminate exotic grass and forb species	4d
52	07/09/16	-6.4976	146.58574		Colluvial outwash plain	Exotic savannah woodland	Emergents: *Albizia saman**. Shrubs: *Glyricidia sepium**. Ground: *Imperata cylindrica*.	5a
53	07/09/16	-6.5048	146.58342		Colluvial outwash plain	Exotic woodland open forest	Canopy: *Albizia saman**. Shrubs: *Glyricidia sepium**. Ground: *Megathyrsus maximus*, Imperata cylindrica.*	5b
54	07/09/16	-6.5098	146.59485		Colluvial outwash plain	Exotic woodland / open forest	Canopy: *Albizia saman**. Shrubs: *Leucaena leucocephala*, Glyricidia sepium*.* Ground: *Megathyrsus maximus*, Imperata cylindrica.*	5b
55	07/09/16	-6.5159	146.60517		Alluvial plain	Grassland	Emergent shrubs: ***Cycas schumanniana***, *Leucaena leucocephala**. Groundcover: *Imperata cylindrica,* ***Cycas schumanniana***, *Desmodium* sp., *Passiflora foetida*, Synedrella nodiflora*, Tridax procumbens**.	

Site	Date	Latitude	Longitude	Locality	Landform	Structure	Characteristic floristics	Map unit
56	07/09/16	-6.5203	146.60534		Colluvial outwash	Grassland dominated by *Imperata cylindrica* with emergent shrubs.	Emergent shrubs: *Antidesma ghaesembilla, Timonius timon, Clerodendrum tomentosum, Muessanda* sp. Groundcover: Imperata *cylindrica, Desmodium* sp., *Passiflora foetida*, Crotalaria sp., Tridax procumbens*, Vitex* sp., *Pueraria lobata*, Euphorbia schumanniana, Bothriochloa bladhii*.	4b
57	07/09/16	-6.5247	146.60435		Colluvial outwash	Low plantation open forest	*Acacia crassicarpa*, Acacia mangium*.	8a
58	07/09/16	-6.5260	146.59973		Colluvial outwash	Kunai grassland	Ground: *Imperata cylindica*. Shrubs: *Leucaena leucocephala** (recently burnt).	4c
59	07/09/16	-6.5248	146.59465		Floodplain alluvium	Woodland to open forest	Canopy/ shrub: *Nauclea orientalis, Antidesma ghaesembilla*. Ground: *Megathyrsus maximus**.	3b
60	07/09/16	-6.5279	146.58359		Footslope gully line/ Footslope	Exotic dominant open forest	Canopy: *Albizia saman**. Shrub: *Leucaena leucocephala*, Macaranga involucrata*. Ground: *Megathyrsus maximus**.	5b
61	07/09/16	-6.5781	146.60758		Alluvial floodplain deposits	Plantation	*Eucalyptus pellita*.*	9a
62	07/09/16	-6.5783	146.60722		Alluvial floodplain	Kunai grassland	Ground: *Themeda triandra, Imperata cylindica, Polytocca monophylla*. Shrubs: *Antidesma ghaesembilla*.	4c
63	08/09/16	-6.5881	146.63282		Alluvial Plain	Exotic dominated secondary forest (15-18m).	Upper: *Albizia saman**. Mid/Understorey: *Melanolepis multiglandulosa, Dysoxylum gaudichaudianum, Mallotus* sp., *Carica papaya*, Passiflora edulis*, Piper aduncum*, Stephania japonica* var. *timorensis, Asplenium* sp. Groundcover: *Megathrysus maximus**, *Alpinia* sp., *Stephania japonica* var. *timorensis, Urena lobata*.*	
64	08/09/16	-6.5863	146.63931		Colluvial outwash plain	Exotic woodland / open forest	Canopy: *Albizia saman**. Shrubs: *Leucaena leucocephala*, Glyricidia sepium*.* Ground: *Megathyrsus maximus*, Imperata cylindrica.*	5b
65	08/09/16	-6.5837	146.64940		Alluvial plain	Exotic shrubland	Shrubs: *Leucaena leucocephala**.	6a
66	08/09/16	-6.6053	146.66427		Gully of raintree adjacent to Kunai hill.	Grassland dominated by *Imperata cylindrica*.	Emergent shrubs: *Antidesma ghaesembilla*. Groundcover: *Imperata cylindrica, Passiflora foetida*, Tridax procumbens*, Euphorbia schumanniana, Bothriochloa bladhii*.	5b
67	08/09/16	-6.5811	146.63864		Alluvial Plain	Exotic grassland dominated by *Urochloa decumbens** on swampy plain.	Groundcover: *Urochloa decumbens*, Brachiaria reptans*, Arthraxon* sp., *Bothriochloa pertusa*, Cyperus brevifolius*, Commelina ensifolia*.	4d
68	08/09/16	-6.5746	146.66981		Alluvial floodplain	Plantation	Canopy: *Cocos nucifera**. Shrubs: *Theobroma cacao*, Glyricidia sepium**.	9a
69	08/09/16	-6.5551	146.69356		Alluvial plain	Exotic shrubland/ plantation	Shrubs: *Leucaena leucocephala**.	8a
70	08/09/16	-6.5405	146.69888		Alluvial plain	Exotic grassland	Ground: Mostly rice plantation mixed with exotic grasses and forbs.	4d

Site	Date	Latitude	Longitude	Locality	Landform	Structure	Characteristic floristics	Map unit
71	08/09/16	-6.5321	146.70216		Footslope on unconsolidated volcanics	Plantation	Canopy: *Pinus carribea**.	8b
72	08/09/16	-6.5219	146.70700		Alluvial floodplain	Exotic open forest	Canopy: *Albizia saman**, *Tectonia grandis**.	5b

Appendix B

Terrestrial flora species recorded within the study area

APPENDIX B: Terrestrial Flora Species Recorded Within the Study Area

Abbreviations:
Status: IUCN: Extinct in the Wild (EW), Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT).
Habitat type: Broad crowned lowland forest (1a), Small crowned forest / regrowth forest (2a), Savannah dominated by *Nauclea orientalis/Albizia procera* (3a), Kunai grassland on riverine alluvium (4a), Kunai grassland on footslopes and hillsopes (4b), Kunai grassland on riverine alluvium – severely degraded (4c), Savannah dominated by *Albizia saman** (5a), Open forest dominated by *Albizia saman** (5b), Shrubland dominated by *Leucaena leucocephala** (6a), Degraded pasture grassland (7a), Plantation areas / rice and palm oil (8a), *Pinus* and *Araucaria* plantations (8b), Roadsides, gardens and village areas (9).
Biocultural: Plants with recorded traditional uses (refer to Appendix D for further details).
Asterix *: Denotes an exotic (non-native) plant species.
Pic: Digital Image available
Survey record sources: BAAM 2016: September 2016 field survey (D.G. Fell, D.J. Stanton, P. Lloyd); **HERBRECS**: Records of the Queensland Herbarium (BRI) database of vouchered specimens.

Plant name			Source		Status		Habitat code													
Family name	Species	Common name	BAAM 2016	Herbrecs	Biocultural significance	IUCN	1a	2a	3a	4a	4b	4c	5a	5b	6a	7a	8a	8b	9	pic
Pteridiophytes (Ferns & Fern Allies)																				
Adiantaceae	*Adiantum atroviride*	Maidenhair fern	-	-	-		x	-	-	-	-	x	-	-	-	-	-	-	-	-
Adiantaceae	*Pityrogramma calomelanos* var. *calomelanos*	-	x	x	-		-	-	-	-	-	-	-	-	-	-	-	-	x	
Aspleniaceae	*Asplenium nidus*	Bird's nest fern	x	-	-		x	x	-	-	-	-	x	-	-	-	-	-	-	-
Athyriaceae	*Diplazium esculentum*	-	x	-	x		x	x	-	-	-	-	-	x	-	-	-	-	-	x
Cycadaceae	*Cycas schumanniana*	-	x	-	x	NT	x	-	-	-	-	-	-	-	-	-	-	-	-	x
Davalliaceae	*Davallia solida*	Hares foot fern	-	-	-		x	-	-	-	-	-	-	-	-	-	-	-	-	-
Nephrolepiadaceae	*Nephrolepis bisecta*	Sword fern	-	-	-		-	x	-	-	-	-	-	x	-	-	-	-	-	-
Nephrolepiadaceae	*Nephrolepis bisserata*	Giant sword fern	x	-	-		-	x	-	-	-	-	-	x	-	-	-	-	-	-
Polypodiaceae	*Platycerium bifurcatum*	Elkhorn fern	-	-	-		x	x	-	-	-	-	-	-	-	-	-	-	-	-
Polypodiaceae	*Pyrrosia lanceolata*	-	x	-	-		x	x	-	-	-	-	-	x	-	-	-	-	-	-
Thelypteridaceae	*Christella arida*	-	x	-	-		x	x	-	-	-	-	-	-	-	-	-	-	-	-
Thelypteridaceae	*Cyclosorus interruptus*	-	x	-	-		x	x	-	-	-	-	-	-	-	-	-	-	-	-
Gymnosperms (Pines)																				
Araucariaceae	*Araucaria cunninghamii* var. *papuana*	Hoop Pine	x	-	x		-	-	-	-	-	-	-	-	-	-	-	x	-	x
Araucariaceae	*Araucaria hunstenii*	Kinki Pine	x	-	x		-	-	-	-	-	-	-	-	-	-	-	x	-	-
Gnetaceae	*Gnetum gnemon*	Tulip	x	-	x		x	x	-	-	-	-	-	-	-	-	-	-	-	x
Pinaceae	*Pinus carribbea**	Carribean Pine	x	-	-		-	-	-	-	-	-	-	-	-	-	-	x	-	-
Angiosperms (Flowering plants)																				
Acanthaceae	*Asystasia sp.**	-	x	-	-		-	-	-	-	-	-	-	-	-	x	-	x	x	x
Agavaceae	*Agave sisalana**	Sisal hemp, Manilla Rope	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	x	
Amaranthaceae	*Achyranthes aspera*	Chaff flower	x	-	-		-	-	-	x	x	-	-	-	-	-	-	-	x	
Amaranthaceae	*Alternanthera brasiliana**	Brazilian joyweed	x	-	-		-	-	-	-	-	-	-	-	-	-	-	-	x	-
Amaranthaceae	*Alternanthera denticulata var. denticulata**	Lesser joyweed	x	-	-		-	-	-	-	-	-	-	-	-	x	-	-	x	-
Amaranthaceae	*Alternanthera ficoidea**	Red threads	x	-	-		-	-	-	-	-	-	-	-	-	x	-	-	x	

Plant name			Source		Status		Habitat code													
Family name	**Species**	**Common name**	**BAAM 2016**	**Herbrecs**	**Biocultural significance**	**IUCN**	**1a**	**2a**	**3a**	**4a**	**4b**	**4c**	**5a**	**5b**	**6a**	**7a**	**8a**	**8b**	**9**	**pic**
Amaranthaceae	*Amaranthus viridis**	Slender amaranth	x	-	-		-	-	-	-	-	-	-	-	-	-	-	-	x	
Amaranthaceae	*Celosia spicata**	Cockscomb	x	-	-		-	-	-	-	-	-	X	-	-	-	-	-	x	x
Amaryllidaceae	*Crinum asiaticum*	Crinum lily	x	-	-		-	-	x	-	-	-	-	-	-	-	-	-	-	-
Anacardiaceae	*Buchanania arborescens*	Satinwood	x	-	-		x	x	-	-	x	-	-	-	-	-	-	-	-	-
Anacardiaceae	*Buchanania macrocarpa*	-	x	-	-		x	x	-	-	x	-	-	-	-	-	-	-	-	-
Anacardiaceae	*Dracontomelon dao*	New Guinea walnut	x	-	x		x	-	-	-	-	-	-	-	-	-	-	-	-	x
Anacardiaceae	*Mangifera minor*	Wild mango	x	-	x		-	-	-	-	x	-	-	-	-	-	-	-	-	x
Anacardiaceae	*Rhus taitensis*	Sumac	-	-	-		-	-	-	-	x	-	-	-	-	-	-	-	-	-
Apiaceae	*Centella asiatica*	Gotu kolu	x	-	-		-	-	-	x	-	-	-	-	-	-	-	-	x	x
Apocynaceae	*Alstonia scholaris*	Milky pine	x	-	x		x	x	-	-	x	-	-	-	-	-	-	-	-	x
Apocynaceae	*Asclepias curassavica**	Inkweed	x	x	-		-	-	-	-	-	-	-	-	x	x	x	-	x	-
Apocynaceae	*Calotropis procera**	Calatropis	x	-	x		-	-	-	-	-	-	-	-	-	-	-	-	x	-
Apocynaceae	*Cascabela thevetia**	Yellow Oleander	x	-	-		-	-	-	-	-	-	-	-	-	-	-	-	x	-
Apocynaceae	*Catharanthus roseus**	Madagascar periwinkle	x	-	x		-	-	-	-	-	-	x	-	-	-	-	-	x	-
Apocynaceae	*Cynachum sp.*	-	x	-	x		x	-	-	-	-	-	x	-	-	-	-	-	-	x
Apocynaceae	*Ichnocarpus frutescens*	-	x	x	x		x	x	x	-	-	-	-	x	-	-	-	-	x	-
Apocynaceae	*Marsdenia* sp.	-	-	-	-		x	-	-	-	-	-	x	-	-	-	-	-	-	-
Apocynaceae	*Parsonsia oligantha*	-	-	x	-		x	x	-	-	-	-	-	-	-	-	-	-	-	-
Apocynaceae	*Parsonsia* sp.	-	-	-	x		x	-	-	-	-	-	x	-	-	-	-	-	-	-
Apocynaceae	*Plumeria odorata**	Frangipani	x	-	x		-	-	-	-	-	-	-	-	-	-	-	-	x	-
Apocynaceae	*Tabernaemontana pandacaqui*	Banana bush	x	-	-		x	x	-	-	-	-	-	-	-	-	-	-	-	-
Araceae	*Calocasia esculenta*	Taro	x	-	x		-	-	-	-	-	-	-	-	-	-	-	-	x	x
Araceae	*Epipremum amplissimum*	-	x	-	x		x	x	-	-	-	-	x	-	-	-	-	-	-	-
Araceae	*Rhaphidophora pachyphylla*	-	x	-	-		x	-	-	-	-	-	x	-	-	-	-	-	-	-
Arecaceae	*Areca catchu*	Betel nut	x	-	x		x	-	-	-	-	-	-	-	-	-	-	-	-	x
Arecaceae	*Calamus longipinna*	Wait a while	x	-	x		x	x	-	-	-	-	x	-	-	-	-	-	-	x
Arecaceae	*Calamus sp.*	A Wait a while	-	-	x		x	-	-	-	-	-	-	-	-	-	-	-	-	-
Arecaceae	*Caryota rumphiana*	Fishtail palm	x	-	x		x	-	-	-	-	-	-	-	-	-	-	-	-	-
Arecaceae	*Cocos nucifera**	Coconut palm	x	-	x		-	-	-	-	-	-	-	-	-	-	x	-	x	x
Arecaceae	*Hydriastele costata*	Galubia palm	x	-	x		x	-	-	-	-	-	-	-	-	-	-	-	-	x
Arecaceae	*Metroxylon sagu*	Sago palm	x	-	x		x	-	-	-	-	-	-	-	-	-	-	-	-	x
Arecaceae	*Orania* sp.	-	x	-	x		x	-	-	-	-	-	-	-	-	-	-	-	-	-
Arecaceae	*Ptychosperma macarthurii*	MacArthur Palm	x	-	x		x	-	-	-	-	-	-	-	-	-	-	-	-	x
Arecaceae	*Ptychosperma sp.*	-	-	-	x		x	-	-	-	-	-	x	-	-	-	-	-	-	-
Aristolochiaceae	*Aristolochia momandul*	-	x	-	-		x	x	-	-	-	-	-	-	-	-	-	-	-	-
Asteraceae	*Acmella grandiflora var. brachyglossa*	-	x	x	-		-	-	-	-	-	-	-	-	-	-	-	-	x	-
Asteraceae	*Bidens pilosa**	Cobblers pegs	x	-	-		-	-	-	-	x	-	x	-	-	-	-	x	x	-
Asteraceae	*Blumea lacera var. blumei**	-	-	x	-		-	-	-	x	x	x	-	-	-	-	-	-	-	
Asteraceae	*Camptacra gracilis*	-	-	x	-		-	-	-	-	-	-	x	-	-	-	-	-	x	-
Asteraceae	*Chromolaena odorata**	Siam weed	x	-	-		-	-	-	x	x	x	x	x	x	x	x	x	x	x

Plant name			Source		Status		Habitat code													
Family name	Species	Common name	BAAM 2016	Herbrecs	Biocultural significance	IUCN	1a	2a	3a	4a	4b	4c	5a	5b	6a	7a	8a	8b	9	pic
Asteraceae	*Conyza sumatrensis**	Conyza	x	-	-		-	-	-	x	x	x	x	x	x	x	x	x	x	-
Asteraceae	*Cosmos caudatus**	Cosmos	-	x	-		-	-	-	-	-	-	-	-	-	-	-	-	x	-
Asteraceae	*Crassocephalum crepidioides**	Thickhead	x	x	-		-	-	-	-	-	-	-	x	x	x	x	x	x	-
Asteraceae	*Cyanthillium cinereum*	Little ironweed	x	x	-		-	-	-	-	x	x	x	-	-	-	x	x	x	-
Asteraceae	*Eclipta prostrata*	False daisy	x	x	-		-	-	x	x	x	-	-	-	-	-	-	-	-	-
Asteraceae	*Eleutheranthera ruderalis**	Ogiera	x		-		-	-	-	-	-	-	-	-	-	x	x	x	x	-
Asteraceae	*Mikania micrantha**	Bitter vine	x	-	-		x	-	-	-	-	x	x	x	-	-	-	-	-	x
Asteraceae	*Pterocaulon redolens*	-	x	x	-		-	x	x	x	-	-	-	-	-	-	-	-	-	x
Asteraceae	*Sigesbeckia orientalis*	-	x	x	-		-	-	x	x	x	-	-	-	-	-	-	-	-	-
Asteraceae	*Synedrella nodiflora**	Cinderella weed	x	-	-		-	-	-	-	-	x	x	x	x	x	x	x	x	x
Asteraceae	*Tridax procumbens**	Tridax daisy	x	-	-		-	-	-	-	-	-	-	-	x	x	x	x	x	x
Asteraceae	*Wollastonia biflora*	-	-	x	-		-	-	-	x	-	-	-	-	-	-	-	-	-	-
Asteraceae	*Apowollastonia major*	-	-	x	-		-	-	-	-	-	-	x	-	-	-	-	-	-	-
Balsaminaceae	*Impatiens* sp.*	Impatiens	x	-	x		-	-	-	-	-	-	-	-	-	-	-	-	-	x
Bignoniaceae	*Spathodea campanulata**	African Tulip Tree	x	-	-		-	x	-	-	-	-	-	x	-	-	-	-	x	-
Bignoniaceae	*Tecoma stans var. stans**	Yellow bells	x	-	-		-	-	-	-	-	-	-	-	x	-	-	-	x	-
Bignoniaceae	*Tectonia grandis**	Burmese Teak	x	-	-		-	-	-	-	-	-	-	-	-	-	-	x	x	-
Bombacaceae	*Bombax ceiba var. leiocarpum*	Bombax	x	-	x		x	x	-	-	-	-	-	-	x	-	-	-	-	x
Boraginaceae	*Heliotropium* sp.*	Heliotropium	x	-			-	-	-	-	-	-	-	-	-	-	-	-	x	x
Bromeliaceae	*Ananus comosus**	Pineapple	x	-	x		-	-	-	-	-	-	-	-	-	-	-	-	x	-
Burseraceae	*Garuga floribunda* var. *floribunda*	Garuga	x	-	x		x	x	-	-	-	-	-	-	-	-	-	-	-	x
Byttneriaceae	*Commersonia bartramia*	Brown kurrajong	x	-	x		x	x	-	-	-	-	-	-	-	-	-	-	-	-
Byttneriaceae	*Commersonia novoguineensis*	New Guinea Kurrajong	x	-	x		x	x	-	-	-	-	-	-	-	-	-	-	-	-
Byttneriaceae	*Kleinhovia hospita*	Kleinhovia	x	-	x		x	x	-	-	-	-	-	x	-	-	-	-	-	x
Byttneriaceae	*Melochia umbellata*	-	x	x	-		x	x	-	-	-	-	-	x	-	-	-	-	-	-
Caesalpiniaceae	*Cassia fistula**	Golden Shower tree	x	-	-		-	-	-	-	-	-	-	-	-	-	-	-	x	-
Caesalpiniaceae	*Cassia javanica**	Apple blossom tree	x	-	-		-	-	-	-	-	-	-	x	-	-	-	-	x	-
Caesalpiniaceae	*Cassia renigera**	Burmese pink cassia	x	-	-		-	-	-	-	-	-	-	-	-	-	-	-	x	-
Caesalpiniaceae	*Cassia sp.**	A Cassia	x	-	x		-	-	-	-	-	-	x	x	x	x	-	-	x	x
Caesalpiniaceae	*Senna alata**	Candlenut bush	x	-	x		-	-	-	-	-	-	-	-	-	-	-	-	x	x
Caesalpiniaceae	*Senna hirsuta**	Hairy senna	x	-	-		-	-	-	-	-	-	x	-	-	x	-	-	x	x
Caesalpiniaceae	*Senna occidentalis**	Coffee bush	x	-	-		-	-	-	-	-	-	x	-	-	x		-	x	-
Caeslapiniaceae	*Sesbania cannabina*	Sesbania	x	-	-		-	-	x	-	-	-	-	-	-	-	-	-	-	-
Capparaceae	*Capparis sepiaria*	-	-	x	-		x	-	-	-	-	-	-	-	-	-	-	-	-	-
Caricaceae	*Carica papaya**	Papaya	x	-	x		-	-	-	-	-	-	-	x	-	-	-	-	x	-
Cleomaceae	*Cleome viscosa*	-	x	-	-		-	x	x	x	-	-	-	-	-	-	-	-	-	x
Combretaceae	*Terminalia catappa*	Indian almond	x	-	x		-	-	-	-	-	-	-	-	-	-	-	-	x	-
Combretaceae	*Terminalia complanata*	Damson	x	-	x		-	-	-	-	-	-	-	-	-	-	-	-	-	x
Commelinaceae	*Commelina diffusa*	Wandering dew	x	-	-		-	x	x	x	-	-	-	-	-	-	-	-	x	-
Commelinaceae	*Commelina ensifolia*	Scurvy Weed	x	x	-		-	x	x	x	-	-	-	-	-	-	-	-	x	-

Plant name			Source		Status		Habitat code													
Family name	**Species**	**Common name**	**BAAM 2016**	**Herbrecs**	**Biocultural significance**	**IUCN**	**1a**	**2a**	**3a**	**4a**	**4b**	**4c**	**5a**	**5b**	**6a**	**7a**	**8a**	**8b**	**9**	**pic**
Convolvulaceae	*Erycibe grandiflora*	-	x	x	-		-	-	x	x	-	-	-	-	-	-	-	-	-	-
Convolvulaceae	*Ipomoea batatas**	Sweet potato	x	-	x		-	-	-	-	-	-	-	-	-	-	-	-	x	-
Convolvulaceae	*Ipomoea hederifolia**	Scarlet creeper	x	-	-		-	-	-	-	-	-	x	x	-	-	-	-	-	x
Convolvulaceae	*Ipomoea nil*	-	x	-	-		-	-	-	-	-	-	x	x	-	-	-	-	-	x
Convolvulaceae	*Ipomoea obscura*	Obscur Morning Glory	x	-	-		-	-	-	-	-	-	x	x	-	-	-	-	-	x
Convolvulaceae	*Ipomoea quamoclit**	Cupids Flower	x	-	-		-	-	-	-	-	-	x	x	-	-	-	-	-	x
Convolvulaceae	*Ipomoea sp.*	-	x	-	-		-	-	-	-	-	-	x	x	-	-	-	-	-	x
Convolvulaceae	*Merremia quinata*	-	x	x	-		-	-	-	x	x	-	-	-	-	-	-	-	-	-
Cucurbitaceae	*Citrullus lanatus**	Watermelon	x	-	x		-	-	-	-	-	-	-	-	-	-	-	-	x	-
Cucurbitaceae	*Cucumis melo**	Melon	x	-	x		-	-	-	-	-	-	-	-	-	-	-	-	x	-
Cucurbitaceae	*Cucumis sativus**	Cucumber	x	-	x		-	-	-	-	-	-	-	-	-	-	-	-	x	-
Cucurbitaceae	*Cucurbita maxima**	Pumpkin	x	-	x		-	-	-	-	-	-	-	-	-	-	-	-	x	-
Cucurbitaceae	*Diplocyclos palmatus*	Striped cucumber	x	x	-		-	-	-	x	x	x	-	-	-	-	-	-	x	-
Cucurbitaceae	*Momordica charantia*	Bitter melon	x	-	-		-	-	-	-	-	-	-	x	-	-	-	-	x	
Cucurbitaceae	*Momordica cochinchinensis**	Gac	x	-	-		-	-	-	-	-	-	-	-	-	-	-	-	x	x
Cucurbitaceae	*Mukia maderaspatata*	-	x	-	-		-	-	-	x	x	x	-	-	-	-	-	-	-	-
Cucurbitaceae	*Trichosanthes edulis*	-	x	-	x		-	x	-	-	-	-	-	x	-	-	-	-	-	-
Cyperaceae	*Cyperus javanicus*	-	x	x	-		-	-	-	-	-	-	-	-	-	x	x	-	-	x
Cyperaceae	*Cyperus brevifolius*	Mullumbimby couch	x	-	-		x	-	-	-	-	-	-	-	-	-	-	-	-	x
Cyperaceae	*Cyperus difformis*	Variable flatsedge	x	-	-		-	-	-	-	-	-	x	-	-	-	-	-	-	-
Cyperaceae	*Cyperus haspan* subsp. *haspan*	-	x	-	-		-	x	-	-	-	-	-	-	-	-	-	-	-	-
Cyperaceae	*Cyperus nutans*	-	-	x	-		-	-	-	-	-	-	-	-	-	x	-	-	-	-
Cyperaceae	*Fimbristylis dichotoma*	Common fringerush	x	-	-		-	-	-	x	x	-	-	-	-	x	-	-	-	-
Cyperaceae	*Scleria ciliaris*	-	-	-	-		-	-	-	x	x	x	-	-	-	-	-	-	-	-
Cyperaceae	*Scleria leavis*	-	-	-	-		-	-	-	x	x	x	-	-	-	-	-	-	-	-
Cyperaceae	*Schoenus falcatus*	-	-	x	-		-	-	-	-	x	-	-	-	-	-	-	-	-	-
Dioscoreaceae	*Dioscorea bulbifera*	Yam	x	-	x		x	-	-	-	-	-	-	x	-	-	-	-	x	-
Dioscoreaceae	*Dioscorea* sp.	A Yam	x	-	x		x	-	-	-	-	-	-	x	x	-	-	-	-	-
Elaeocarpaceae	*Muntingia calabura**	Japanase strawberry	x	-	x		-	-	-	-	-	-	x	-	-	-	-	-	x	x
Euphorbiaceae	*Abelmoschus manihot* subsp. *manihot*	Aibeka	x	-	x		-	-	-	-	-	-	-	-	-	-	-	-	x	-
Euphorbiaceae	*Acalypha lanceolata**	-	-	x	-		-	-	-	-	-	-	-	-	-	-	-	-	x	-
Euphorbiaceae	*Endospermum medullosum*	Moon tree	x	-	x		x	x	-	-	-	-	-	-	-	-	-	-	-	x
Euphorbiaceae	*Euphorbia bifida*	-	x	-	x		-	-	-	x	x	-	-	-	-	-	-	-	-	x
Euphorbiaceae	*Euphorbia cyathophora**	Painted spurge	x	-	-		-	-	-	-	-	-	-	-	-	-	-	-	x	-
Euphorbiaceae	*Euphorbia heterophylla**	Painted spurge	x	-	-		-	-	-	-	-	-	-	-	-	-	-	-	x	-
Euphorbiaceae	*Euphorbia hirta**	Caustic weed	x	-	-		-	-	-	-	-	-	-	-	-	-	-	-	x	x
Euphorbiaceae	*Euphorbia reniformis*	-	-	x	-		-	-	-	x	-	-	-	-	-	-	-	-	x	-
Euphorbiaceae	*Euphorbia schumanniana*	-	x	-	-		-	-	-	-	x	-	-	-	-	-	-	-	-	-
Euphorbiaceae	*Homalanthus novoguineensis*	Bleeding heart	x	-	-		x	x	-	-	-	-	-	-	-	-	-	-	-	x
Euphorbiaceae	*Jatropha gossypifolia**	Belly ache bush	x	-	-		-	-	-	-	-	-	-	-	-	-	-	-	x	x

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Euphorbiaceae	*Macaranga involucrata* var. *mallotoides*	-	x	-	x		x	-	x	-	-	-	-	-	-	-	-	-	-	-
Euphorbiaceae	*Macaranga quadriglandulosa*	-	x	-	x		x	-	-	-	-	-	-	-	-	-	-	-	-	x
Euphorbiaceae	*Macaranga tanarius*	Macaranga	x	-	x		x	-	-	-	-	-	-	-	-	-	-	-	-	x
Euphorbiaceae	*Mallotus mollisimus*	-	x	-	x		x	-	-	-	-	-	-	-	-	-	-	-	-	-
Euphorbiaceae	*Mallotus paniculatus*	Turn in the wind	x	-	x		x	-	-	-	-	-	-	-	-	-	-	-	-	x
Euphorbiaceae	*Mallotus philippensis*	Red Kamala	x	x	-		x	-	-	-	-	-	-	-	-	-	-	-	-	x
Euphorbiaceae	*Manihot esculenta**	Cassava	x	-	x		-	-	-	-	-	-	-	-	-	-	-	-	x	x
Euphorbiaceae	*Manihot glaziovii**	Ceara Rubber	X	-	-		-	-	-	-	-	-	x	-	-	-	-	-	x	x
Euphorbiaceae	*Melanolepis multiglandulosa*	-	x	-	x		x	-	-	-	-	-	-	x	-	-	-	-	-	x
Euphorbiaceae	*Ricinis communis**	Castor oil plant	x	-			-	-	-	-	-	-	-	-	-	-	-	-	x	x
Fabaceae	*Abrus precatorius* subsp. *precatorius*	Precatory bean	x	-	x		x	-	-	-	-	-	-	-	-	-	-	-	-	x
Fabaceae	*Aeschynomene americana* var. *glandulosa*	American Jointvetch	x	x	-		-	-	-	-	-	x	-	-	-	x	-	-	-	-
Fabaceae	*Aeschynomene falcata*	-	-	x	-		-	-	-	-	-	-	-	-	-	x	-	-	x	-
Fabaceae	*Aeschynomene indica**	Buddha pea	x	-	-		-	-	-	-	-	x	-	-	-	x	-	-	-	-
Fabaceae	*Alysicarpus vaginalis**	Alyce clover	x	-	-		-	-	-	-	-	x	-	-	-	x	-	-	x	-
Fabaceae	*Calopogonium mucunoides**	Calapo	x	-	-		-	-	-	-	-	x	-	-	-	x	-	-	x	-
Fabaceae	*Centrosema molle**	Centro	x	-	x		-		-	-	-	x	-	-	-	x	-	-	x	-
Fabaceae	*Clitoria ternatea**	Butterfly pea	x	-	-		-		-	-	-	x	-	-	-	x	-	-	x	-
Fabaceae	*Crotalaria calycina*	Rattlepod	x	-	-		-	-	-	x	x	-	-	-	-	-	-	-	-	-
Fabaceae	*Crotalaria montana*	-	x	-	-		-	-	-	x	x	-	-	-	-	-	-	-	-	-
Fabaceae	*Crotalaria pallida**	Streaked rattlepod	x	-	-		-	-	-	-	-	x	-	-	-	x	-	-	x	x
Fabaceae	*Desmanthus pernambucanus**	-	x	x	-		-	-	-	-	-	x	-	x	-	x	-	-	x	x
Fabaceae	*Desmodium gangeticum*	-	-	x	-		-	-	-	x	-	-	-	-	-	-	-	-	-	-
Fabaceae	*Desmodium heterocarpon var. strigosum*	-	x	x	-		-	-	x	x	x	-	-	-	-	-	-	-	-	-
Fabaceae	*Desmodium intortum**		x	x	-		-	-	-	-	-	-	-	-	x	-	-	-	x	-
Fabaceae	*Desmodium rhtidiophyllum*	-	x	-	-		-	-	x	x	x	-	-	-	-	-	-	-	-	-
Fabaceae	*Flemingia strobilifera*	-	x	x	-		-	-	x	x	x	-	-	-	-	-	-	-	-	-
Fabaceae	*Galactia tenuiflora*	-	x	x	-		-	-	x	x	x	-	-	-	-	-	-	-	-	-
Fabaceae	*Glycine tomentella*	-	x	x	-		-	-	x	x	x	-	-	-	-	-	-	-	-	-
Fabaceae	*Glyricidia sepium**	Glyricidia	x	-	x		-	-	-	-	-	-	x	x	x	x	x	x	x	x
Fabaceae	*Hanslia hentyi*	-	x	x	x		x	x	-	-	-	-	-	-	-	-	-	-	-	x
Fabaceae	*Hanslia ormocarpoides*	-	x	x	-		x	x	-	-	-	-	-	-	-	-	-	-	-	x
Fabaceae	*Indigofera hirsuta*	Hairy rattlepod	x	x	-		-	-	-	-	-	-	-	-	-	x	-	-	x	-
Fabaceae	*Indigofera linnaei*	Nine leaf indigo	-	x	-		-	-	x	x	x	-	-	-	-	-	-	-	-	-
Fabaceae	*Indigofera linnifolia*	-	-	x	-		-	-	x	x	x	-	-	-	-	-	-	-	-	-
Fabaceae	*Indigofera suffruticosa*	-	x	-	-		-	-	x	x	x	-	-	-	-	-	-	-	-	-
Fabaceae	*Indigofera tinctoria*	-	x	x	-		-	-	-	-	x	-	-	-	-	x	-	-	x	-
Fabaceae	*Indigofera trifoliata*	-	-	x	-		-	-	-	-	x	-	-	-	-	x	-	-	x	-

Plant name			Source		Status		Habitat code													
Family name	Species	Common name	BAAM 2016	Herbrecs	Biocultural significance	IUCN	1a	2a	3a	4a	4b	4c	5a	5b	6a	7a	8a	8b	9	pic
Fabaceae	*Intsia bijuga*	Kwila	x	-	x	V	-	x	-	-	-	-	-	-	-	-	-	-	-	-
Fabaceae	*Lourea obcordata*	-	--	x	-		-	-	-	x	-	-	-	-	-	-	-	-	-	-
Fabaceae	*Macroptilium atropurpureum**	Siratro	x	x	-		-		-	-	-	x	-	-	-	x	-	-	x	-
Fabaceae	*Macroptilium lathyroides**	Phasey bean	x	x	-		-		-	x	x	x	-	-	-	x	-	-	x	-
Fabaceae	*Pueraria montana var. lobata*	Kudzu	x	x	x		-		x	x	x	x	x	-	-	x	-	-	x	-
Fabaceae	*Pycnospora lutescens*	-	x	-	-		-	-	x	x	x	-	-	-	-	-	-	-	-	x
Fabaceae	*Rhynchosia acumatissima*	Pointed trefoil	x	-	-		-	x	x	-	-	-	-	-	-	-	-	-	-	-
Fabaceae	*Stylosanthes guianensis**	Stylo	x	-	-		-	-	-	-	-	-	-	-	-	x	-	-	x	-
Fabaceae	*Stylosanthes hamata**	Carribean stylo	x	x	-		-	-	-	-	-	-	-	-	-	x	-	-	x	-
Fabaceae	*Stylosanthes humilis**	Stylo	x	-	-		-	-	-	-	-	-	-	-	-	x	-	-	x	x
Fabaceae	*Tephrosia purpurea var. pubescens*	-	x	x	-		-	-	-	x	x	-	-	-	-	-	-	-	-	-
Fabaceae	*Uraria lagopodioides*	Chakulia	x	-	-		-	-	-	x	x	-	-	-	-	-	-	-	-	x
Fabaceae	*Uraria picta*	-	x	-	-		-	-	-	x	x	-	-	-	-	-	-	-	-	-
Flacourtiaceae	*Casearia clutiifolia*	-	-	x	-		x	-	-	-	-	-	-	-	-	-	-	-	-	-
Flagellariaceae	*Flagellaria indica*	Supplejack	x	-	x		x	x	-	-	-	-	-	-	-	-	-	-	-	x
Lamiaceae	*Hyptis capitata**	Knob weed	x	-	-		-	-	-	-	-	-	-	-	x	x	-	-	x	x
Lamiaceae	*Hyptis suaveolens**	Chinese mint	x	-	-		-	-	-	-	-	-	-	-	x	x	-	-	x	x
Lamiaceae	*Ocimum gratissimum*	Wild basil	x	-	-		-	-	-	x	-	-	-	-	-	-	-	-	-	-
Lamiaceae	*Premna obtusifolia*	-	x	-	-		-	x	-	-	-	-	-	-	-	-	-	-	-	x
Lamiaceae	*Premna odorata*	-	x	-	x		X	x	-	-	-	-	-		-	-	-	-	-	x
Lamiaceae	*Vitex sp.*	-	x	-	x		-	-	-	x	x	-	-	-	-	-	-	-	-	x
Lauraceae	*Cassytha filiformis*	Dodder	x	-	-		-	-	-	x	x	-	-	x	-	-	-	-	-	x
Lauraceae	*Litsea guppyi*	-	x	-	x		x	x	-	-	-	-	-	-	-	-	-	-	-	x
Lauraceae	*Litsea timoriana*	-	-	-	x		x	x	-	-	-	-	-	x	-	-	-	-	-	x
Laxmanniaceae	*Cordyline fruticosa*	Cordyline	x	-	-		x	-	-	-	-	-	-		-	-	-	-	-	-
Laxmanniaceae	*Cordyline terminalis*	Cordyline	x	-	-		-	-	-	-	-	-	-	-	-	-	-	-	x	-
Lecythidaceae	*Planchonia papuana*	Planchonia	x	-	x		x	x	-	-	-	-	-	-	-	-	-	-	-	x
Linderniaceae	*Lindernia antipoda*	-	-	x	-		-	-	x	x	-	-	-	-	-	x	-	-	-	-
Loganiaceae	*Mitrasacme pygmaea*	Pygmy bishop’s hat	-	-	-		-	-	-	x	x	-	-	-	-	-	-	-	x	-
Loranthaceae	*Amyema* sp.	Mistletoe	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-
Malvaceae	*Abelmoschus moschatus*	Musk mallow	x	x	x		-	-	-	x	x	x	-	-	-	-	-	-	-	-
Malvaceae	*Abelmoschus manihot* subsp. *tetraphyllus*	-	x	-	-		-	-	-	-	-	-	-	-	-	-	-	-	x	x
Malvaceae	*Hibiscus rosa-sinensis**	HIbiiscus	x	-	x		-	-	-	-	-	-	-	-	-	-	-	-	x	-
Malvaceae	*Hibiscus tiliaceus*	Cottonwood	x	x	-		-	x	-	-	-	-	-	-	-	-	-	-	-	-
Malvaceae	*Malvastrum coromandelianum subsp. coromandelianum**	-	x	-	-		-	-	-	-	-	-	-	-	-	-	-	-	x	-
Malvaceae	*Sida acuta**	Spinyhead sida	x	-	x		-	-	-	-	-	-	-	-	-	-	-	-	x	x
Malvaceae	*Sida cordifolia**	Fannel weed	x	-	-		-	-	-	-	-	-	-	-	-	-	-	-	x	-
Malvaceae	*Sida rhombifolia**	Arrowleaf sida	x	-	-		-	-	-	-	-	-	-	-	-	-	-	-	x	
Malvaceae	*Sida spinosa*	-	-	x	-		-	-	-	-	-	-	-	-	-	-	-	-	x	-

Plant name			Source		Status		Habitat code													
Family name	**Species**	**Common name**	**BAAM 2016**	**Herbrecs**	**Biocultural significance**	**IUCN**	**1a**	**2a**	**3a**	**4a**	**4b**	**4c**	**5a**	**5b**	**6a**	**7a**	**8a**	**8b**	**9**	**pic**
Malvaceae	*Theobroma cacao**	Cacao	x	-	x		-	-	-	-	-	-	-	-	-	-	-	-	x	x
Malvaceae	*Urena lobata**	Caeser weed	x	-	-		-	-	-	-	-	-	-	x	-	x	x	-	x	-
Marantaceae	*Phrynium macrocephalium*	-	x	-	-		x	x	-	-	-	-	-	x	-	-	-	-	x	-
Meliaceae	*Azadirachta indica**	Neem Tree	x	-	-		-	-	-	-	-	--	-	x	-	-	-	-	x	x
Meliaceae	*Dysoxylum gaudichaudianum*	Ivory mahogany	x	-	x		x	x	-	-	-	-	-	x	-	-	-	-	-	x
Meliaceae	*Dysoxylum parasiticum*	Yellow mahogany	x	-	x		x	x	-	-	-	-	-	x	-	-	-	-	-	-
Meliaceae	*Dysoxylum pettigrewianum*	Spur mahogany	x	-	x		x	x	-	-	-	-	-	-	-	-	-	-	-	-
Meliaceae	*Melia azederach*	White Cedar	x	-	-		-	x	-	-	-	-	-	x	-	-	-	-	-	-
Menispermaceae	*Pachygone sp.*	-	x	-	-		x	x	-	-	-	-	-	x	-	-	-	-	-	x
Menispermaceae	*Stephania japonica var. timorensis*	Snake vine	x	-	-		x	x	-	-	-	-	-	x	-	-	-	-	-	-
Mimosaceae	*Acacia crassicarpa**	Spoon wattle	x	-	x		-	-	-	-	-	-	-	-	-	-	x	-	-	x
Mimosaceae	*Albizia procera*	Forest siris	x	-	x		-	-	-	x	x	x	-	-	-	-	-	-	-	x
Mimosaceae	*Albizia saman**	Raintree	-	-	x		x	x	x	x	-	x	x	x	x	x	-	-	x	x
Mimosaceae	*Falcataria moluccana**	Moluccan albizia	x	--	-		-	-	-	-	-	-	x	-	-	-	-	-	x	-
Mimosaceae	*Leucaena leucocephala* subsp. *leucocephala**	Leucaena	x	-	x		-	x	-	-	-	x	x	x	x	x	x	x	x	x
Mimosaceae	*Mimosa diplotricha**	Giant sensitive weed	x	-	-		-	-	-	-	-	x	x	-	x	x	x	-	x	x
Mimosaceae	*Mimosa pudica**	Sensitive weed	x	-	-		-	-	-	-	-	x	x	-	x	x	x	-	x	x
Moraceae	*Antiaris toxicarya var. macrophylla*	Poison Fig	x	-	x		x	x	-	-	-	-	-	x	-	-	-	-	x	x
Moraceae	*Artocarpus altilis*	Breadfruit	x	-	x		x	x	-	-	-	-	-	x	-	-	-	-	x	-
Moraceae	*Ficus adenosperma*	A fig	-	x	-		-	-	-	x	-	-	-	-	-	-	-	-	-	-
Moraceae	*Ficus copiosa*	Plentiful fig	x	-	x		x	x	-	-	-	-	-	x	-	-	-	-	-	-
Moraceae	*Ficus mollior*	Sandpaper fig	x	-			x	x	-	-	-	-	-	x	-	-	-	-	-	-
Moraceae	*Ficus septica*	Septic fig	x	-	x		x	x	-	-	-	-	-	x	-	-	-	-	-	-
Moraceae	*Ficus variegata*	Red stem fig	x	-	x		x	x	-	-	-	-	-	x	-	-	-	-	-	-
Moraceae	*Ficus wassa*	A fig	x	-	x		x	x	-	-	-	-	-	x	-	-	-	-	-	-
Moraceae	*Maclura cochichinensis*	Cockspur thorn	x	-			x	x	-	-	-	-	x	x	x	-	-	-	-	-
Moraceae	*Trophis scandens* subsp. *scandens*	Burney vine	x	-	x		x	x	-	-	-	-	-	x	-	-	-	-	-	-
Musaceae	*Musa* sp.*	Banana	x	-	x		x	x	-	-	-	-	-	x	-	-	-	-	x	x
Myristicaceae	*Horsfieldia hellwigii* var. *hellwigii*	-	x	-			x	x	-	-	-	-	-	-	-	-	-	-	-	-
Myristicaceae	*Myristica* cf. *hollrungii*	-	-	x	x		x	x	-	-	-	-	-	x	-	-	-	-	-	x
Myristicaceae	*Myristica fatua*	-	-	-	-		x	x	-	-	-	-	-	-	-	-	-	-	-	-
Myrtaceae	*Eucalyptus camaldulensis**	River Red Gum	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	x	x
Myrtaceae	*Eucalyptus pellita**	Red Mahogany	x	-	x		-	-	-	-	-	-	-	-	-	-	x	-	x	x
Myrtaceae	*Psidium guajava**	Guava	x	-	x		-	-	-	-	-	-	-	x	-	-	-	-	x	-
Myrtaceae	*Syzygium aquem*	Bell fruit	x	-	x		-	x	-	-	-	-	-	-	-	-	-	-	x	-
Nyctaginaceae	*Boerhavia erecta*	-	x	x	-		-	-	-	x	x	-	-	-	-	-	-	-	-	x
Nyctaginaceae	*Bouganvillea spectabilis**	Bouganvillea	x	-	-		-	-	-	-	-	-	-	-	-	-	-	-	x	-
Onagraceae	*Ludwigia hyssopifolia**	Seed box	x	-	-		-	-	-	x	-	-	-	x	-	x	-	-	x	-
Onagraceae	*Ludwigia octovalis*	Willow primrose	x	-	-		-	-	-	x	-	-	X	-	-	-	-	-	-	-
Opilaceae	*Cansjera leptostachya*	-	-	x	-		x	x	-	-	-	-	-	-	-	-	-	-	-	-

Plant name			Source		Status		Habitat code													
Family name	**Species**	**Common name**	**BAAM 2016**	**Herbrecs**	**Biocultural significance**	**IUCN**	**1a**	**2a**	**3a**	**4a**	**4b**	**4c**	**5a**	**5b**	**6a**	**7a**	**8a**	**8b**	**9**	**pic**
Pandanaceae	*Pandanus* sp. *1*	Pandanus	x	-	x		x	x	-	-	-	-	-	-	-	-	-	-	-	x
Pandanaceae	*Pandanus* sp. *2*	Pandanus	x	-	x		x	x	-	-	-	-	-	-	-	-	-	-	x	x
Pandanaceae	*Pandanus* sp. *3*	Pandanus	x	-	x		x	-	-		-	-	-	-	-	-	-	-	-	x
Passifloraceae	*Adenia heterophylla*	Lacewing vine	x	-	-		x	x	-	-	-	-	x	-	-	-	-	-	-	x
Passifloraceae	*Passiflora edulis**	Passionfruit	x	-	x		-	-	-	-	-	-	x	-	-	-	-	-	x	-
Passifloraceae	*Passiflora foetida**	Stinking passionflower	x	-	x		-	x	x	x	x	x	x	x	x	x	x	x	x	x
Phyllanthaceae	*Antidesma ghaesembilla*	Black currant tree	x	-	x		-	-	x	x	x	-	x	x	-	-	-	-	-	x
Phyllanthaceae	*Antidesma olivaceum*	-	x	-	x		-	x	-	-	-	-	-	-	-	-	-	-	-	x
Phyllanthaceae	*Breynia cernua*	Imer	x	-	x		x	x	x	x	-	-	x	x	-	-	-	-	-	x
Phyllanthaceae	*Glochidion novoguineensis*	-	x	x	x		x	x	-	-	-	-	-	x	-	-	-	-	-	x
Phyllanthaceae	*Phyllanthus tenellus**	-	x	-	-		-	-	-	-	-	x	-	-	-	x	-	-	x	-
Phyllanthaceae	*Phyllanthus virgatus*	-	x	x	-		-	-	-	x	x	x	-	-	-	-	-	-	-	-
Piperaceae	*Piper aduncum**	Spiked pepper	x	-	x		-	x	-	-	-	-	-	x	-	-	x	-	x	x
Piperaceae	*Piper betle*	Betel	x	-	x		x	x	-	-	-	-	-	-	-	-	-	-	x	-
Piperaceae	*Piper caninum*	Common piper	x	-	-		x	x	-	-	-	-	-	x	-	-	-	-	-	x
Pittosporaceae	*Pittosporum ferrugineum*	Pittosporum	-	x	-		-	x	-	-	-	-	x	-	-	-	-	-	-	-
Plantaginaceae	*Mecardonia procumbens**	Baby jump up	x	-	-		-	-	-	-	-	-	x	x	-	-	-	-	x	-
Plantaginaceae	*Scoparia dulcis**	Scoparia	x	x	-		-	-	-	-	-	-	-	-	x	x	x	-	x	-
Poaceae	*Allopteropsis semialata*	Cockatoo grass	x	-	-		-	-	-	x	x	-	-	-	-	-	-	-	-	
Poaceae	*Arthraxon* cf. *hispidus*	Hairy joint grass	x	-	-		-	x	-	x	x	-	-	-	-	-	-	-	-	x
Poaceae	*Arundinella setosa*	-	x	-	-		-	-	-	x	x	-	-	-	-	-	-	-	-	-
Poaceae	*Axonopus compressus**	Broad leaved carpet grass	x	-	-		-	-	-	-	-	-	x	x	x	-	x	x	x	x
Poaceae	*Bambusa* sp.*	A bamboo	x	-	x		-	-	-	-	-	-	-	-	-	-	-	-	x	-
Poaceae	*Bothriochloa bladhii* subsp. *bladhii*	Forest bluegrass	x	-	-		-	-	-	-	x	x	-	-	-	-	-	-	-	-
Poaceae	*Bothriochloa pertusa**	Indian Couch	x	-	-		-	-	-	-	-	x	-	-	-	x	x	-	x	-
Poaceae	*Brachiaria decumbens**	Signal grass	x	-	-		-	-	-	-	-	-	-	-	-	x	-	-	x	-
Poaceae	*Brachiaria reptans**	-	x	-	-		-	-	-	x	x	x	-	-	-	-	-	-	x	x
Poaceae	*Capillipedium parviflorum*	Scented top grass	x	-	-		-	-	-	x	x	-	-	-	-	-	-	-	-	-
Poaceae	*Cenchrus ciliaris**	Buffel Grass	x	x	-		-	-	-	-	-	-	-	-	-	x	-	-	x	x
Poaceae	*Cenchrus echinatus**	Mosman River grass	x	x	-		-	-	-	-	-	-	-	-	-	x	-	-	x	x
Poaceae	*Cenchrus polystachios* (syn. Pennisetum polystachyon)*	Mission Grass	x	-	-		-	-	-	-	-	-	-	-	-	x	-	-	x	x
Poaceae	*Chloris inflata**	A Windmill grass	x	x	-		-	-	-	x	-	x	-	-	-	x	-	-	x	-
Poaceae	*Chrysopogon acicularis**	Spiny top grass	x	-	-		-	-	-	-	-	-	-	-	-	x	-	-	x	-
Poaceae	*Cynodon dactylon**	Bermuda grass	x	-	-		-	-	-	-	-	-	-	-	-	x	x	x	x	-
Poaceae	*Dactyloctinuem aegyptum**	Button grass	x	-	-		-	-	-	-	-	-	-	-	-	x	-	-	x	-
Poaceae	*Dichanthium annulatum*	-	-	x	-		-	-	-	-	-	-	-	-	-	-	-	-	x	-
Poaceae	*Digitaria ciliaris**	Summer grass	x	-	-		-	-	-	-	-	-	-	-	-	x	-	-	x	-
Poaceae	*Digitaria setigera**	Hairy crab grass	x	-	-		-	-	-	-	-	-	-	-	-	x	-	-	x	-
Poaceae	*Digitaria* sp.*	-	-	-	-		-	X	-	-	-	-	-	-	-	x	-	-	x	-
Poaceae	*Echinochloa colona**	Barnyard awn grass	x	-	-		-	-	-	-	-	-	-	-	-	x	-	-	x	-

Plant name			Source		Status		Habitat code													
Family name	**Species**	**Common name**	**BAAM 2016**	**Herbrecs**	**Biocultural significance**	**IUCN**	**1a**	**2a**	**3a**	**4a**	**4b**	**4c**	**5a**	**5b**	**6a**	**7a**	**8a**	**8b**	**9**	**pic**
Poaceae	*Eleusine indica**	Crows foot grass	x	-	-		-	-	-	-	-	-	-	-	-	x	x	-	x	-
Poaceae	*Imperata cylindrica*	Blady grass	x	-	x		-	-	x	x	x	x	x	-	-	x	-	-	x	x
Poaceae	*Megathyrsus maximus* var. *maximus**	Giant Guinea grass	x	x	-		-	-	-	-	x	-	-	-	-	x	x	-	x	-
Poaceae	*Melinus repens**	Red Natal Grass	x	-	-		-	-	-	x	x	x	-	-	-	-	-	-	x	-
Poaceae	*Mnesithea rottboellioides*	-	x	-	-		-	-	x	x	x	-	-	-	-	-	-	-	x	-
Poaceae	*Neoloebra atra*	Cape Bamboo	x	-	-		x	x	-	-	-	-	-	-	-	-	-	-	-	x
Poaceae	*Ophiuros exaltatus*	-	x	-	-				x	x	x	-	-		-	-	-	-	-	-
Poaceae	*Oplismenus compositus*	Basket grass	x	-	-		-	-	x	x	-	-	-	x	-	-	-	-	x	x
Poaceae	*Panicum* sp.	-	x	-	-		-	-	-	x	-	-	-	-	-	-	-	-	-	-
Poaceae	*Paspalum paniculatum*	-	x	-	-		-	-	x	x	-	-	-	-	-	-	-	-	-	-
Poaceae	*Paspalum* sp.*	-	x	-	-		-	-	-	-	-	-	-	-	-	-	-	-	x	-
Poaceae	*Pennisetum purpureum**	Elephant Grass	x	-	-		-	-	-	-	-	x	-	-	-	-	-	-	x	-
Poaceae	*Phragmites vallatorius*	Reed grass	-	-	-		-	-	x	x	-	-	-	-	-	-	-	-	-	x
Poaceae	*Pogonatherum crinitum*	-	-	x	-		-	-	-	x	-	-	-	-	-	-	-	-	-	-
Poaceae	*Polytoca macrophylla*	-	x	-	x		-	-	x	x	x	-	-	-	-	-	-	-	-	x
Poaceae	*Rottboelia cochinchinensis*	Itch grass	x	-	-		-	-	-	-	-	x	-	-	-	-	-	-	x	-
Poaceae	*Saccharum myosuroides*	-	-	-	-			-	-	-	-	x	-	-	-	-	-	-	x	-
Poaceae	*Saccharum robustum*	Robust cane	x	-	x		-	-	-	-	-	x	-	-	-	-	-	-	x	-
Poaceae	*Saccharum spontaneum*	African fodder cane	-	-	-		-	-	-	-	-	x	-	-	-	-	-	-	x	-
Poaceae	*Setaria* sp.*	-	-	-	-		-	-	-	-	-	x	-	-	-	-	-	-	x	-
Poaceae	*Sorghum almun**	Columbus grass	-	-	-		-	-	-	-	-	x	-	-	-	-	-	-	x	-
Poaceae	*Sorghum halepense**	Johnson River grass	x	-	-		-	-	-	-	-	x	-	-	-	-	-	-	x	-
Poaceae	*Sporobolus* sp.*	-	x	-	-		-	-	-	x	-	x	-	-	-	-	-	-	x	x
Poaceae	*Themeda arguens*	Kangaroo grass	x	-	x		-	-	x	x	x	-	-	-	-	-	-	-	-	x
Poaceae	*Themeda triandra*	Kangaroo grass	x	-	x		-	-	x	x	x	-	-	-	-	-	-	-	-	-
Poaceae	*Urochloa decumbens**	Para Grass	x	-	-		-	-	-	-	-	x	-	-	-	-	-	-	x	-
Poaceae	*Zea mays**	Corn	x	-	x		-	-	-	-	-	-	-	-	-	-	-	-	x	-
Polygalaceae	*Polygala triflora*	-	-	x	-		-	-	-	-	-	-	-	-	-	-	-	-	x	-
Polygonaceae	*Persicaria lapathifolia*	-	-	-	-		-	-	-	x	-	-	-	-	-	-	-	-	-	-
Portulaccaceae	*Portulaca pilosa**	-	x	x	-		-	-	-	-	-	x	-	-	-	x	-	-	x	-
Rubiaceae	*Ichnocarpus frutescens*	-	x	x	x		x	x	-	-	-	-	-	x	-	-	-	-	-	x
Rubiaceae	*Knoxia sumatrensis**	-	-	x	-		-	-	-	-	-	-	-	-	-	x	-	-	x	-
Rubiaceae	*Morinda citrifolia*	Noni plum	x	-	x		-	x	-	-	-	-	-	x	-	-	-	-	x	-
Rubiaceae	*Muesaendra sp.*	-	x	-	-		-	-	-	-	x	-	-	-	-	-	-	-	-	x
Rubiaceae	*Nauclea orientalis*	Yellow cheeswood	x	-	x		-	x	x	-	-	-	-	x	--	-	-	-	-	x
Rubiaceae	*Neonauclea sp.*	-	-	-	x		x	x	-	-	-	-	-	-	-	-	-	-	-	-
Rubiaceae	*Spermacocce* sp.	-	-	-	-		-	-	x	x	-	-	-	-	-	-	-	-	-	-
Rubiaceae	*Timonius timon*	Timonius	x	-	x		x	x	x	-	-	-	-	x	-	-	-	-	-	-
Rutaceae	*Melicope bonwickii*	Yellow evodia	-	-	x		x	x	-	-	-	-	-	-	-	-	-	-	-	-
Rutaceae	*Melicope elleryana*	Pink doughwood	x	-	-		x	x	-	-	-	-	-	-	-	-	-	-	-	-

Plant name			Source		Status		Habitat code													
Family name	Species	Common name	BAAM 2016	Herbrecs	Biocultural significance	IUCN	1a	2a	3a	4a	4b	4c	5a	5b	6a	7a	8a	8b	9	pic
Sapindaceae	*Dictyoneura obtusa*	-	x	-	-		x	x	-	-	-	-	-	-	-	-	-	-	-	-
Sapindaceae	*Ganophyllum falcatum*	Scaly bark	x	-	-		x	x	-	-	-	-	-	-	-	-	-	-	-	-
Sapindaceae	*Pometia pinnata*	Taun	x	-	x		x	x	-	-	-	-	-	-	-	-	-	-	-	-
Sapindaceae	*Tristiropsis acutangula*	Fern leaved tamarind	x	-	x		x	x	-	-	-	-	-	-	-	-	-	-	-	x
Simaroubaceae	*Ailanthus integrifolia*	White siris	x	-	-		x	x	-	-	-	-	-	-	-	-	-	-	-	-
Simaroubiaceae	*Brucea javanica*	-	x	-	-		-	-	x	x	-	-	-	-	-	-	-	-	-	x
Solanaceae	*Nicotiana tabaccum**	Tobacco	x	-	x		-	-	-	-	-	-	-	-	-	-	-	-	x	-
Solanaceae	*Physalis angulata**	Cape Gooseberry	x	-	x		-	-	-	-	-	-	-	x	-	-	-	-	-	x
Solanaceae	*Solanum americanum**	Black nightshade	x	-	-		-	-	-	-	-	-	-	x	-	-	-	-	x	-
Solanaceae	*Solanum erianthum*	-	-	x	-		-	-	-	x	-	-	-	-	-	-	-	-	-	-
Solanaceae	*Solanum mauritianum**	Tobacco Bush	x	-	-		-	-	-	-	-	x	-	x	-	-	-	-	x	x
Solanaceae	*Solanum torvum**	Devils fig	x	-	-		-	-	-	-	-	x	-	x	-	-	-	-	x	x
Sparrmanniaceae	*Trichospermum pleiostigma*	False Commersonia	x	-	x		x	x	-	-	-	-	-	-	-	-	-	-	-	x
Sterculiaceae	*Sterculia schumanniana*	-	x	-	x		x	x	-	-	-	-	-	-	-	-	-	-	-	x
Sterculiaceae	*Sterculia shillinglawii* subsp. *shillinglawii*	Tulip sterculia	x	-	x		x	x	-	-	-	-	-	-	-	-	-	-	-	-
Ulmaceae	*Celtis latifolia*	Celtis	x	-	-		x	x	-	-	-	-	-	-	-	-	-	-	-	-
Ulmaceae	*Trema orientalis*	Tree peach	x	-	x		x	x	-	-	-	-	-	-	-	-	-	-	-	-
Verbenaceae	*Clerodendrum floribundum*	Clerodendrum	x	-	-		-	-	x	x	x	-	-	-	-	-	-	-	-	x
Verbenaceae	*Clerodendrum tomentosum*	Hairy clerodendrum	x	-	x		-	-	x	x	x	-	-	-	-	-	-	-	-	x
Verbenaceae	*Duranta erecta**	Geisha girl	x	-	x		-	-	-	-	-	-	-	-	-	-	-	-	x	-
Verbenaceae	*Phyla nodiflora*	-	-	x	-		-	-	-	x	-	-	-	-	-	-	-	-	-	-
Verbenaceae	*Stachytarpheta cayennensis**	Snake weed	x	-	x		-	-	-	-	-	x	-	-	-	-	-	-	x	x
Verbenaceae	*Stachytarpheta jamaicensis**	Dark blue snake weed	x	-	-		-	-	-	-	-	x	x	-	-	-	-	-	x	-
Vitaceae	*Cayratia geniculata*	-	-	-	-		x	x	-	-	-	-	-	-	-	-	-	-	-	-
Vitaceae	*Cissus trifolia*	-	x	-	-		x	x	x	-	-	-	x	-	-	-	-	-	-	-
Vitaceae	*Leea novoguineensis*	Bandicoot berry	x	-	x		x	x	-	-	-	-	-	-	-	-	-	-	-	x
Zingiberaceae	*Alpinia* sp.	A ginger	x	-	-		x	x	x	-	-	-	-	x	-	-	-	-	-	x
Zingiberaceae	*Amomum aculeatum*	-	-	-	x		x	x	-	-	-	-	-	x	-	-	-	-	-	x
Zingiberaceae	*Etlingera* sp.	-	-	-	-		x	x	-	-	-	-	-	x	-	-	-	-	-	x
Zingiberaceae	*Hornstedtia scottiana*	Scott's ginger	x	-	x		x	x	-	-	-	-	-	x	-	-	-	-	-	x
Zygophyllaceae	*Tribulus terrestris**	Caltrope	x	-	-		-	-	-	-	-	-	-	-		x	-	-	-	x

Appendix C

Assessment of likelihood of occurrence of threatened and near threatened flora within the study area

APPENDIX C: Assessment of Likelihood of Occurrence of Threatened and Near Threatened Flora within the study area

Status abbreviations: IUCN: Extinct in the Wild (EW), Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), Data Deficient (DD).

Species	Family	IUCN status	Habitat*	Distribution*	Threats	Likelihood in study area
Threatened and Near Threatened species that are known to occur						
Intsia bijuga	Fabaceae	VU A1cd ver 2.3 (1994)	A lowland rainforest tree which produces one of the most valuable timbers of South East Asia.	American Samoa (American Samoa); Australia; British Indian Ocean Territory (Chagos Archipelago); Cambodia; India; Indonesia (Irian Jaya, Kalimantan, Lesser Sunda Is.); Japan; Madagascar; Malaysia (Peninsular Malaysia, Sabah, Sarawak); Myanmar; PNG (Bismarck Archipelago); Philippines; Seychelles; Singapore; Solomon Islands; Tanzania, United Republic of; Thailand; Vanuatu; Vietnam.	The species has been exploited so intensively for merbau timber that few sizeable natural stands remain. Few plantations are established.	Known to occur – Immature trees in gully lines in footslope localities
Cycas schumanniana (Cites Listing)	Cycadaceae	Lower Risk – Near Threatened	A grassland species locally abundant in savanna grasslands or less frequently in woodlands or forests with a dense grassy understorey (RBGSYD 2012b).	Commonly occurs along the foothills of the Bismarck Range, in the Markham and Ramu valleys. Restricted to the northern side of PNG (RBGSYD 2012b).	Not specified	Known to occur. Recorded during field surveys on footslopes and outwash plains.
Threatened and Near Threatened species that possibly occur						
Aglaia rimosa	Meliaceae	Lower Risk – Near Threatened	Generally found in secondary forests around rivers or streams	Morobe, Western, Gulf, Central, Milne Bay, New Britain, Manus & Bougainville.	Habitat Loss	Possible
Pterocarpus indicus (Amoyna Wood Burmese Rosewood Red Sandlewood Santal Rouge)	Fabaceae	VU A1d ver 2.3 (1994)	A widespread tree found in lowland primary and some secondary forest, mainly along tidal creeks and rocky shores.	Cambodia; India; Indonesia (Bali, Irian Jaya, Jawa, Kalimantan, Lesser Sunda Is., Maluku, Sulawesi, Sumatera); Malaysia (Peninsular Malaysia, Sabah); Myanmar; PNG (Bismarck Archipelago, North Solomons); Philippines; Solomon Islands; Sri Lanka; Taiwan, Province of China; Thailand; Vanuatu. Collections also form Madang Province (Gogol Valley)	Subpopulations have declined because of overexploitation, sometimes illegal exploitation of the timber, as well as from increasing general habitat loss.	Likely
Threatened species that are considered to be unlikely to occur						
Acacia crassicarpa	Mimosaceae	VU A1cd	A tree of savannah woodland, monsoon forest and gallery-type forest at altitudes of between 10 and 30 m.	Restricted to the Western Province, PNG, and to Queensland, Australia.	Logging is occurring and the timber is actively sought-after.	Unlikely in Natural Habitat (Note that this species is grown as a plantation species).
Aglaia cremea	Meliaceae	VU A1c ver 2.3 (1994)	It grows in secondary forest and hill forest.	Scattered collections through Irian Jaya, West Sepik, Central Highlands to Morobe Province	Habitat loss through clearing	Unlikely
Aglaia barbanthera	Meliaceae	VU A1c ver 2.3 (1994)	This species is restricted to primary forest between 60 and 2,000 m.	Indonesia and PNG. Collections from Milne Bay area (Rossel Island	Habitat loss and clearing	Unlikely
Aglaia brownii	Meliaceae	VU A1c ver 2.3 (1994)	Small tree mainly found in coastal forest.	Australia (Northern Territory, Queensland); Indonesia (Irian Jaya); PNG. Distribution in Bismarck Archipelago unknown.	Habitat loss through clearing	Unlikely
Aglaia cinnamomea	Meliaceae	VU A1c ver 2.3 (1994)	Unspecified	PNG- Distribution unknown.	Unspecified	Unlikely
Aglaia cuspidata	Meliaceae	VU D2 ver 2.3 (1994)	Primary and secondary rainforest	Known from three localities in PNG in the Milne Bay and Madang Provinces	Habitat loss through clearing	Unlikely

Species	Family	IUCN status	Habitat*	Distribution*	Threats	Likelihood in study area
Aglaia integrifolia	Meliaceae	VU D2 ver 2.3 (1994)	A small tree restricted to lowland deciduous hill forest.	So far it is known from only four undisclosed localities.	Utilised for house construction	Unlikely
Aglaia leucoclada	Meliaceae	VU A1c ver 2.3 (1994)	Understory tree in rainforest.	Endemic to PNG with local distribution unknown.	Habitat loss through clearing	Unlikely
Aglaia mackiana	Meliaceae	CR D ver 2.3 (1994)	Mid –elevation rainforest. Trees may be easily overlooked as this dioecious species is only identified from the fruit. It is only definitely known from the type locality. Additional collections, which differ from the type specimen but may represent the same species, have been gathered from three localities.	Endemic to PNG with local distribution unknown.Type specimen known from the Crater Mountain Wildlife Area in Simbu Province in mixed evergreen rainforest at 900 – 1200 m elevation (Mack et al 1999)	Habitat fragmentation. Dioceous species which requires undisturbed habitat to pollinate.	Unlikely
Aglaia parksii	Meliaceae	VU A1c ver 2.3 (1994)	A small tree of lowland primary forest.	PNG-North Solomon Islands.	Habitat loss through clearing	Unlikely
Aglaia penningtoniana	Meliaceae	VU A1c ver 2.3 (1994)	It occurs in rainforest from low to montane elevations.	A taxonomically variable species endemic to PNG.	Logging and habitat loss through clearing	Unlikely
Aglaia polyneura	Meliaceae	VU D2 ver 2.3 (1994)	Small shrubby tree confined to two unspecified localities	Indonesia (Irian Jaya); PNG.	Restricted Range	Unlikely
Aglaia puberulanthera	Meliaceae	VU D2 ver 2.3 (1994)	Primary montane rainforest	A very small tree, endemic to New Guinea with collections from Western and Morobe Provinces	Restricted Range	Unlikely
Aglaia rubrivenia	Meliaceae	VU A1c ver 2.3 (1994)	Primary montane rainforest	Restricted to the North Solomon Islands.	Forest Clearing and Habitat Destruction	Unlikely
Albizia carrii	Mimosaceae	VU A1c ver 2.3 (1994)	Monsoon forest	This endemic tree is so far known only from areas in the Port Moresby region and Motupore Island.	Forest Clearing and Habitat Destruction	Unlikely
Alectryon repandodentatus	Sapindaceae	VU B1+2c ver 2.3 (1994)	A small tree of scrub and savannah.	Only known from the Port Moresby region and Motupore Island in PNG and Murray Island in Australia.	Continued and projected decline in range.	Unlikely
Alloxylon brachycarpum	Proteaceae	EN A2cd ver 2.3 (1994)	This tree is scattered in lowland rainforest and monsoon forest.	Confined to Western Province in south PNG and adjacent Digul District, Irian Jaya, extending into the Aru Islands. 16 individual collections in lowland rainforest	Continued and projected decline in range.	Unlikely
Alstonia breviloba	Apocynaceae	VU B1+2c ver 2.3 (1994)	The species occurs in secondary and primary montane forest.	Endemic to PNG with single collection in the Eastern Highlands Province	Continued and projected decline in range. Restricted distribution	Unlikely
Alstonia rubiginosa	Apocynaceae	VU B1+2c ver 2.3 (1994)	The species occurs in secondary and primary montane forest.	Endemic to PNG. Single collection from the Central Province.	Continued and projected decline in range. Restricted distribution	Unlikely
Archidendron forbesii	Mimosaceae	VU B1+2c ver 2.3 (1994)	A late secondary tree scattered in lowland rainforest.	It is confined to the Central province.	Unspecified	Unlikely

Species	Family	IUCN status	Habitat*	Distribution*	Threats	Likelihood in study area
Arthrophyllum proliferum	Araliaceae	VU D2 ver 2.3 (1994)	Submontane rainforest on steep slopes.	Known only from two collections in the Kuper Range, Morobe District (IUCN 2007). Known from disturbed lowland forest in Morobe district and lowland rainforest in Manus District (PNG Plants Database). A single record from Mt Lululua, ca 30 miles NE of Fulleborn Harbour. Dist. E New Britain Subdistrict Pomio is from montane Nothofagus forest (PNG Plants Database).	Unspecified	Unlikely
Avicennia rhumphiana	Avicenniaceae	Vulnerable –A2c (2008)	Mangrove forest	Littoral zone around the coast of PNG including Madang district	Harvesting of mangrove forests	Unlikely
Bleasdalea papuana	Proteaceae	EN C2a ver 2.3 (1994)	Lower montane forest on serpentine soils.	An uncommon species of isolated occurrence. It has been recorded from the Vogelkop Peninsula and Jayapura in Irian Jaya and the East Sepik and Morobe provinces in PNG.	Habitat destruction	Unlikely
Brachychiton carruthersii	Sterculiaceae	VU B1+2c, C2a ver 2.3 (1994)	A tree scattered in lowland coastal and monsoon forest, often in the transition zone between savannah woodland and lowland forest	It is mainly restricted to monsoon forest in Central Province, Milne Bay, Popondetta, Gulf Province. Single collection in vicinity of Lae (PNG Plants).	Habitat destruction	Unlikely
Brachychiton velutinosus	Sterculiaceae	VU B1+2c, C2a ver 2.3 (1994)	A tree scattered in lowland coastal and monsoon forest, often in the transition zone between savannah woodland and lowland forest. In PNG, it is mainly restricted to monsoon forest.	In PNG, it is mainly restricted to the Central Province. It occurs also on the Cape York Peninsula, Qld, Australia.	Habitat destruction	Unlikely
Brugieria hainesii	Rhizophoraceae	CR – C1 (2008)	Very rare tree restricted to mangrove forest	South coast of Papua New Guinea in mangrove forest	Mangrove harvesting	Unlikely
Calophyllum acutiputamen	Clusiaceae	CR B1+2abcde ver 2.3 (1994)	This canopy species is found on ridges in colline forest.	Known only from Rossel Island.	Habitat destruction	Unlikely
Calophyllum morobense	Clusiaceae	EN B1+2c ver 2.3 (1994)	Lowland rainforest on alluvium	Endemic to Morobe Province with records in the Lae district.	Logging and habitat destruction	Unlikely
Calophyllum robustum	Clusiaceae	VU B1+2abcde ver 2.3 (1994)	This uncommon tree is found in lowland rainforest.	In the Morobe district and near Ioma in the Northern district. However, the limits of this taxon are unclear.	It is vulnerable on account of restricted distribution and possible exploitation.	Unlikely
Calophyllum waliense	Clusiaceae	EN B1+2abcde ver 2.3 (1994)	A species restricted to lowland rainforest on ridges.	Manus Island – Bismarck Archipelago	The habitat has been heavily logged and degraded.	Unlikely
Canthium suborbiculare	Rubiaceae	VU D2 ver 2.3 (1994)	It is found in savannah or scrub.	This shrub or small tree is restricted to the Port Moresby region and Morupore Island. It is known only from five or six collections.	Unspecified	Unlikely
Ceratopetalum succirubrum	Cunoniaceae	VU A2cd ver 2.3 (1994)	Primary monsoon forest. Lowland to sub montane forest	19 collections in PNG across, West New Britain, Western Province, Milne Bay and Papua Indonesia. In PNG sub-populations are mainly confined to Western Province. More information is needed on the sub-population status in Australia.	Habitat degradation	Unlikely
Cupaniopsis acuticarpa	Sapindaceae	VU D2 ver 2.3 (1994)	Unspecified	A small tree or shrub known only from the type collection from Central Province.	Habitat Destruction	Unlikely

Species	Family	IUCN status	Habitat*	Distribution*	Threats	Likelihood in study area
Cupaniopsis bullata	Sapindaceae	VU D2 ver 2.3 (1994)	A small tree found in secondary vegetation.	Morobe and Central Province; known only from the type collection.	Habitat destruction	
Chisocheton stellaris	Meliaceae	VU D2 ver 2.3 (1998)	Primary and Secondary Rainforest	In PNG known from Madang Province	Logging and woodchipping operations	Unlikely
Cupaniopsis euneura	Sapindaceae	VU D2 ver 2.3 (1994)	Montane Rainforest. Collection at 2250m	This species is only known from the type collection, gathered from West Highlands Province.	Habitat destruction with restricted range	Unlikely
Diospyros lolinopsis	Ebenaceae	CR B1+2c, C2b ver 2.3 (1994)	Open hillside forest.	Only a few recorded occurrences of this tree. Type collection from near the Bigei River in Madang Province and also in Adelbert Mountains (Madang Province). Additional records provided by the Lae Herbarium in the Madang and Milne Bay Provinces.	Habitat Loss/Degradation - Extraction - Wood - Clear-cutting (ongoing).	Unlikely
Cupaniopsis napaensis	Sapindaceae	VU D2 ver 2.3 (1994)	Scrub	This species is known only from the type collection, which was located near a dry creek in Central Province.	Unspecified	Unlikely
Cupaniopsis phanerophleibia	Sapindaceae	VU D2 ver 2.3 (1994)	Understorey tree in primary rainforest	A tree from Western Province, known only from a single collection.	Unspecified	Unlikely
Diospyros benstonei	Ebenaceae	CR C2b ver 2.3 (1994)	This small rare tree occurs in streamside rainforest in a gorge.	Apparently confined to Misima Island in Milne Bay Province.	The population is threatened by mining and cutting for local use.	Unlikely
Diospyros gillisonii	Ebenaceae	EN A1cd+2cd, C2a ver 2.3 (1994)	Occurs in beach scrub on coral limestone at sea level.	A tree scattered throughout the small coral islands in the Kiriwina (Trobriand) Group and the Louisiade Archipelago. Very few mature trees, if any, remain.	Heavily exploited by the local people for its black heartwood, which is used in carvings, native hair combs and ceremonial pieces.	Unlikely
Diospyros insularis	Ebenaceae	EN A1cd+2cd, B1+2c ver 2.3 (1994)	A tree of primary lowland rainforest.	Found in only a few localities in the Solomon Islands and New Ireland of the Bismarck Archipelago.	Overexploitation and logging have resulted in the species becoming highly endangered, possibly critically endangered.	Unlikely
Ellatostachys aiyurensis	Sapindaceae	VU D2	Small palmoid tree in primary rainforest	Known only from type description in the Eastern Highlands (Madang Province??)	Habitat Loss	Unlikely
Ellatostachys goropuensis	Sapindaceae	VU D2	Small palmoid tree in ficus Euphorbia forest.	Known only from type description in the Northern Province	Habitat Loss	Unlikely
Ellatostachys rubrofractus	Sapindaceae	VU B1 and 2c	Small tree of lowland rainforest and swamp forest	Seven collections all from northern and central provinces. Collection also from eastern highlands	Fragmentation and habitat loss	Unlikely
Flindersia ifflaina	Rutaceae	EN A2cd, B1+2c ver 2.3 (1994)	This tree is found in monsoon and gallery forest up to 50 m.	PNG. The species occurs in the Oriomo River ecosystem in Western Province. The above threat category applies only to the population in PNG. More information is needed from Queensland.	The area is relatively restricted, fragile and threatened by logging activities.	Unlikely
Flindersia laevicarpa	Rutaceae	VU C1+2a ver 2.3 (1994)	Found in monsoon, gallery and hill forest from lowland to sub-montane rainforest.	This large tree is threatened in New Guinea by exploitation and logging activities. Its status in Australia is not considered in this evaluation.	It has a sporadic occurrence in hill forest in Varirata National Park, Central Province, where it is hoped populations will survive. Collections also from Western and Morobe Province	Unlikely

Species	Family	IUCN status	Habitat*	Distribution*	Threats	Likelihood in study area
Flindersia pimenteliana	Rutaceae	EN C2a ver 2.3 (1994)	A large tree found mainly in lower montane rainforest or in foothill rainforest.	In PNG, the species is widespread but uncommon and sporadic. The population status in Australia is not taken into consideration in this evaluation. Fifty collections throughout the Central, Morobe, Milne Bay Provinces and Papua (Indonesia). Collections in the Lae district.	It has been heavily exploited in the Bulolo/Wau region of Morobe Province. Populations on spurs and ridges of mountain ranges may be spared from future exploitation.	Unlikely
Geijera salicifolia	Rutaceae	Lower Risk – Near Threatened	Lowland and sub-montane rainforest	A timber species, which in New Guinea is mainly confined to the Bulolo/Wau region of Morobe Province. Also known from Australia	This region was once heavily exploited, logged and converted into *Araucaria* plantations.	Unlikely
Geniostoma umbellatum	Loganiaceae	VU D2 ver 2.3 (1994)	Hillside secondary forest on well-drained soil.	A small semi-erect tree found only once on Guadalcanal.	Unspecified	Unlikely
Guioa grandifolia	Sapindaceae	CR B1+2c ver 2.3 (1994)	From lowland rainforest and advanced secondary forest.	An extremely localised species known only from four collections near the Buso River (Morobe Province)	Large areas of lowland forest in PNG are threatened by increased logging activity.	
Guioa hospita	Sapindaceae	CR D ver 2.3 (1994)	Unspecified	The only record of this species is the type specimen collected in 1890 in Gulf Province. Despite the area being relatively well studied, it has not been recorded since.	Unspecified	Unlikely
Guioa molliuscula	Sapindaceae	VU D2 ver 2.3 (1994)	Understorey tree of alluvial swamp.	To date there are just two collections from the 1950-'60s in the Eastern Highlands NB distribution unknown	Unspecified	Unlikely
Guioa normanbiensis	Sapindaceae	VU D2 ver 2.3 (1994)	Unspecified	Confined to the Milne Bay province on Normanby Island, this tree is known from only four collections to date.	Unspecified	Unlikely
Guioa novobritannica	Sapindaceae	VU D2 ver 2.3 (1994)	*Casuarina rumphiana*-dominated montane forest.	A tree known only from the type specimen, collected in west New Britain.	Unspecified	Unlikely
Guioa oligotricha	Sapindaceae	VU D2 ver 2.3 (1994)	Found in lowland secondary forest.	A small tree, known only from three collections in the Southern Division of Irian Jaya and the Western Province of PNG. These areas are under explored.	Unspecified	Unlikely
Guioa pauciflora	Sapindaceae	VU D2 ver 2.3 (1994)	Unspecified	Single specimen collection from the West Sepik area.	Unspecified	Unlikely
Guioa plurinervis	Sapindaceae	VU D2 ver 2.3 (1994)	Secondary hill rainforest.	To date this species is known only from three collections in Milne Bay Province in Rossel Island. There has been little collecting from this island.	Unspecified	Unlikely
Guioa scalariformis	Sapindaceae	VU D2 ver 2.3 (1994)	A shrub or small tree restricted to primary montane forest.	Morobe province. It has been collected only twice.	Unspecified	Unlikely
Guioa unguiculata	Sapindaceae	VU D2 ver 2.3 (1994)	Unspecified	A small tree known only from four collections in the Central Highlands and Morobe Province	Unspecified	Unlikely
Halfordia papuana	Rutaceae	CR ver 2.3 (1994)	This tree is scattered in submontane and montane rainforest between 1,200 and 2,700 m. Some collections as low as 250m.	Mostly confined to the Bulolo/Wau region in Morobe Province. Collections also in the West New Britain, Central Highlands Province	Logging and plantation development	Unlikely
Helicia acutifolia	Proteaceae	VU D2 ver 2.3 (1994)	A small tree of secondary forest at 2,040 m.	Confined to Mt. Victoria in the central district.	Unspecified	Unlikely

Species	Family	IUCN status	Habitat*	Distribution*	Threats	Likelihood in study area
Helicia australasica	Proteaceae	VU C2b ver 2.3 (1994)	A tree usually found in patches of rainforest along rivers and streams.	In PNG, it is known only from the Western province. The status of this species in Northern Australia has not been considered in this threat category.	Unspecified	Unlikely
Helicia calocoma	Proteaceae	VU B1+2c ver 2.3 (1994)	Montane and sub-montane rainforest	Confined to the Morobe district up to 1800m	Extraction - Wood - Clear-cutting (ongoing)	Unlikely
Horsfieldia clavata	Myristicaceae	VU D2 ver 2.3 (1994)	A shrub or small tree from tall lowland forest on well-drained soils	Although locally common, has been collected only three times in the Northern Province and Morobe Province.	Unspecified	
Horsfieldia urceolata	Myristicaceae	VU D2 ver 2.3 (1994)	A small tree or shrub from lowland primary rainforest.	PNG-Unspecifed with range in NB unknown. Although only confirmed collections are from the Milne Bay Province	Unspecified	Unlikely
Helicia insularis	Proteaceae	EN B1+2abcde ver 2.3 (1994)	This tree is restricted to ridgeline mossy rainforests	Milne Bay Province – Normanby and Ferguson Islands	Habitat Destruction	Unlikely
Helicia neglecta	Proteaceae	VU A1cd, C2a ver 2.3 (1994)	A tree of primary and secondary forest up to 400 m.	Occurs only on New Britain and New Ireland in the Bismarck Archipelago.	It is potentially threatened by ongoing and future logging activities and encroaching agriculture.	Unlikely
Helicia peekelii	Proteaceae	VU D2 ver 2.3 (1994)	It is thought to occur in coastal forest.	This lowland tree is known only from Namatanai, New Ireland.	Unspecified	Unlikely
Helicia peltata	Proteaceae	CR B1+2abcde ver 2.3 (1994)	This tree occurs in forest at 450 m.	Known only from a single location, Bisiatabu in the Central Province.	The habitat is threatened by logging and the increasing settlement.	Unlikely
Helicia polyosmoides	Proteaceae	CR B1+2abcde ver 2.3 (1994)	Occurs in ridge forest between the elevations of 100 and 550 m.	This small tree is restricted to Manus Island in the Bismarck Archipelago.	This species may face extinction through the commercial logging of its habitat.	Unlikely
Helicia retusa	Proteaceae	VU D2 ver 2.3 (1994)	Occurring in ridge forest between 1,600 and 1,900 m.	This small tree found is known only from Milne Bay District.	Unspecified	Unlikely
Helicia rostrata	Proteaceae	VU D2 ver 2.3 (1994)	A small tree, so far known only from lower montane forest between 2,000 and 2,200 m.	Only collection at Mt. Dayman.- Milne Bay Province	Unspecified	Unlikely
Helicia subcordata	Proteaceae	CR B1+2abcde ver 2.3 (1994)	Tall forest tree in primary forest.	A tall tree found only once near Wagau in the Morobe province.	Habitat Loss/Degradation - Extraction - Wood - Clear-cutting (ongoing)	Unlikely
Hopea inexpectata	Dipterocarpaceae	CR A1cd, B1+2c ver 2.3 (1994)	Occurs in primary forest on clay soils (PNG Plant Database).	West Papua - Irian Jaya (PNG Plant Database).	Unspecified	Unlikely
Horsfieldia ampla	Myristicaceae	VU D2 ver 2.3 (1994)	Dense humid forest.	A small tree known only from the type collection which was found in Sepik Province.	Unspecified	Unlikely
Horsfieldia ampliformis	Myristicaceae	VU D2 ver 2.3 (1994)	A small tree of lower montane rainforest.	Known from two collections, one from Sepik Province and the other from Morobe Province.	Unspecified	Unlikely
Horsfieldia sepikensis	Myristicaceae	VU D2 ver 2.3 (1994)	Tree found in both primary and secondary forest.	So far it is only known from three collections from East Sepik Province.	Unspecified	Unlikely
Horsfieldia squamulosa	Myristicaceae	VU D2 ver 2.3 (1998)	Unspecified	A locally common understorey shrub or small tree restricted to the Western Province and known only from three collections.	Unspecified	Unlikely
Kayea coriacea	Clusiaceae	VU D2 ver 2.3 (1994)	Occurs in lowland seasonally flooded or ridge forest.	This tree is found in Western District and has recently been discovered on Sudest Island, Milne Bay. The taxonomic limits of the species are presently unknown. It could represent more than one taxon.	Unspecified	Unlikely

Species	Family	IUCN status	Habitat*	Distribution*	Threats	Likelihood in study area
Kayea macrophylla	Clusiaceae	VU D2 ver 2.3 (1994)	A small tree of lowland rainforest.	Known from two collections: one from Geelvink Bay, Irian Jaya, and the other from an area near Angoram in the East Sepik district of PNG.	Unspecified	Unlikely
Koompassia grandiflora	Caesalpiniaceae	VU A1cd+2cd ver 2.3 (1994)	A primary rainforest tree occurring on coastal plain foothills and stony low hills.	Vogelkop, Irian Jaya and the Morobe, Gulf and Central provinces of PNG.	Observations of active exploitation for the timber of this species in PNG were made in the 1960s; the timber continues to be in high demand and is heavily exploited in areas subject to logging. As it occurs in primary forest and in readily accessible areas, the species is considered highly vulnerable.	Unlikely
Madhuca boerlageana	Sapotaceae	CR A1cd, C2ab, D ver 2.3 (1994)	Tree of primary lowland forest.	New Guinea and the Moluccas. In PNG, this species is extremely rare and known from a single sterile collection made from the Vanimo area, West Sepik province. The above threat category applies to the situation in PNG only.	Habitat Loss/Degradation - Extraction - Wood - Clear-cutting (ongoing)	Unlikely
Mammea grandifolia	Clusiaceae	VU D2 ver 2.3 (1994)	Unspecified (Lowland Rainforest)	This small tree, known only from the type collection, was found along Pinini Creek in the Gulf province. The taxonomic limits of this species are unclear.	Unspecified	Unlikely
Mammea papuana	Clusiaceae	VU D2 ver 2.3 (1994)	Unspecified	A rainforest tree known only from two collections from East Sepik. The taxonomic limits of this species are unclear.	Unspecified	Unlikely
Mammea papyracea	Clusiaceae	VU D2 ver 2.3 (1994)	Unspecified	A small tree, known only from the type collection, found in Buso, south of Lae in the Morobe district.	Unspecified	Unlikely
Mammea veimauriensis	Clusiaceae	VU D2 ver 2.3 (1994)	Lowland rainforest.	The description of this species is based on two herbarium specimens. This tree is found along the Veimauri River, Pt Moresby district where it is reported to be quite common.	Unspecified	Unlikely
Mangifera altissima	Anacardiaceae	VU A1d ver 2.3 (1994)	A timber species of lowland evergreen forest.	Indonesia (Irian Jaya, Lesser Sunda Is., Maluku, Sulawesi); Malaysia (Sabah); PNG (Bismarck Archipelago); Philippines; Solomon Islands.	Logging	Unlikely
Manilkara kanosiensis	Sapotaceae	EN A1cd+2cd, C2a ver 2.3 (1994)	This timber tree is scattered in primary lowland rainforest.	Relatively widespread but uncommon. It occurs mainly in areas where intense logging is being carried out, such as New Britain and New Ireland in the Bismarck Archipelago and the north-west of PNG.	Logging	Unlikely
Mastixiodendron stoddardii	Rubiaceae	VU A1cd+2cd, B1+2abcde ver 2.3 (1994)	A large timber tree of primary lowland rainforest.	Poorly collected with existing data indicating this species is restricted to Kiunga area, New Britain in the Bismarck Archipelago and the Solomon Islands.	New Britain is one of the most intensively logged islands in the Bismarck Archipelago, thereby threatening this species with habitat destruction. The Solomon Islands subpopulation is also at risk from logging activities.	Unlikely

Species	Family	IUCN status	Habitat*	Distribution*	Threats	Likelihood in study area
Myristica atresens	Myristicaceae	VU D2 ver 2.3 (1994)	Lowland forest.	The type specimen is the only known collection of the tree. It was gathered near the border of PNG in south-eastern Irian Jaya.	Unspecified	Unlikely
Myristica brachypoda	Myristicaceae	VU D2 ver 2.3 (1994)	Lowland forest.	The type species was gathered in 1955 in logged-over forest near the Seribi River in the Gulf Province. It is the only known collection of the species.	Unspecified	Unlikely
Myristica brevistipes	Myristicaceae	VU D2 ver 2.3 (1994)	Tall lowland / foothill rainforest	A small tree collected only on one occasion in tall foothill forest in the Central Province.	Unspecified	Unlikely
Myristica buchneriana	Myristicaceae	VU A1d ver 2.3 (1994)	Frequently found on ridge tops between 300 and 1,300 m.	22 Collection records from Irian Jaya and PNG in Northern, Central, Morobe and Milne Bay Provinces. Specimens from Ramu Valley in Madang Province	Unspecified	Unlikely
Myristica byssacea	Myristicaceae	VU D2 ver 2.3 (1994)	A small tree of montane forest.	Known from only two collections from the montane forest in the Northern Province.	Unspecified	Unlikely
Myristica coacta	Myristicaceae	VU D2 ver 2.3 (1994)	This species occurs in degraded Fagaceous forest.	Known only from the type collection of 1968 in West Sepik Province.	Unspecified	Unlikely
Myristica dasycarpa	Myristicaceae	VU D2 ver 2.3 (1994)	This subcanopy tree was found growing on a ridge at approximately 50 m.	Known only from the type collection in the Waskuk Hills, East Sepik Province. Another collection from Irian Jaya might belong to this recently described species.	Unspecified	Unlikely
Myristica fasciculata	Myristicaceae	VU D2 ver 2.3 (1994)	Primary and secondary forest.	Collected three times, this species is locally common in the upper Sepik River region of Sepik Province.	Unspecified	Unlikely
Myristica incredibilis	Myristicaceae	VU D2 ver 2.3 (1994)	Unspecified	A tree known only from the type specimen collected on Rossel Island.	This island has a fragile ecosystem, with very poor soils, which is possibly threatened by gold and copper mining and logging.	Unlikely
Myristica inundata	Myristicaceae	VU D2 ver 2.3 (1994)	Seasonally inundated swamp forest.	Known only from the type specimen, this species occurs in Kiunga, Western Province.	Unspecified	Unlikely
Myristica lasiocarpa	Myristicaceae	VU D2 ver 2.3 (1994)	A subcanopy species, occurring as solitary trees in *Nothofagus* forest.	It has only been collected only twice from the Kuper Range area of the Morobe Province.	Unspecified	Unlikely
Myristica leptophylla	Myristicaceae	VU D2 ver 2.3 (1994)	The species occurs in secondary regrowth at medium elevation.	Known only from the type locality, near Busilmin, West Sepik Province.	Unspecified	Unlikely
Myristica mediterranea	Myristicaceae	VU D2 ver 2.3 (1994)	This small tree occurs in disturbed forest or semi-swamp in valley forest.	Known only from three collections from the southern border between Irian Jaya and PNG.	Unspecified	Unlikely
Myristica nana	Myristicaceae	VU D2 ver 2.3 (1994)	Unspecified	A small tree, known from four collections, locally endemic to forest in the Central and Milne Bay Provinces.	Habitat destruction	Unlikely
Myristica olivacea	Myristicaceae	VU D2 ver 2.3 (1994)	An understorey rainforest tree.	Known only from four collections from near Amazon Bay, Central Province	Unspecified	Unlikely
Myristica ornata	Myristicaceae	VU D2 ver 2.3 (1994)	Lowland rainforest.	Known only from the type specimen, the tree was discovered in the Kiunga area, Western Province.	Unspecified	Unlikely
Myristica ovicarpa	Myristicaceae	VU D2 ver 2.3 (1994)	Lowland hill forest.	This tree is known only from the type collection. It was found on Mt. Don of Rossel Island.	Unspecified	Unlikely

Species	Family	IUCN status	Habitat*	Distribution*	Threats	Likelihood in study area
Myristica pachycarpidia	Myristicaceae	VU D2 ver 2.3 (1994)	Oak forest.	A tree known only from the type locality on Mt. Dayman, Milne Bay Province.	Unspecified	Unlikely
Myristica papillatifolia	Myristicaceae	VU D2 ver 2.3 (1994)	Valley forest.	A small tree found only once near Ingambit in the Western Province, near the border with Irian Jaya.	Unspecified	Unlikely
Myristica pilosella	Myristicaceae	VU D2 ver 2.3 (1994)	*Castanopsis* forest.	A small tree known only from a site at the junction of the Ugat and Mayu Rivers in Milne Bay Province.	Unspecified	Unlikely
Myristica polyantha	Myristicaceae	VU D2 ver 2.3 (1994)	A canopy or subcanopy tree.	Restricted to Goodenough Island, where it has been collected twice. The D'Entrecasteaux Islands harbour many locally endemic species and require botanical investigation.	Unspecified	Unlikely
Myristica psilocarpa	Myristicaceae	VU D2 ver 2.3 (1994)	Lowland rainforest.	An endemic to Manus Island, this tree has been collected twice.	Unspecified	Unlikely
Myristica pygmaea	Myristicaceae	VU D2 ver 2.3 (1994)	Lowland rainforest and logged forest.	A small tree, endemic to Morobe Province, where it has been collected twice.	Unspecified	Unlikely
Myristica schlechteri	Myristicaceae	VU D2 ver 2.3 (1994)	Unspecified	The only specimen of this understorey tree was collected in 1908 in forest near Pema, Morobe Province.	Unspecified	Unlikely
Myristica simulans	Myristicaceae	VU D2 ver 2.3 (1994)	Riverine rainforest.	The sole collection of this tree was gathered at Modewa Bay, Milne Bay Province.	Unspecified	Unlikely
Myristica sinclairii	Myristicaceae	VU D2 ver 2.3 (1994)	This understorey tree grows in *Castanopsis* forest	A total of five collections have been gathered from Morobe Province.	Unspecified	Unlikely
Myristica sogeriensis	Myristicaceae	VU D2 ver 2.3 (1994)	Shrub or small tree in foothill forest.	Endemic to the Sogeri region of Central Province, it has been collected twice in foothill forest.	Unspecified	Unlikely
Neubergia tubiflora	Loganiaceae	VU D2 Ver 2.3	Secondary Lowland Forest	A shrub or small tree, so far known only from two collections taken in the Vogelkop district.	Habitat destruction –restricted range	Unlikely
Nothofagus nuda	fagaceae	VU D2 ve 2.3 (1994)	Mixed lower montane forest	A single collection in the Tauri River, Gulf Province	Habitat destruction –restricted range	Unlikely
Osmoxylon arrhenicum	Araliaceae	VU D2 ver 2.3 (1994)	Steep hill forest at 700 m.	Endemic to Santa Isabel, this species is known only from the site where it was first collected.	Unspecified	Unlikely
Osmoxylon chrysanthum	Araliaceae	VU D2 ver 2.3 (1994)	The type was found in a riverine community on the debris banks of a deep gorge at 300 m.	A small tree, known only from the type collection on Guadalcanal Island (North Solomons)	Unspecified	Unlikely
Osmoxylon corneri	Araliaceae	VU D2 ver 2.3 (1994)	This small tree was collected at 1,470 m.	Endemic to Guadalcanal (North Solomons), known only from the type specimen.	Unspecified	Unlikely
Osmoxylon ellipsoideum	Araliaceae	VU D2 ver 2.3 (1994)	A many-branched tree, presently known only from areas of secondary or disturbed lowland hill forest.	Milne Bay district.	Unspecified	Unlikely

Species	Family	IUCN status	Habitat*	Distribution*	Threats	Likelihood in study area
Osmoxylon lanceolatum	Araliaceae	VU D2 ver 2.3 (1994)	An understorey tree in ridge-top forest on limestone between 750 and 850 m.	Endemic to central and south New Ireland.	Unspecified	Unlikely
Osmoxylon reburrum	Araliaceae	VU D2 ver 2.3 (1994)	Unspecified	A small tree, so far known only from the type collection from the Malaita district.	Unspecified	Unlikely
Osmoxylon whitmorei	Araliaceae	VU D2 ver 2.3 (1994)	Unspecified	Endemic to Guadalcanal – North Solomons	Unspecified	Unlikely
Pericopsis mooniana	Leguminosae	VU D2 ver 2.3 (1998)	Coastal forest	In Papua New Guinea, this species is restricted to the heavily logged Oriomo River in the Western Province, where it is possibly now extinct.	The species has been heavily exploited for its timber.	Unlikely
Pongamia velutina	Leguminosae	Vulnerable B1 and B2 + C2a Version 2.3	Coastal rainforest	Coastal areas of the central province	/	Unlikely
Psydrax suborbicularis	Rubiaceae	Vulnerable D2 Version 2.3	Coastal rainforest	Several records near Port Moresby and more broadly in the central province		Unlikely
Ptychosperma gracile	Aracaceae	EN A1a+2c ver 2.3 (1994)	This palm tree is scattered in rainforest on both limestone and volcanic soils. This species can survive in open vegetation or in secondary forest if it is allowed to regenerate.	Confined to New Ireland and New Britain.	Subpopulations have declined because of rapid and extensive deforestation for plantation agriculture.	Unlikely
Rosselia bracteata	Burseraceae	Vulnerable B1+2c ver 2.3 (1998)	Uspecified	Endemic to Rossel Island in the Louisade Archipelago	Unspecified	Unlikely
Santalum macgregorii	Santalaceae	EN A1cd, C1 ver 2.3 (1994)	A parasitic or semi-parasitic species found in open savannah vegetation and in savannah forest in gullies.	Found in the Central Province, eastern part of Western Province and possibly also in south-east Irian Jaya.	As with all other sources of sandalwood, this species is overexploited for its scented wood, which is used for incense, perfume, essential oil and carving. In PNG the exploitation began at the turn of the last century; now the resource is greatly depleted as there are few mature trees or virgin stands.	Unlikely
Schistochela undulatifolia	Schistochilaceae (Liverwort)	Critically Endangered B1+2c ver 2.3 (2000)		Known from one type locality in the Sepik Province	Fallen trunks in undisturbed rainforest	Unlikely
Tabernaemontana remota	Apocynaceae	VU B1+2c ver 2.3 (1994)	A shrub or small tree up to 10 m high, occurring in submontane scrub or forest.	It is known from several collections from Sulawesi and Rossel Island of PNG.	The fragile ecosystem of Rossel Island is threatened by logging and mining activities.	Unlikely
Terminalia archipelagi	Combretaceae	EN A1cd+2cd, C2a ver 2.3 (1994)	This large well-formed tree can be locally dominant in lowland primary rainforest.	Occurring on the islands of the Bismarck Archipelago. A single collection also from the Madang Province	It has been and still is heavily exploited through intensive logging practices. It is much sought-after for the production of plywood.	Unlikely
Terminalia eddowsii	Combretaceae	VU B1+2abcde ver 2.3 (1994)	The species is found mainly in small pockets of riverine forest surrounded by savannah woodland, and occasionally in lowland rainforest.	Confined to Central Province with 18 collections recorded from the Central Province.	It is mainly threatened by urban expansion, local exploitation and logging activities.	Unlikely
Xanthostemon oppositifolius	Myrtaceae	Endangered B1+2c, C2a ver 2.3 (1998)	Coastal rainforest	Papua New Guinea, in Milne Bay Province.	Heavy exploitation	Unlikely

Species	Family	IUCN status	Habitat*	Distribution*	Threats	Likelihood in study area
Acacia aulacocarpa	Mimosaceae	Lower Risk – Near Threatened	Savannah and monsoon forest up to an altitude of 50 m.	In New Guinea, this tree is restricted to Digul District in Irian Jaya and the Oriomo River area in the Western Province of Papua New Guinea. More information is needed on subpopulations in eastern and northern Australia.	Part of the range is subject to logging. Continued exploitation and habitat destruction have reduced the number of mature individuals and, if not halted, will render the species as a whole vulnerable.	Unlikely
Adinandra forbesii	Pentaphylaceae	Lower Risk – Near Threatened	A tree scattered in monsoon forest, savannah woodland and lower montane forest up to 1,200 m.	Morobe, Western Highlands, Eastern Highlands, Southern Highlands, Western, Gulf, Central, Northern & New Britain	In Papua New Guinea, the subpopulation has suffered from logging activities over recent years in the Oriomo River area, Western Province, where the species was once fairly common.	Unlikely
Agathis labillardieri	Araucariaceae	Lower Risk – Near Threatened	Scattered emergents survive in small exposed groves of rainforest in the eastern highlands.	Collections in the Morobe Province, Sepik and Irian jaya	Over exploitation of the timber is a threat.	Unlikely.
Aglaia agglomerata	Meliaceae	Lower Risk – Near Threatened	This tree is scattered in lowland to midmontane primary and secondary forest.	Six collections all from Simbu Province	Habitat loss	Unlikely
Aglaia subcuprea	Meliaceae	Lower Risk – Near Threatened	A tree of primary and secondary forest up to 2,570 m, often in periodically inundated areas.	Restricted to Morobe – Milne Bay Area	Logging and habitat loss through clearing	Unlikely
Aglaia parviflora	Meliaceae	Lower Risk – Near Threatened	Small rainforest tree	Known from Bismarck Archipelago and Solomon Island	Habitat Destruction	Unlikely
Aglaia sexipetala	Meliaceae	Lower Risk – Near Threatened	Limited information	Indonesia (Irian Jaya, Jawa, Sumatera); Malaysia (Peninsular Malaysia); Papua New Guinea; Singapore; Thailand	Limited information	Unlikely
Aglaia silvestris	Meliaceae	Lower Risk – Near Threatened	A widespread, variable species of various habitat types, occurring up to 2,100 m.	Cosmopoliton species with widespreas scattered distribution throughout Papua New Guinea	Habitat loss through clearing	Unlikely
Aglaia somoensis	Meliaceae	Lower Risk – Near Threatened	Understory tree in rainforest up to 830m	Samoa (American Samoa); Indonesia (Irian Jaya); Papua New Guinea (Bismarck Archipelago, North Solomons); Samoa; Solomon Islands (Santa Cruz Is.); Vanuatu; Wallis and Futuna	Habitat loss through clearing	Unlikely
Appendicula tenuispica	Orchidaceae	Lower Risk – Near Threatened	Mossy primary forest	Throughout mainland PNG	Logging and habitat loss through clearing	Unlikely
Araucaria hunsteinii	Araucariaceae	Lower Risk – Near Threatened	Recorded to be the tallest tree in Malesia, reaching 90 m in height, the species occurs mainly in Fagaceae forest between 520 and 2,100 m.	Madang, Morobe and Eastern Highlands	Logging	Unlikely
Burckella sorei	Sapotaceae	Lower Risk – Near Threatened	This timber tree is found mainly in primary lowland rainforest.	Restricted to Bouganville and North Solomons	Logging acivities and over exploitation	Unlikely

Species	Family	IUCN status	Habitat*	Distribution*	Threats	Likelihood in study area
Cycas apoa (Cites Listing)	Cycadaceae	Lower Risk – Near Threatened	Closed mesophyll forest in wet lowland areas.	Known from northern coastal New Guinea, from the Huon Peninsula west to at least the Mamberamo River in Indonesian New Guinea. Species is an occupant of wet lowland rainforest although is often associated with low ridgelines (RBGSYD 2012c)	Not specified	Unlikely
Cycas scratchleyana (Cites Listing)	Cycadaceae	Lower Risk – Near Threatened	Closed mesophyll forest in wet lowland areas.	All collections from the Western, Gulf, Central, Milne Bay Provinces plus Irian Jaya. No current collections from the northern part of PNG.	Not specified	Unlikely
Cycas bouganvilleana (Cites Listing)	Cycadaceae	Lower Risk – Near Threatened	Monsoon forest	Restricted to North Solomons, New Britain with scattered collections on the north coast of Madang	Not specified	Unlikely
Cycas campestris (Cites Listing)	Cycadaceae	Lower Risk – Near Threatened	Unspecified	All collections from the Central Province, mostly in the vicinity of Port Moresby	Not specified	Unlikely
Cycas papuana (Cites Listing)	Cycadaceae	Lower Risk – Near Threatened	Unspecified	All collections from the Western Province, Madabuan Hill and Morehead River.	Not specified	Unlikely
Cycas rumphii	Cycadaceae	Lower Risk – Near Threatened	Unspecified	Widespread from Western Province, Irian Jaya to North Solomens including collections from Madang sub-district.	Not specified	Unlikely
Dacrydium magnum	Podocarpaceae	Lower Risk – Near Threatened	Lowland rainforest, particularly on hill crests.	Populations are known from the islands of Guadalcanal, Choiseul and Santa Ysabel in the Solomons, from the Louisades in Papua New Guinea and Obi Island in the Moluccas.	Forest management activities and agricultural pressures could cause rapid population losses to most or all parts of the range.	Unlikely
Eucalyptopsis papuana	Myrtaceae	Lower Risk – Near Threatened	This tree is locally common, sometimes forming pure stands, in scattered areas of rainforest up to 1,500 m.	It occurs in a small patch on Woodlark Island, in the headwaters of the Watut River in the Morobe Province and in the Western and East Sepik Provinces.	The species has been logged and exported from Woodlark Island and occurs in areas subject to further exploitation.	Unlikely
Flindersia amboinensis	Rutacaea	Lower Risk – Near Threatened	Lowland and sub-montane rainforest	A large tree, widespread but of sporadic occurrence on mainland Papua New Guinea, Seram Island and Tanimbar Islands of the Moluccas. Collections also from Morobe Province.	Logging	Unlikely
Flindersia schottiana	Rutacaea	Lower Risk – Near Threatened	This species is widespread in monsoon, hill and lower montane forest.	Widespread although prominent in the Western and Central Provinces	In Papua New Guinea, it was subject to exploitation in two major logging areas in Morobe and Western Provinces. Subpopulations in the rugged mountains of Owen Stanley Range may be spared from exploitation.	Unlikely
Helicia albiflora	Proteaceae	Lower Risk – Near Threatened	A tree often found in *Castanopsis-Nothofagus* rainforest from 900 to 2,000 m.	Known from the East and Western Highlands, Morobe, Northern and Central provinces of Papua New Guinea.	Habitat destruction	Unlikely
Helicia amplifolia	Proteacea	Lower Risk – Near Threatened	A tree occurring in primary or secondary rainforest or submontane forest from 600 to 1,300 m.	It is known from the Eastern, Western and Southern Highlands, Madang and Morobe Provinces.	Logging and habitat destruction	Unlikely

Species	Family	IUCN status	Habitat*	Distribution*	Threats	Likelihood in study area
Helicia latifolia	Proteacea	Lower Risk – Near Threatened	A tree scattered on slopes and ridges in primary and secondary rainforest up to 800 m.	Widespread -Occurring in the Gulf, Central, Milne Bay and Northern Provinces of Papua New Guinea and New Britain of the Bismarck Archipelago.	Unspecified	Unlikely
Mastixiodendron plectocarpum	Rubiaceae	Lower Risk – Near Threatened	This large tree grows in lowland seasonal moist forest.	Confined to south-west Papua New Guinea and south-east Irian Jaya.	Logging.	Unlikely
Myristica globosa	Myristicaceae	Lower Risk – Near Threatened	Rainforest up to 1200m	West Sepik, East Sepik, Madang, Morobe, Eastern Highlands, Western, Gulf, Central, Northern, Milne Bay, Papuan Islands, New Britain & Bougainville. A large number of collections in the Ramu Valley, Madang Province	Habitat destruction	Unlikely
Podocarpus atjehensis	Podocarpaceae	Lower Risk – Near Threatened	In local forest populations, probably on poor soils, … at 2,500 to 3,300 m, near Wissel Lakes at 1,800 m." (de Laubenfels 1988).	The species occurs in the Gajo Lands in northern Sumatra and the Wissel Lakes in Papua New Guinea. The hugely disjunct range of this species, as presently known, merits a critical revision of this species.	Habitat degradation	Unlikely
Podocarpus rumphii	Podocarpaceae	Lower Risk – Near Threatened	Widespread tree occurring in lowland to lower montane forest.	Widespread throughout Oceania	Habitat degradation	Unlikely
Sonneratia ovata	Sonneratiaceae	Lower Risk – Near Threatened	Mangrove forest and woodland	All collections from Gulf and Western Province	Mangrove harvesting	Unlikely

Appendix D

Bio-cultural flora resources recorded within the study area

APPENDIX D: Bio-cultural flora resources recorded within the study area
Bampu Village area, Markham Valley, Morobe Province, PNG.
Wampar language group.

September 2016 – D.G. Fell and D.J. Stanton survey records
Sources of cultural use information and Tok ples names:
Primary: Jim Ouogore, Kelly Jim.
Secondary: Nathan Jim, Ben Jim, Eribano, Joel Nathan, Freda Kelly, Bougi Erich, Lidia Nathan, Jim Kelly

Family	Species name (* =introduced, c=cultivated; cs=cultivated staple, w=wild)	Wampar language (Tok ples name)	Common name	Habit	Part used and uses	Food	Material	Medicinal	Spiritual-Cultural	Fauna use	Commercial	Abundance and distribution notes	Photos
Amaranthaceae	*Coleus argenteus (c, w)*	Kokaruk sobempean	Cocks Comb	Herb	A garden plant valued for attractive flowers.	-	x	-	-	-	-	Village and garden areas. Also on disturbed sites and roadsides.	x
Anacardiaceae	*Dracontomelon dao (w, c)*	Mon	New Guinea walnut	Tree	Timber is highly valued for building purposes. Fruits are edible.	x	x	-	-	-	-	Rare in lowland swamp forests and swampy riparian forests. Observed planted in village. This resource is more plentiful on the southern side of the Markham in the lowland forests of the lower Watut Valley.	x
Anacardiaceae	*Mangifera minor (w, c)*	TBD	Wild mango	Tree	Valued for shade. Edible fruits.	x	x	-	-	-	-	Village areas and gardens.	-
Apocynaceae	*Alstonia scholaris (w)*	Pod	Milky pine	Tree	Timber traditionally used to make paddles for canoes. Timber used for carvings. Timber used for making chairs.	-	x	-	-	-	-	Occasional in lowland swamp forests and in Raintree dominated swampy forests.	-
Apocynaceae	*Calotropis procera* (c)*	-	Calotropis	Shrub	A garden plant valued for attractive flowers.	-	x	-	-	-	-	An introduced plant uncommon in village areas and gardens.	x
Apocynaceae	*Catharanthus roseus* (c)*	-	Madagascar periwinkle	Herb	Valued as an ornamental for attractive flowers and possibly for bilas.	-	x	-	-	-	-	Village areas and gardens.	-
Apocynaceae	*Cynanchum sp. (w)*	Geline	-	Vine	Used as a rope for tying.	-	x	-	-	-	-	Uncommon in lowland swamp forests and in Raintree dominated swampy forests. Species not identified.	x
Apocynaceae	*Ichnocarpus sp. (w)*	Watag	-	Vine	The most commonly used and highly valued rope that is used for house construction and all tying and binding purposes. Recognised as the strongest rope of all.	-	x	-	-	-	-	Occurs in lowland, riparian, swamp and regrowth forests and disturbed sites. Species not identified.	x
Apocynaceae	*Parsonsia* sp. *(w)*	Zoncha	-	Vine	White sap considered as dangerous and poisonous. If sap gets on you it makes the affected part itchy.	-	-	-	-	-	-	Not identified to species level. The plant has opposite leaves which are hairy and the exudate is milky. Uncommon in lowland swamp forests and in Raintree	x

Family	Species name (* =introduced, c=cultivated; cs=cultivated staple, w=wild)	Wampar language (Tok ples name)	Common name	Habit	Part used and uses	Food	Material	Medicinal	Spiritual-Cultural	Fauna use	Commercial	Abundance and distribution notes	Photos
												dominated swampy forests. Species not identified.	
Apocynaceae	*Plumeria odorata (c)*	TBD	Frangipani	Tree	Attractive flowers used for 'bilas'.	-	x	-	-	-	-	Planted around villages and gardens.	-
Araceae	*Alocasia* sp. *(c, w)*	TBD	Wild taro	Aroid	Tuber used.	x	-	-	-	-	-	Planted around villages and gardens and occurring wild in swampy forests.	x
Araceae	*Calocasia esculenta* (c)*	TBD	Taro	Aroid	Tuber used.	x	-	-	-	-	-	Planted around villages and gardens and occurring wild in swampy forests.	
Araceae	*Rhaphidophora pachyphylla* (w) or *Epipremum amplissimum (w)*	Sisig	-	Climbing aroid	When a snake catches its prey, they put prey down and eat this plant so as to make the snakes mouth open wider.	-	-	-	-	x	-	Occurs in better developed lowland, riparian, swamp forests and disturbed sites.	x
Arecaceae	*Areca catchu (c, w)*	TBD	Betel nut	Palm	Nuts chewed as a stimulant and mixed with lime and mustard.	-	x	x	x	-	x	Kelly Jim reports that the Betel Nut palm used to be very abundant in the study area however was affected by a bug that injected sap into the plant causing palms to die off. This changed the local economy.	-
Arecaceae	*Calamus longipinna (w)*	Kapu	Lawyer Cane	Vine	The small fruits are eaten whole as a snack. The hard seed which is enclosed by a fleshy aril is also eaten and cracked with teeth. The spiny tendrils are also traditionally used to catch flying foxes. The tendrils are wrapped around the end of a long stick made out of the mid rib of sago palm leaf. The stick is used to swipe at the bats with the spiny tendrils tearing the outstretched wings.	x	x	-	-	-	-	Common in lowland forest, regrowth and Raintree forests.	x
Arecaceae	*Calamus* sp. (possibly *C. aurensis or C. hollrungii*) *(w)*	TBD	Wait a while	Vine	Cane is dried and split and used for house construction.	-	x	-	-	-	-	Not seen during survey. A robust vine. Uncommon and restricted to lowland forests and swampy forests.	-
Arecaceae	*Caryota rumphiana*	TBD. Name not recorded.	Fishtail Palm	Palm	The fruit can be chewed but considered bitter.	x	-	-	-	-	-	Uncommon to rare palm in lowland and swamp forests.	-
Arecaceae	*Cocos nucifera* (cs)*	TBD	Coconut palm	Palm	Leaves used for construction and material items, nuts eaten and milk consumed.	x	x	-	-	-	x	Planted in village and garden areas in in large plantations.	-
Arecaceae	*Hydriastele costata (w)*	Ramid (bark is	Galubia palm	Palm	A valuable and restricted	-	x	-	x	-	-	Uncommon palm restricted to lowland	x

Family	Species name (* =introduced, c=cultivated; cs=cultivated staple, w=wild)	Wampar language (Tok ples name)	Common name	Habit	Part used and uses	Food	Material	Medicinal	Spiritual-Cultural	Fauna use	Commercial	Abundance and distribution notes	Photos
		Ompan)			resource. The trunk is cut and the outer bark is split in lengths and used for flooring and walls, and for making bows. The sheath of the leaf frond is peeled off the trunk and used as a mat. The midrib of the leaflets are bundled and used as a broom. Also used as a stretcher for carrying children, or the sick. Reported to be used for wrapping deceased bodies for burial. Fruits favoured by pigs; when fruiting it is a sign for hunting.							forests, swampy forest habitats along the Markham. The habitat is often invaded by Raintree. Note that the bark is called Ompan and the palm itself is Ramid.	
Arecaceae	*Metroxylon sagu (w)*	Montam	Sago palm	Palm	A high value resource. Pith extracted and processed for food. Fronds used for shelter and building. Frond stems used for various purposes including wrapping the sharp tendrils of Kapu (*Calamus longipinna*) for hunting flying foxes.	x	x	-	-	-	x	Uncommon palm restricted to swampy lowland forest habitats along the Markham River.	x
Arecaceae	*Ptychosperma sp. (w)*	Katz	-	Palm	Trunks split and traditionally used to make bows.	-	x	-	-	-	-	Uncommon palm restricted to lowland forests, swampy forests and Raintree regrowth forests. Not seen during survey. Species name unknown. Further field work required.	-
Arecaceae	*Ptychosperma sp. (w)*	Mofop	-	Palm	Trunks split and traditionally used to make bows.	-	x	-	-	-	-	Uncommon palm restricted to lowland forests, swampy forests and Raintree regrowth forests. Not seen during survey. Species name unknown. Further field work required.	-
Arecaceae	Unknown slender palm like betel nut (w)	Sagabua	-	Palm	Seeds are edible	x	-	-	-	-	-	Not seen during survey. Reported to be uncommon in lowland swampy forests.	-

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												Further field work required.	
Athyriaceae	*Diplazium esculentum (w)*	Zempoz	-	Terrestrial fern	Leaves eaten after cooking.	x	-	-	-	-	--	Occasional in Raintree forests and lowland forests areas.	x
Balsaminaceae	*Impatiens* sp.* *(c)*	-	Impatiens	Herb	A decorative garden plant cultivated for attractive flowers.	-	x	-	-	-	-	Garddens and village areas.	
Bombacaceae	*Bombax ceiba var. leioclada (w)*	Waif	Cotton Tree	Tree	Timber used for furniture making including chairs and tables.	-	x	-	-	-	-	A deciduous tree uncommon in lowland forest.	x
Burseraceae	*Garuga floribunda var. floribunda (w)*	Sanaprenen	Garuga	Tree	Valued as for firewood. Valued for house timber.	-	x	-	-	-	-	Uncommon to rare deciduous tree recorded only in gully scrubs on foothills near Bismark ranch.	-
Byttneriaceae	*Kleinhovia hospita (w)*	Zafutz	Kleinhovia	Tree	Timber used for house construction.	-	x	-	-	-	-	Occasional on margins of lowland forests and raintree regrowth forests.	-
Caesalpiniaceae	*Cassia sp. (w)*	-	Cassia	Tree	Used for firewood, building materials and fence posts.	-	x	-	-	-	-	An introduced multi stemmed shrub to tree common in disturbed areas often in association with Leucaena, Glycridia and Raintree regrowth. Forms dense stands closer to the river.	x
Caesalpiniaceae	*Senna alata* (w)*	Gampos	Ringworm Shrub	Shrub	Leaves are crushed to release a juice that is squeezed and rubbed onto skin to treat ringworm.	-	-	x	-	-	-	An introduced shrub uncommon in disturbed areas.	x
Caesalpiniaceae	*Senna sp.* (w)*	-	-	Shrub-Tree	Seed pods eaten by cattle, which disperse the seeds in manure.	-	-	-	-	-	-	An aggressive woody weed throughout parts of the study area particularly on areas subject to heavy grazing pressure in the past.	x
Caricaceae	*Papaya carica*(c, w, cs)*	-	Papaya	Shrub	Fruits edible. Sold at markets. Seeds reported to have antibacterial properties and are chewed.	x	-	x	-	-	X	Commonly cultivated in gardens.	-
Combretaceae	*Terminalia catappa (w, c)*	TBD	Indian almond	Tree	Nuts inside of fruits are edible. Timber is strong. Planted for shade.	x	x	-	-	-	-	Not seen in bush but observed as planted specimens in village areas.	-
Combretaceae	*Terminalia complanata (w)*	Tib	Damson	Tree	Timber valued for house construction.	-	x	-	-	-	-	Large deciduous canopy tree with buttressing, uncommon in lowland forest and in Raintree regrowth forests on swampy soils.	x
Convolvulaceae	*Ipomoea batatas* (cs)*		Sweet potato	Tuber	Tuber is a staple food.	x	-	-	-	-	x	Commonly cultivated in gardens.	-
Cycadaceae	*Cycas schumanniana*	Luwari	Cycad	Cycad	Leaves used for bilas for	-	x	-	-	-	-	Restricted to patchy populations on	x

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	(w)				sing sings. Seeds also said to look nice when cut at base and plaited in a line.							foothills and adjoining alluvial plains.	
Datiscaceae	*Octomeles sumatrana (w)*	Leso	Erima	Tree	Timber valued for making canoes. Hollows utilised by Hornbills and other fauna.	-	x	-	-	x	-	Not recorded in study area. Possibly once present in remnants of lowland forest on floodplain. Known to occur on the south side of the Markham River along the Watut River (DG Fell pers. obs. 2015)	-
Dioscoreaceae	*Dioscorea bulbifera (w, c)*	TBD	Yam	Vine	Tuber dug and eaten after cooking.	x	-	-	-	-	-	Uncommon in lowland forest and possibly also cultivated.	-
Dioscoreaceae	*Dioscorea transversa (w)*	TBD	Yam	Vine	Tuber dug and eaten after cooking.	x	-	-	-	-	-	Grasslands and riparian forests.	-
Elaeocarpaceae	*Muntingia calurbra* (w)*	Pepaye	Japanese Strawberry	Shrub to small tree	Fruits are edible but only eaten by birds and bandicoots. Timber used for firewood	-	x	-	-	x	-	An introduced species widespread within disturbed areas along roadsides and forest edges.	x
Euphorbiaceae	*Abelmoschus manihot* subsp. *manihot (cs)*	TBD	Aibeka	Herb	Leaves used as a common vegetable.	x	-	-	-	-	-	Gardens and village areas.	-
Euphorbiaceae	*Endospermum medullosum (w)*	Bompog	Moon tree	Tree	Leaves eaten by cuscus. Bark used medicinally for treatment of bruising and swelling.	-	-	x	-	x	-	Uncommon in lowland forest and in Raintree regrowth forests on swampy soils.	x
Euphorbiaceae	*Euphorbia bifida (w)*	Ngareo fan	-	Herb	The milky sap from the stem and broken leaves is used on tattoos to set the ink. Used for sing sing preparation general body decoration.	-	x	-	x	-	-	An erect slender herb to 50cm occasional in Kunai dominated grasslands on plains and foothills.	x
Euphorbiaceae	*Macaranga involucrata* var. *mallotoides (w)*	Preampre	-	Tree	Timber is used for housing construction for rafters and walls.	-	x	-	-	-	-	Occasional on margins of lowland forests and Raintree regrowth forests.	-
Euphorbiaceae	*Macaranga quadriglandulosa (w)*	Preampre	-	Tree	Timber is used for housing construction for rafters and walls.	-	x	-	-	-	-	Occasional on margins of lowland forests and Raintree regrowth forests.	x
Euphorbiaceae	*Macaranga tanarius (w)*	Preampre	Macaranga	Tree	Timber is used for housing construction for rafters and walls.	-	x	-	-	-	-	Occasional on margins of lowland forests and Raintree regrowth forests.	-
Euphorbiaceae	*Mallotus mollissimus (w)*	Preampre	-	Tree	Timber is used for housing construction for rafters and walls.	-	x	-	-	-	-	Occasional on margins of lowland forests and Raintree regrowth forests.	-
Euphorbiaceae	*Mallotus paniculatus (w)*	Opiaf	Turn in the wind	Tree	Timber is used for housing construction for rafters and	-	x	x	-	-	-	A fast growing small to medium tree often in regrowth on margins of tracks and roads	x

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					walls. When the tree has died the dry timber supports grubs, which can be eaten. Used medicinally to treat sores and infections. Bark is boiled in water and juice is used to dry up boils.							and in lowland and raintree forests.	
Euphorbiaceae	*Manihot esculenta* (cs)*	TBD	Cassava	Shrub	Tuber eaten after preparation.	x	-	-	-	-	-	Widespread in gardens and village areas.	-
Euphorbiaceae	*Manihot glaviozii* (w)*	-	Ceara Rubber	Shrub to small tree	Recognised as a poisonous plant introduced to the area.	-	-	-	-	-	-	Occurs in degraded sites and along roads. An aggressive tropical weed similar in appearance to Cassava.	x
Euphorbiaceae	*Melanolepis multiglandulosa (w)*	Zizipu	-	Tree	Fruits eaten by birds.	-	-	-	-	x	-	Abundant in lowland forest and margins and Raintree dominant open and closed forests.	x
Euphorbiaceae	*Ricinus communis* (w)*	Wusuwis	Castor oil bush	Shrub	Introduced weed species with a recognised name but not used and considered toxic.	-	-	-	-	-	-	Scattered along disturbed roadsides and degraded forest margins.	x
Fabaceae	*Abrus preacatorius (w)*	Zri	Gidee Gidee	Vine	Brightly coloured red and black seeds used for bilas.	-	x	-	-	-	-	Occasional to uncommon in forest margins and regrowth.	x
Fabaceae	*Arachis hypogaea*	-	Peanut	Vine	Plant cultivated for edible nuts eaten raw or roasted. Sold in markets.	x	-	-	-	-	x	Grown in village gardens.	-
Fabaceae	*Centrosema molle* (w)*	Mozo	Centro	Vine	Used locally as a rope for tying up fish and possible other smaller items.	-	x	-	-	-	-	Abundant leguminous vine in all disturbed grassland and savannah habitats. Introduced for cattle fodder.	x
Fabaceae	*Crotalaria pallida* (w)*	Zerab Zerab	Rattlepod	Shrub	No uses. Recognised as an introduced weed.	-	-	-	-	-	-	Disturbed roadsides and kunai grasslands.	-
Fabaceae	*Glyricidia sepium* (c, w)*	No local name	Glyricidia	Shrub	Timber utilised for poles in house construction and for firewood. Also used as a cover crop for cocao and other crops.	-	x	-	-	-	x	An introduced leguminous multi stemmed shrub to small tree. Abundant throughout disturbed areas. Although plentiful the resource is reported as not as good as native species	x
Fabaceae	*Intsia bijuga (w)*	Ngarowagef	Kwila	Tree	Timber.	-	x	-	-	-	-	Very rare in study area and limited to gully forests on foothills. Potentially historically present in lowland forest.	-
Fabaceae	*Puearia montana* var. *montana (w)*	Pur. mpur	Kudzu	Vine	Tuber reported to be eaten 'bepotaim' however now only used for feeding pigs. Vine possibly used as a general purpose rope for	x	X	-	-	-	-	A robust trifoliate leguminous vine with large underground tuber. Common in grasslands and disturbed forest margins.	x

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					tying.								
Fabaceae	*Unknown*	Mosamos	-	Shrub	Flowers have prominent cascading bracts which are placed upon young coconuts to promote bearing of good fruit.	-	-	-	X	-	-	Uncommon in riparian forests.	x
Flagellariaceae	*Flagellaria indica (w)*	Moangen	Supplejack, Whip Vine	Vine	A robust cane used for all tying and binding purposes. Cane is split to make finer ropes. Used in house construction. Women make frames for fishing nets out of the canes.	-	x	-	-	-	-	Occasional in broad leaved lowland forests, riparian forests and rain tree dominated regrowth areas.	x
Gnetaceae	*Gnetum gnemon (w)*	Kring	Tulip	Tree	New leaves edible and cooked as a vegetable. Seeds are edible. Inner bark is stripped and used as a rope and for making of bilums, baskets and general tying purposes.	x	x	-	-	-	-	Uncommon in lowland swamp forests and swampy riparian forests. Often planted in village areas. This resource is more plentiful on the southern side of the Markham River in the lowland forests of the lower Watut Valley.	x
Lamiaceae	*Premna sp.*	Onka	-	Shrub-small tree	New leaves reported to be edible.	-	x	-	-	-	-	Low confidence.	x
Lamiaceae	*Vitex sp. (w)*	Guaron abuf	-	Shrub	Leaves are boiled and used as a remedy for toothache and sore joints. Wallabies used to eat it.	-	-	x	-	x	-	Uncommon shrub restricted to roadsides in grasslands and savannah woodlands.	x
Lauraceae	*Litsea guppyi (w)*	Ngarosaor	A Bolly Gum	Tree	Valued as for its timber that is used for building purposes.	-	x	-	-	-	-	Common in broad leaved lowland forests and rain tree dominated regrowth areas.	-
Laxmanniaceae	*Cordyline terminalis (c)*	TBD	Cordyline	Shrub	A decorative garden plant.	-	x	-	-	-	-	Gardens and villages.	-
Lecythidaceae	*Planchonia papuana (w)*	Morril	-	Tree	A strong timber valued for building purposes and used for bearers and joices.	-	x	-	-	-	-	A large tree. Uncommon and restricted to lowland forests and swampy forests.	x
Malvaceae	*Hibiscus rosa-sinensis (c)*	-	Hibiscus	Shrub	Attractive flowers valued for bilas and garden decorations.	-	x	-	-	-	-	Gardens and village areas.	-
Malvaceae	*Theobroma cacao* (cs)*	-	Cacao	Shrub	Seeds dried and sold to market for making chocolate.	x	-	-	-	-	x	Common in plantation areas and around villages and gardens.	-
Meliaceae	*Azederach indica* (c, w)*	-	Neem Tree	Tree	Planted as a windbreak for	-	x	-	-	-	-	An introduced plant planted extensively as	x

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					shade.							an avenue tree and for shade near the Chinese-built school. The tree has bird dispersed fruits and it has invaded nearby grazing land forming dense thickets with Cassia.	
Meliaceae	*Dysoxylum gaudichaudianum (w)*	Esea	Ivory mahogany	Tree	Timber used for building. Fruits eaten by birds and Cuscus. Meat cooked over this wood deters people who eat too much meat.	-	x	-	-	x	-	Common in broad-leaved lowland forests and Raintree dominated regrowth areas.	x
Mimosaceae	*Acacia crassicarpa* (c)*	-	Coast Wattle	Tree	Timber and firewood.	-	x	-	-	-	x	Introduced as a fast growing tree for firewood and timber production. Recorded in planted rows in trial forestry plots and seen as wildings in nearby areas.	x
Mimosaceae	*Albizia procera (w)*	Nginzib	Forest siris	Tree	Highly value timber for house foundations. Reported to be the best firewood available. The timber was targeted during the cattle era for strainer posts and fence which do not suffer rot.	-	x	-	-	-	-	Common tree in savannah woodlands in association with Ngempang (*Nauclea orientalis*) or as an emergent in kunai grasslands.	x
Mimosaceae	*Leucaena leucocephala* subsp. *leucocephala* (w)*	-	Leucaena	Shrub to small tree	Timber utilised for house construction and for firewood. Although plentiful the resource is reported as not as good as native species.	-	x	-	-	-	-	An introduced leguminous multi stemmed shrub to small tree. Planted for cattle fodder. Occurs throughout disturbed areas and in regrowth forests.	-
Moraceae	*Antiaris toxicarya var. macrophylla*	Lave	Poison Fig	Tree	Outer bark traditionally used as a material/cloth for men and women. Women use the cloth as a top over breasts.	-	x	-	-	-	-	Uncommon deciduous tree observed only once on margin of rain tree forest.	-
Moraceae	*Artocarpus altilis (c, w)*	kupiak	Breadfruit	Tree	Edible fruits. Shade tree. Timber for building purposes.	x	x				-	Occasional in large crown forests and in garden areas.	-
Moraceae	*Ficus copiosa (w)*	Lampor	Plentiful fig	Small tree	Leaves used as a sandpaper. In old days fruits were eaten but not now.	x	x	-	-	-	-	Occasional to uncommon in lowland forests and in understorey of rain tree regrowth forests.	-
Moraceae	*Ficus septica (w)*	Sisig	A Fig	Small tree	Fruits used as a spinning top toy.	-	x	-	-	-	-	Uncommon in lowland forests and in understorey of rain tree regrowth forests.	-

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Moraceae	*Ficus sp. (w)*	Fansif	A Fig	Small tree	Leaves used as a bush sandpaper. Small fruits eaten by birds.	-	x	-	-	x	-	A small tree with sandpaper leaves and small orange fruits. Occasional in lowland forests and in the understorey of Raintree regrowth forests.	-
Moraceae	*Ficus sp. (w)*	Mamro	Sandpaper fig	Small tree	Leaves used as bush sandpaper.	-	x	-	-	-	-	Uncommon to occasional in lowland forests and in understorey of Raintree regrowth forests.	-
Moraceae	*Ficus sp. (w)*	Zengetz	A Fig	Shrub-Tree	Birds eat fruits. Outer bark used as a rope for tying and binding.	-	x	-	-	-	-	Uncommon in lowland forests and in understorey of Raintree regrowth forests.	-
Moraceae	*Ficus sp. (w)*	Meab	-	Small tree	The fruits are food for birds and considered useful indicator for hunting. Fish eat the fruit.	-	-	-	-	x	-	Not recorded in study area during survey. Possibly in lowland or riverine forests.	-
Moraceae	*Ficus virgata (w)*	Oka	Red stem fig	Tree	Young leaf tips reported to be edible and cooked in pot with meat. Birds eat fruits.	x	-	-	-	x	-	Uncommon in lowland forests and in understorey of Raintree regrowth forests.	-
Moraceae	*Ficus wassa (w)*	Mosangen	A Fig	Tree	Birds and bandicoots eat fruits. Outer bark used as a rope for tying and binding. Leaf tips can be eaten.	-	x	-	-	-	-	Occasional in lowland forests and in understorey of Raintree regrowth forests.	-
Moraceae	*Maclura cochichinensis (w)*	Sinnamon	Cockspur	Vine	The dense and prickly vine/shrub protects animals.	-	-	-	-	x	-	Occasional in lowland forests and in understorey of Raintree regrowth forests.	-
Moraceae	*Trophis scandens* subsp. *scandens (w)*	Ngamusiririp	Burny vine	Vine	Outer bark used as a rope for tying and binding. Bark of vine very rough and known to cause burns or shallow cuts when walking through bush.	-	x	-	-	-	-	Occasional in lowland forests and in understorey of Raintree regrowth forests.	-
Musaceae	*Musa* sp. (cs, w)	TBD	Banana	Herb	Fruits eaten raw and cooked. Leaves used for wrapping	x	x	-	-	-	x	Abundant in gardens and village areas.	-
Myristicaceae	*Myristica sp. (w)*	Zerer	A Nutmeg	Tree	Fruits eaten by cuscus and hornbills. The branchlets of the young plants are symmetrical from the main stem	-	-	-	-	x	-	Tree restricted to lowland forests, swampy forests and Raintree regrowth forests.	x
Myrtaceae	*Eucalyptus camaldulensis*	-	River Red Gum	Tree	A few trees planted around the Bismark yards and	-	x	-	-	-	-	Limited to plantings at one site.	x

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					homestead for shade. Possibly utilised for firewood.								
Myrtaceae	*Eucalyptus pellita* (c)*	-	Red Mahogany	Tree	Valued locally as a fast growing timber for building purposes and firewood.	-	x	-	-	-	x	Introduced as a fast growing tree for timber production. Planted rows in trial forestry plots.	x
Myrtaceae	*Psidium guajava* (c, w)*	-	Guava	Small tree	The fruits are edible but not appeared to be used.	-	-	-	-	-	-	A common woody weed in disturbed areas and in regrowth shrublands and forests.	x
Myrtaceae	*Syzygium aquem (c, w)*	Lour lour	Bell fruit		Fruit edible when ripe as a snack.	-	x	-	-	-	-	A small to medium tree uncommon in regrowth and lowland forests and cultivated in village gardens.	-
Pandanaceae	*Pandanus* sp. *1 (w)*	Ngag	Pandanus	Pandan	Fruits edible when ripe when yellow in colour. The juice is sucked and fibre thrown away. Eaten in old days but not so now. The dry leaves are a house for rats and some reptiles. Pandanus fruits are recognised as the best fruits for pigs and are a sign to focus pig hunting efforts in areas where fruiting pandanus are.	-	x	-	-	-	-	Restricted in lowland forests and swampy areas along creeks.	x
Pandanaceae	*Pandanus* sp. *2 (w)*	samase	Pandanus	Pandan	Fruits are edible and occur in a bunch like coconuts.	-	x	-	-	-	-	Not seen. Reported to occur in swampy lowland habitats.	-
Pandanaceae	*Pandanus* sp. *3 (w)*	umi	Pandanus	Pandan	Fruits are edible, long and red and yellow in colour.	-	x	-	-	-	x	Not seen. Reported to occur in swampy lowland habitats. Sold at markets.	-
Passifloraceae	*Passiflora edulis* (c)*	-	Passionfruit	Vine	Edible fruit. Also eaten by birds and bandicoots.	x	-	-	-	x	-	Common in grasslands and disturbed forest margins.	-
Passifloraceae	*Passiflora foetida (w)*	Guzog	Stinking passionflower	Vine		x	-	-	-	-	-	Edible fruits also eaten by birds and bandicoots.	x
Phyllanthaceae	*Antidesma ghaesembilla (w)*	Titif	Black currant tree	Shrub/small tree	Small black fruits are edible as a snack. Timber used as firewood. The bushy crown provides habitat for doves and other small birds who also favour the fruits. Snakes coil up in the branches.	x	x	-	-	x	-	Common shrub to small tree in kunai grasslands and in better developed savannah woodlands with *Nauclea* and *Albizia*.	x
Phyllanthaceae	*Antidesma olivaceum (w)*	Mamoro	A currant tree	Tree	Juice from the dark fruits used as a ink.	-	x	-	-	-	-	Uncommon in lowland forests, swamp and riparian forests.	x

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Phyllanthaceae	*Breyania oblongifolia (w).*	Ziziri	Stinkbush	Shrub	Not used but small red fruits recognised as bird food.	-	-	-	x	-	-	Common on forest margins and regrowth and in savannah woodlands.	-
Phyllanthaceae	*Breynia cernua* (w)	Ziziri	Stinkbush	Shrub	Not used but small red fruits recognised as bird food.	-	-	-	x	-	-	Common on forest margins and regrowth and in savannah woodlands.	x
Phyllanthaceae	*Glochidion* sp. *(w)*	Matsak	Cheese Tree	Tree	Sap under bark extracted and used as a general purpose glue for sticking snake, lizard or cuscus skins to drums, or for furniture. Juice extracted by chewing of the bark and spitting juice in a container.	-	x	-	-	-	-	Occasional to common in lowland forests, swamp and riparian forests.	x
Piperaceae	*Piper aduncum* (w)*	TBD	Spiked pepper	Shrub-small tree	Firewood	-	x	-	-	-	-	An introduced species naturalised throughout the Markham. Not as abundant in the drier Markham valley than observed in the Watut Valley where it aggressively invades following any disturbance (DG Fell pers. obs.).	x
Poaceae	*Bambusa* sp. *(w)*	TBD	A bamboo	Bamboo	Stems for building and general uses.	-	x	-	-	-	-	rare to uncommon in village areas. Kelly Jim mentioned that it used to be more widespread in olden days.	-
Poaceae	*Imperata cylindrica (w)*	Poatz	Kunai	Grass	Dry grass used for roofing of huts and houses throughout the area.	-	x	-	-	-	-	A valuable and widespread resource occurring throughout the valley and on foothill slopes. Loss of kunai grasslands has occurred as a result of shrubby thickening and progression of Raintree dominated forests in some areas particularly along the Markham River.	x
Poaceae	*Miscanthus sp. (w)*	Zegenzeg	Small Pit Pit	Grass	Eaten by cattle. Slender stems make a noose for carrying fish.	-	x	-	-	-	-	Occurs as a subordinate grass in Kunai grasslands.	-
Poaceae	*Neololebra atra*	TBD. Name not recorded.	Cape Bamboo	Bamboo	Use not recorded however likely to be utilised for material purposes.	-	?	-	-	-	-	Rare native bamboo in lowland and swamp forests.	-
Poaceae	*Phragmites karka (w)*	Zaeg	Bamboo reed	Grass	Stems used to make walls. The pith is chewed and spat out and weaved together. An indicator of water logged ground and swampy areas.	-	x	-	-	-	-	Occurs in Kunai grasslands and swampy places of the river.	x

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Poaceae	*Polytoca macrophylla (w)*	TBD	-	Grass	Stems used. Use type not documented.	-	x	-	-	-	-	Occurs in Kunai grasslands often as a dominant species.	-
Poaceae	*Saccharum robustum (c, cs)*	TBD	Sugar cane	Grass	Food item.	x	-	-	-	-	x	Planted in gardens and village areas and sold at markets.	-
Poaceae	*Themeda arguens (w)*	Ziz	Kangaroo grass	Grass	Recognised as a food for cattle.	-	-	-	-	-	-	Occurs in savannah woodlands and scattered in kunai grasslands on alluvium and foothills.	x
Poaceae	*Themeda triandra (w)*	Ziz	Kangaroo grass	Grass	Recognised as a food for cattle.	-	x	-	-	-	-	Occurs in savannah woodlands and scattered in kunai grasslands on alluvium and foothills.	-
Poaceae	*Zea mays* (cs)*	TBD	Corn	Corn	Edible cobs.	x	-	-	-	-	-	Cultivated in gardens.	-
Rubiaceae	*Morinda citrifolia (w)*	Sangra	Noni plum	Shrub	Fruits eaten for medicinal purposes. Pigs attracted to fallen fruits.	x	-	x	-	x	-	Occasional to uncommon in broad leaved lowland forests and Raintree dominated regrowth areas and margins of savannah woodlands.	x
Rubiaceae	*Nauclea orientalis (w)*	Ngempang	Yellow cheesewood	Tree	Valuable timber tree. Yellowish timber for furniture making and structural timber. Shade tree in kunai country. Pigs and flying foxes are attracted to fleshy fruits providing a focus for hunting.	-	x	-	-	x	--	Abundant in savannah woodlands and scattered in kunai grasslands often in association with *Albizia procera.*	x
Rubiaceae	*Neonauclea sp. (w)*	Ubu	-	Tree	Highly valued timber tree used for housing construction such as joists and bearers.	-	x	-	-	-	-	Rare tree restricted to swampy places near water. Recorded in a narrow riparian gully approximately 1 km west of Bampu Village.	x
Rubiaceae	*Timonius timon (w)*	Zabi	Timonius	Tree	Timber. Fruits eaten by birds and bandicoots.	-	x	-	-	x	-	Occasional in savannah woodlands and on margins of lowland forests and Raintree regrowth forests.	x
Rutaceae	*Melicope bonwickii (w)*	Damel	Melicope	Tree	Timber	-	x	-	-	-	-	Uncommon tree restricted to lowland forests, swampy forests and Raintree regrowth. More common in the Watut Valley (DG Fell pers. obs.)	x
Sapindaceae	*Allophyllus cobbe (w)*	Ziziri	-	Small tree	Small red fruits eaten by birds and animals only.	-	-	-	-	x	-	Occurs in lowland, riparian, swamp and regrowth forests.	x
Sapindaceae	*Ganophyllum falcatum (w)*	Zara	Scaly Ash	Tree	Used as bilas for sing sing. Unknown plant part boiled to produce good scent.	-	x	-	-	-	-	Uncommon tree in lowland forests and deciduous forest in gullies of foothills.	
Sapindaceae	*Pometia pinnata (w)*	Suk	Taun	Tree	Valued timber for housing and construction.	-	x	-	-	-	-	Uncommon in study area within lowland forests and as a young sapling	x

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												regenerating in Raintree regrowth. More common in the Watut Valley (DG Fell pers. obs.)	
Sapindaceae	*Tristiropsis acutangula (w)*	A Taun	Fern leaved tamarind	Tree	Valued timber for housing and construction.	-	x	-	-	-	-	Uncommon in study area within lowland forests and as a young sapling regenerating in Raintree regrowth. More common in the Watut Valley (DG Fell pers. obs.)	-
Solanaceae	*Nicotiana tabaccum* (cs)*	TBD	Tobacco	Herb	Leaves dried and crushed for tobacco smoking.	-	x	x	-	-	-	Gardens and village areas.	-
Solanaceae	*Physalis angulata*	Dampanupuak	Cape Gooseberry	Herb	Used as a plaything. The seed capsule is pooped against the forehead for amusement.	-	-	-	-	-	-	Occasional weed in disturbed areas.	-
Solanaceae	*Solanum mauritianum* (w)*	Nidinid	Tobacco Bush	Shrub	Soft leaves used as a toilet paper for children. Pigeons eat fruits. Tube nose bats eat fruits.	-	x	-	-	x	-	An introduced weed of disturbed areas.	x
Sparrmanniaceae	*Trichospermum pleiostigma (w) or Commersonia novoguinensis (w)*	Guware	False Commersonia	Tree	Fibrous bark once used as a rope for all general purposes. Considered as very good firewood. Timber used for house construction. Tips of leaves squeezed with water with a slippery juice extract used medicinally to loosen coughs.	-	x	x	-	-	-	Occasional to common in broad leaved lowland forests and Raintree dominated regrowth areas.	x
Sterculiaceae	*Sterculia* sp. (w) Possibly S. *schumanniana* or *S. shillinglawii*	Kurungkir	Sterculia	Tree	A rope is made from outer bark which is used to carry firewood. An edible grub occurs within dry rotten trunks. It's the same grub as in *Mallotus paniculatus*. Leaves used to wrap grubs or for wrapping other foods.		x				-	Tree restricted to lowland forests, swampy forests and Raintree regrowth forests.	x
Ulmaceae	*Celtis latifolia (w)*	TBD	Celtis	Tree	Valued for timber	-	x	-	-	-	-	Uncommon in study area within lowland forests. More common in the Watut Valley (DG Fell pers. obs.)	-
Ulmaceae	*Trema orientalis (w)*	Yangkro	Tree Peach	Tree	Timber for building.	-	x	-	-	-	-	Tree restricted to lowland forests, swampy forests and Rain tree regrowth forests.	-

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Verbenaceae	*Clerodendrum floribundum (w)*	Ngobwanob Ngobwanob	Smooth clerodendrum	Shrub	Attractive flowers recognised as decorative in nature. Not reported to be used otherwise	-	x	-	-	-	-	Occasional in kunai grasslands and savannah woodlands on alluvium and foothills.	-
Verbenaceae	*Clerodendrum tomentosum (w)*	Ngobwanob Ngobwanob	Hairy clerodendrum	Shrub	Attractive flowers recognised as decorative in nature. Not reported to be used otherwise.	-	x	-	-	-	-	Occasional in kunai grasslands and savannah woodlands on alluvium and foothills.	x
Verbenaceae	*Duranta erecta* (c)*	-	Geisha girl	Shrub	Attractive flowers recognised as decorative for garden plantings. Not reported to be used otherwise.	-	x	-	-	-	-	Gardens and village areas.	-
Zingiberaceae	*Alpinia* sp. *(w)*	Chirempo	A ginger	Aroid	The fleshy fruits can be eaten raw. Leaves used for matting.	x	x	-	-	-	-	A common ginger with a rhizome found in lowland forest or Raintree regrowth forests.	-
Zingiberaceae	*Amomum aculeatum (w)*	Yasi	-	Aroid	Edible for both man and animals. Crushed leaves used medicinally to wash body all over when sick.	x	x	x	-	-	-	Occasional in Raintree forests and lowland forests.	x
Zingiberaceae	*Hornstedtia scottiana (w)*	Yangkuan	Scott's ginger	Aroid	Fruits eaten. Stems crushed and split and used as a rope. Juice from squeezed flowers used medicinally to open boils up. Leaves used for wrapping meat. Pigs, bandicoots and rats eat the plant.	x	x	x	-	x	-	Occasional in Raintree forests and in lowland rain forests.	x
Zygophyllaceae	*Tribulus terrestris (w)*	-	Caltrope	Herb	Recognised as a very bad introduced weed with spiky thorns. Not used otherwise.	-	-	-	-	-	-	Abundant on disturbed areas such as roadsides and invading into new *E. pellita* plantations.	x
Unknown	*Unknown (w)*	Papenge	Unknown	Fern	Named but not said to be eaten.	-	-	-	-	-	-	Not recorded in study area.	-
Unknown	*Unknown (w)*	Ngafir	Unknown	Tree	Unknown timber tree.	-	x	-	-	-	-	Not recorded in study area. Possibly in remnants of lowland forest on floodplain or on the south side of the Markham River.	-
Unknown	*Unknown (w)*	Apiz	Unknown	Tree	Timber for building.	-	x	-	-	-	-	Large timber tree not seen during survey. Possibly occurs in lowland forests.	-
Unknown	*Unknown (w)*	Tanam	Unknown	Tree	Unknown timber tree.	-	x	-	-	-	-	Not recorded in study area. Possibly in remnants of lowland forest on floodplain or	-

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												on the south side of the Markham River.	
Unknown	*Unknown (w)*	Ngageng	Unknown	Tree	Unknown timber tree.	-	x	-	-	-	-	Not recorded in study area. Possibly in remnants of lowland forest on floodplain or on the south side of the Markham River.	-
Unknown	*Unknown (w)*	Sanget	Unknown	Tree	Unknown timber tree.	-	x	-	-	-	-	Not recorded in study area. Referred to as an 'old one'' indicating it could occur further afield and recalled by senior elder.	-
Unknown	*Unknown (w)*	Zer	Unknown	Vine	Unknown vine traditionally used as a rope for tying.	-	x	-	-	-	-	Not recorded in study area. Referred to as an 'old one'' indicating it could occur further afield and recalled by senior elder.	-
Unknown	*Unknown (w)*	Ziriri	Unknown	Vine	Unknown vine traditionally used as a rope for tying.	-	x	-	-	-	-	Not recorded in study area. Referred to as an 'old one'' indicating it could occur further afield and recalled by senior elder.	-
Unknown	*Unknown (w)*	Dero	Unknown	Vine	Unknown vine traditionally used as a rope for tying.	-	x	-	-	-	-	Not recorded in study area. Referred to as an 'old one'' indicating it could occur further afield and recalled by senior elder.	-
Unknown	*Unknown (w)*	Zuzunguf	Unknown	unknown	Unknown	-	x	-	-	-	-	Not recorded in study area. Referred to as an 'old one'' indicating it could occur further afield and recalled by senior elder.	-
Unknown	*Unknown (w)*	Mugum	Unknown	unknown	Unknown	-	x	-	-	-	-	Not recorded in study area. Referred to as an 'old one'' indicating it could occur further afield and recalled by senior elder.	-
Unknown	*Unknown (w)*	Mpet	Unknown	unknown	Unknown	-	x	-	-	-	-	Not recorded in study area during survey. Referred to as an 'old one'' indicating it could occur further afield and recalled by senior elder.	-
Unknown	*Unknown (w)*	Osad	Unknown	unknown	A bark from a native tree that is used to make 'tapa'. Possibly a *Ficus* species.	-	x	-	-	-	-	Not recorded in study area during survey. Referred to as an 'old one'' indicating it could occur further afield and recalled by senior elder.	-
Unknown	*Unknown (w)*	Ngaregimpup	Unknown	Vine	A vine used as a rope for tying and binding	-	x	-	-	-	-	Not recorded in study area during survey. Referred to as an 'old one'' indicating it could occur further afield and recalled by senior elder.	-

Photo D1. Nginzib (*Albizia procera)*: highly valued timber for house foundations and building and reported to be the best firewood available. The timber was targeted during the cattle era for strainer posts and fence which do not suffer rot.


Photo D2. Habitat and form of Ngempang (*Nauclea orientalis*).


Photo D3. Flowers of Ngempang (*Nauclea orientalis*).


Photo D4. Site of recently cut and slabbed timber of Ngempang (*Nauclea orientalis*).


Photo D5. Recently slabbed timber of Ngempang (*Nauclea orientalis*) showing yellowish timber.

Photo D6. Fruits of Kapu (*Calamus longipinna).* The spiny tendrils are also traditionally used to catch flying foxes. The tendrils are wrapped around the end of a long stick made out of the mid rib of sago palm leaf. The stick is used to swipe at the bats with the spiny tendrils tearing the outstretched wings.

Photo D7. Individual fruit of Kapu (*Calamus longipinna)* with fleshy aril surrounding hard seed. The small fruits are eaten whole as a snack. The hard seed is also eaten and cracked with teeth.

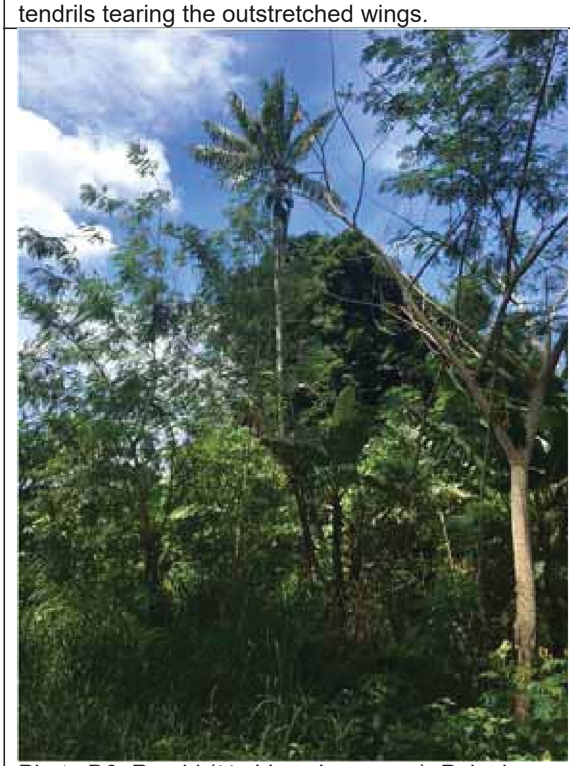

Photo D8. Ramid (*Hydriastele costata*). Palm in background. A valuable and restricted resource. The midrib of the leaflets are bundled and used as a broom. Fruits favoured by pigs.

Photo D9. Flooring constructed with Ompan the bark of Ramid (*Hydriastele costata*). The trunk is cut and the outer bark is split in lengths and used for flooring and walls.

Photo D10. The leaf sheath of Ramid (*Hydriastele costata*). The sheath of the leaf frond is peeled off the trunk and used as a mat. Also used as a stretcher for carrying children, or the sick. Reported to be used for wrapping deceased bodies for burial.

Photo D11. Recently cut and bundles Ompan the bark of Ramid (*Hydriastele costata*). The trunk is cut and the outer bark is split in lengths and also used for making bows.

Photo D12. Luwari (*Cycas schumanniana*). Leaves used for bilas for singsings.

Photo D13. Fruits and blackened trunk of Liwari (*Cycas schumanniana*).


Photo D14. Edible leaf tips of the fern Zempoz.


Photo D15. Flowers of Yangkuan (*Hornsteadia schottiana*). Fruits eaten. Stems crushed and split and used as a rope. Juice from squeezed flowers used medicinally to open boils up. Leaves used for wrapping meat. Pigs, bandicoots and rats eat the plant.


Photo D16. Edible fruits of Yasi (*Amonum aculeatum*). Edible seeds for both man and animals. Crushed leaves used medicinally to wash body all over when sick.


Photo D17. Edible fruits of Yasi (*Amonum aculeatum*).

 Photo D18. Mamoro (*Antidesma* sp.). Juice from blackish/purplish fruits used as an ink.	 Photo D19. Leaves and flowers of Morril (*Planchonia papuana*) a strong timber valued for building purposes and used for bearers and joyces.
 Photo D20. Bompog (*Endospermum medullosum*). Leaves eaten by cuscus. The bark used medicinally for treatment of bruising and swelling. Ants live in hollow stems.	 Photo D21. Esea (*Dysoxylum gaudichaudianum*). The timber is used for general building purposes. Fruits eaten by birds and cuscus.
 Photo D22. Trunk and outer bark of Matsak (*Glochidion* sp.). Sap under bark extracted and used for as a general purpose glue. Juice extracted by chewing of the bark and spitting juice in a container.	 Photo D23. Leaves of Matsak (*Glochidion* sp.).

Photo D24. Leaves of Preampre (*Macaranga quadriglandulosa*). Timber is used for housing construction for rafters and walls.

Photo D25. Leaves of Opiaf (*Mallotus paniculatus*). Timber is used for housing construction for rafters and walls. When the tree has died the dry timber supports grubs, which can be eaten. Used medicinally to treat sores and infections. Bark is boiled in water and juice is used to dry up boils.

Photo D26. Leaves Kring (*Gnetum gnemon*). New leaves edible and cooked as a vegetable. Seeds are edible. Inner bark is stripped and used as a rope and for making of bilums, baskets and general tying purposes.

Photo D27. New leaves of Onka (*Premna* sp.) reported to be edible.

Photo D28. Leaves and fruits of Ngag (*Pandanus* sp.). Fruits edible when ripe when yellow in colour. The juice is sucked and fibre thrown away.

Photo D29. Fruit segments of Ngag (Pandanus sp.). Eaten in old days but not so now. The dry leaves are a house for rats and some reptiles. Pandanus fruits are recognized as the best fruits for pigs and are a sign to focus pig-hunting efforts in areas where fruiting pandanus are.

Photo D30. Flowers of Guaron abuf (*Vitex* sp.). Leaves are boiled and used as a remedy for toothache and sore joints. Wallabies used to eat it.

Photo D31. Nidinid *(Solanum mauritianum*)*. Soft leaves used as a toilet paper for children. Pigeons and tube nose bats eat fruits.

Photo D32. Leaves of Zafutz (*Kleinhovia hospita*). Timber used for house construction

Photo D33. Recently logged stand of Zafutz (*Kleinhovia hospita*) in lowland swamp forest.

Photo D34. Mpur *(Puearia montana* var*. montana*) Tuber reported to be eaten 'bepotaim' however now only used for feeding pigs.

Photo D35. Damel *(Melicope bonwickii).* Uncommon tree restricted to lowland forests, swampy forests and Raintree regrowth and valued for timber.

Photo 36. Guware (*Trichospermum pleiostigma or Commersonia novoguinensis).* Multi-purpose rope, firewood, house construction and medicine.

Photo 37. Guzog *(Passiflora foetida).* Edible fruits also eaten by birds and bandicoots.

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Photo 38. Sago palm *(Metroxylon sagu).* A high value resource. Pith extracted and processed for food.

Photo 39. Sago palm *(Metroxylon sagu).* Split fronds used for shelter and building.


Photo 40. Vine of Watag *(Ichnocarpus* sp.).


Photo 41. Vines of Watag *(Ichnocarpus s*p.) used for tying bundles of recently split Ompan.


Photo 42. Roofing made out of Poatz (*Imperata cylindrica*).


Photo 43. Internal view of Poatz (*Imperata cylindrica)* roofing.


Photo 44. Kokaruk sobempean *(Coleus argenteus).* A garden plant that grows on roadsides and grassland verges valued for attractive flowers.


Photo 45. Mosangen (*Ficus wassa).* Birds and bandicoots eat fruits. Outer bark used as a rope for tying and binding.

Photo 46. Katz (*Ptychosperma* sp.). Trunks split and traditionally used to make bows.

Photo 47. Sapling of Waif *(Bombax ceiba* var. *leioclada*). Timber used for furniture making including chairs and tables.

Photo 48. Sapling of Suk (*Pometia pinnata*). A valuable timber tree rare in the study area.

Photo 49. Titif *(Antidesma ghaesembilla*) as an emergent in kunai grasslands on foothills. Small black fruits are edible as s snack. Timber used as firewood. The bushy crown provides habitat for doves and other small birds. Snakes coil up in the branches.

Appendix E

Weed risk assessment scoring

Appendix E. Results of the Weed Risk Assessment scoring for the assessment of species invasiveness following the methodology of Pheloung *et al*. (1999).

Feature	Criterion	Species		
		E. pellita	*E. camaldulensis*	*A. crassicarpa*
Highly domesticated?	1.01	-3	-3	0
Become naturalized?	1.02	1	1	1
Weedy races for sp.?	1.03	-1	-1	-1
Suited to climate?	2.01	2	2	2
Quality of climate match?	2.02	2	2	2
Climate suitability?	2.03	1	1	1
Native to areas with extended dry seasons?	2.04	1	1	1
Repeated introductions outside its natural range?	2.05	yes	yes	yes
Naturalised beyond native range?	3.01	-2	2	0
Disturbance weed?	3.02	0	0	0
Weed of agric/forestry?	3.03	0	0	0
Environmental weed?	3.04	0	4	0
Congeneric weed?	3.05	2	2	2
Produces spines, thorns, burrs?	4.01	0	0	0
Allelopathic?	4.02	1	1	1
Parasitic?	4.03	0	0	0
Unpalatable to grazing animals?	4.04	-1	-1	1
Toxic to animals?	4.05	0	0	0
Host for recognised pests and pathogens?	4.06	0	0	1
Causes allergies/toxic in humans?	4.07	0	0	0
Creates fire hazard?	4.08	0	0	0
Shade tolerant?	4.09	0	0	0
Grows on infertile soils?	4.10	0	0	1
Climbing or smothering growth habit?	4.11	0	0	0
Forms dense thickets?	4.12	0	0	0
Aquatic?	5.01	0	0	0
Grass?	5.02	0	0	0
Nitrogen fixing woody plant?	5.03	0	0	1
Geophyte?	5.04	0	0	0
Evidence of reproductive failure in native habitat?	6.01	0	0	0
Produces viable seed?	6.02	1	1	1
Hybridises naturally?	6.03	0	0	0
Self-fertilisation?	6.04	1	1	1
Requires specialized pollinators?	6.05	0	0	0
Reproduces by vegetative propagation?	6.06	-1	-1	-1
Minimum generative time (years)?	6.07	-1	-1	0
Propagules likely to be dispersed unintentionally?	7.01	-1	-1	-1

Feature	Criterion	Species		
		E. pellita	*E. camaldulensis*	*A. crassicarpa*
Propagules dispersed intentionally by people?	7.02	1	1	1
Propagules dispersed as produce contaminant?	7.03	-1	-1	-1
Propagules adapted to wind dispersal?	7.04	-1	-1	-1
Propagules buoyant?	7.05	-1	-1	1
Propagules bird dispersed?	7.06	-1	-1	-1
Propagules dispersed by other animals (externally)?	7.07	-1	-1	-1
Propagules dispersed by other animals (internally)?	7.08	0	0	0
Prolific seed production?	8.01	1	1	1
Evidence of persistent propagule bank (>1 yr)?	8.02	-1	-1	1
Well controlled by herbicides?	8.03	0	0	0
Tolerates/benefits from fire or cultivation>	8.04	1	1	1
Effective natural enemies present?	8.05	1	1	1
Overall score		0	8	15

Appendix F

Terrestrial vertebrate species with potential to occur in the study area

Appendix F. Terrestrial vertebrate species (mammals, birds, reptiles and amphibians) identified to have potential to occur in the study area, their threat status under the IUCN Red List (IUCN) and their protection status under the PNG Fauna (Protection & Control) Act 1966, 1978 (PNG).

Species	Common name	Status		Local records[3]
		IUCN[1]	PNG[2]	
NON-VOLANT MAMMALS				
Murexia melanurus	Black-tailed Dasyure			
Murexia longicaudata	Short-furred Dasyure			
Dasyurus albopunctatus	New Guinea Quoll	NT		
Echymipera kalubu	Common Echymipera			X
Echymipera rufescens	Long-nosed Echymipera			X
Peroryctes raffrayana	Raffray's Bandicoot			
Dorcopsis hageni	White-striped Dorcopsis			
Thylogale browni	New Guinea Pademelon	VU		
Phalanger gymnotis	Ground Cuscus			
Phalanger intercastellanus	Eastern (Southern) Common Cuscus			X
Spilocuscus maculatus	Common Spotted Cuscus			X
Spilocuscus rufoniger	Black-spotted Cuscus	CR	P	
Distoechurus pennatus	Feather-tailed Possum		R	
Dactylopsila trivirgata	Striped Possum			X
Petaurus breviceps	Sugar Glider			X
Pseudochirulus canescens	Lowland Ringtail			
Hydromys chrysogaster	Common Water Rat			X
Melomys lutillus	Grassland Melomys			
Melomys rufescens	Black-tailed Melomys			X
Paramelomys platyops	Common Lowland Paramelomys			X
Mammelomys rattoides	Lowland Mammelomys			
Pogonomys macrourus	Chestnut Tree Mouse			
Uromys caudimaculatus	White-tailed Giant Rat			X
Rattus mordax	Eastern Rat			X
Rattus steini	Small Spiny Rat			X
Rattus exulans	Polynesian Rat			X
Rattus rattus	House Rat			
Sus scrofa	Feral Pig			X
Bubalus bubalis	Water Buffalo			X
Felis catus	Feral Cat			X
BATS				
Dobsonia moluccensis	Moluccan Naked-backed Fruit Bat			X
Pteropus conspicillatus	Spectacled Flying-fox			
Pteropus macrotis	Big-eared Flying Fox			
Pteropus neohibernicus	Giant Flying Fox			X
Rousettus amplexicaudatus	Common Rousette Bat			X
Nyctimene aello	Greater Tube-nosed Bat			X
Nyctimene cf. *papuanus*	Common Tube-nosed Fruit Bat			X
Nyctimene sp. A '*albiventer*' group	Common Tube-nosed Fruit Bat			X
Paranyctimene raptor	Unstriped Tube-nosed Bat			X
Macroglossus minimus	Dagger-toothed Long-nosed Fruit Bat			X
Macroglossus sp. A	Long-nosed Fruit Bat			X
Syconycteris australis	Common Blossom Bat			X
Emballonura beccarii	Beccari's Sheath-tailed Bat			X
Emballonura furax	New Guinea Sheath-tailed Bat			
Emballonura raffrayana	Raffray's Sheath-tailed Bat			
Mosia nigrescens	Lesser Sheath-tailed Bat			X
Saccolaimus saccolaimus	Bare-rumped Sheath-tailed Bat			X
Hipposideros ater	Dusky Leaf-nosed Bat			
Hipposideros calcaratus	Spurred Leaf-nosed Bat			X
Hipposideros cervinus	Fawn-colored Leaf-nosed Bat			X
Hipposideros diadema	Diadem Leaf-nosed Bat			X

Hipposideros maggietaylorae	Maggie Taylor's Leaf-nosed Bat			
Hipposideros muscinus	Fly River Leaf-nosed Bat			
Hipposideros wollastoni	Wollaston's Leaf-nosed Bat			X
Aselliscus tricuspidatus	Trident Leaf-nosed Bat			X
Rhinolophus euryotis	New Guinea Horseshoe Bat			X
Rhinolophus megaphyllus	Eastern Horseshoe Bat			X
Myotis moluccarum	Maluku Myotis			
Philetor brachypterus	Short-winged Pipistrelle			X
Pipistrellus angulatus	New Guinea Pipistrelle			
Pipistrellus papuanus	Papuan Pipistrelle			X
Nyctophilus bifax	Eastern Long-eared Bat			
Nyctophilus microtis	Papuan Long-eared Bat			
Nyctophilus timoriensis	Greater Long-eared Bat			
Kerivoula muscina	Fly River Woolly Bat			
Phoniscus papuensis	Golden-tipped Bat			
Miniopterus australis	Little Bent-winged Bat			X
Miniopterus macrocneme	Small Melanesian Bent-winged Bat			
Miniopterus magnater	Large Bent-winged Bat			
Miniopterus medius	Medium Bent-winged Bat			
Miniopterus propitristis	Large Melanesian Bent-winged Bat			X
Miniopterus schreibersi	Common Bent-winged Bat			X
Tadarida jobensis	Greater Northern Free-tailed Bat			
Mormopterus beccarii	Beccari's Free-tailed Bat			X
Otomops secundus	Mantled Free-tailed Bat			
Otomops papuensis	Papuan Free-tailed Bat			
BIRDS				
Casuarius bennetti	Dwarf Cassowary			X
Talegalla jobiensis	Brown-collared Brush-turkey			X
Megapodius decollatus	New Guinea Scrubfowl			X
Microcarbo melanoleucos	Little Pied Cormorant			X
Phalacrocorax sulcirostris	Little Black Cormorant			X
Anhinga novaehollandiae	Australasian Darter			
Dendrocygna arcuata	Wandering Whistling-Duck			
Dendrocygna guttata	Spotted Whistling-Duck			X
Anas gracilis	Grey Teal			
Anas superciliosa	Pacific Black Duck			X
Tadorna radjah	Raja Shelduck			
Tachybaptus novaehollandiae	Australasian Grebe			X
Tachybaptus tricolor	Tricoloured Grebe			
Coturnix ypsilophora	Brown Quail			X
Excalfactoria chinensis	King Quail			
Turnix maculosa	Red-backed Buttonquail			
Aceros plicatus	Blyth's Hornbill		P	X
Eurystomus orientalis	Dollarbird			X
Alcedo atthis	Common Kingfisher			
Alcedo azurea	Azure Kingfisher			X
Alcedo pusilla	Little Kingfisher			X
Ceyx lepidus	Moluccan Dwarf Kingfisher			X
Dacelo gaudichaud	Rufous-bellied Kookaburra			X
Clytoceyx rex	Shovel-billed Kookaburra			
Todirhamphus nigrocyaneus	Blue-black Kingfisher			X
Todirhamphus macleayii	Forest Kingfisher			X
Todirhamphus sanctus	Sacred Kingfisher			X
Melidora macrorrhina	Hook-billed Kingfisher			X
Syma torotoro	Yellow-billed Kingfisher			X
Tanysiptera galatea	Common Paradise-Kingfisher			
Tanysiptera nympha	Red-breasted Paradise-Kingfisher			X
Merops philippinus	Blue-tailed Bee-eater			X
Merops ornatus	Rainbow Bee-eater			X

Cuculus opatus	Oriental Cuckoo			X
Cacomantis variolosus	Brush Cuckoo			X
Cacomantis castaneiventris	Chestnut-breasted Cuckoo			
Rhamphomantis megarhynchus	Long-billed Cuckoo			
Chrysococcyx minutillus	Little (Malay) Bronze-Cuckoo			X
Chrysococcyx lucidus	Shining Bronze-Cuckoo			X
Chrysococcyx meyeri	White-eared Bronze-Cuckoo			X
Caliechthrus leucolophus	White-crowned Koel			X
Microdynamis parva	Dwarf Koel			X
Eudynamys orientalis	Pacific Koel			X
Scythrops novaehollandiae	Channel-billed Cuckoo			X
Centropus menbeki	Ivory-billed Coucal			X
Centropus phasianinus	Pheasant Coucal			X
Centropus bernsteini	Black-billed Coucal			X
Pseudeos fuscata	Dusky Lory			X
Trichoglossus haematodus	Coconut Lorikeet			X
Lorius lory	Black-capped Lory			X
Charmosyna placentis	Red-flanked Lorikeet			X
Charmosyna pulchella	Fairy Lorikeet			X
Psittrichas fulgidus	Pesquet's Parrot	VU	R	X
Micropsitta pusio	Buff-faced Pygmy-Parrot			X
Cyclopsitta gulielmitertii	Orange-breasted Fig-Parrot			
Cyclopsitta diophthalma	Double-eyed Fig-Parrot			X
Psittaculirostris edwardsii	Edwards's Fig Parrot			X
Geoffroyus geoffroyi	Red-cheeked Parrot			X
Eclectus roratus	Eclectus Parrot			X
Loriculus aurantiifrons	Orange-fronted Hanging-Parrot			X
Probosciger aterrimus	Palm Cockatoo		P	X
Cacatua galerita	Sulphur-crested Cockatoo		R	X
Collocalia esculenta	Glossy Swiftlet			X
Aerodramus hirundinaceus	Mountain Swiftlet			
Aerodramus vanikorensis	Uniform Swiftlet			X
Mearnsia novaeguineae	Papuan Spine-tailed Swift			X
Hirundapus caudacutus	White-throated Needletail			X
Hemiprocne mystacea	Moustached Treeswift			X
Tyto tenebricosa	Greater Sooty-Owl			X
Tyto delicatula	Eastern Barn Owl			X
Tyto longimembris	Eastern Grass Owl			X
Ninox rufa	Rufous Owl			X
Ninox connivens	Barking Owl			X
Ninox theomacha	Papuan Boobook			
Uroglaux dimorpha	Papuan Hawk-Owl			X
Aegotheles bennettii	Barred Owlet-Nightjar			X
Podargus papuensis	Papuan Frogmouth			X
Podargus ocellatus	Marbled Frogmouth			X
Eurostopodus mystacalis	White-throated Nightjar			
Caprimulgus macrurus	Large-tailed Nightjar			X
Columba livia	Rock Pigeon			
Columba vitiensis	Metallic Pigeon			
Macropygia amboinensis	Slender-billed Cuckoo-Dove			X
Macropygia nigrirostris	Bar-tailed Cuckoo-Dove			X
Reinwardtoena reinwardtsi	Great Cuckoo-Dove			X
Chalcophaps longirostris	Pacific Emerald Dove			X
Chalcophaps stephani	Stephan's Emerald Dove			X
Henicophaps albifrons	New Guinea Bronzewing			X
Geopelia placida	Peaceful Dove			X
Gallicolumba rufigula	Cinnamon Ground-Dove			
Otidiphaps nobilis	Pheasant Pigeon		R	X
Ptilinopus magnificus	Wompoo Fruit-Dove			X

Ptilinopus perlatus	Pink-spotted Fruit-Dove			X
Ptilinopus ornatus	Ornate Fruit-Dove			X
Ptilinopus superbus	Superb Fruit-Dove			
Ptilinopus coronulatus	Coroneted Fruit-Dove			X
Ptilinopus pulchellus	Beautiful Fruit-Dove			
Ptilinopus rivoli	White-bibbed Fruit-Dove			
Ptilinopus iozonus	Orange-bellied Fruit-Dove			X
Ptilinopus naina	Dwarf Fruit-Dove			X
Ducula rufigaster	Purple-tailed Imperial-Pigeon			
Ducula pinon	Pinon Imperial-Pigeon			X
Ducula zoeae	Zoe's Imperial Pigeon			X
Gymnophaps albertisii	Papuan Mountain-Pigeon			X
Rallina tricolor	Red-necked Crake			X
Amaurornis olivacea	Plain Bush-hen			X
Porzana cinerea	White-browed Crake			X
Gallirallus philippensis	Buff-banded Rail			X
Gymnocrex plumbeiventris	Bare-eyed Rail			
Gallinula tenebrosa	Dusky Moorhen			X
Porphyrio melanotus	Australasian Swamphen			X
Amaurornis moluccana	Pale-vented Bush-hen			X
Irediparra gallinacea	Comb-crested Jacana			X
Gallinago hardwickii	Latham's Snipe			
Gallinago megala	Swinhoe's Snipe			
Tringa stagnatilis	Marsh Sandpiper			
Actitis hypoleucos	Common Sandpiper			X
Charadrius dubius	Little Ringed Plover			X
Vanellus miles	Masked Lapwing			
Stiltia isabella	Australian Pratincole			
Aviceda subcristata	Pacific Baza			X
Henicopernis longicauda	Long-tailed Honey-buzzard			X
Macheiramphus alcinus	Bat Hawk			X
Elanus caeruleus	Black-winged Kite			X
Milvus migrans	Black Kite			X
Haliastur sphenurus	Whistling Kite			X
Haliastur indus	Brahminy Kite			X
Circus spilothorax	Papuan Harrier		R	X
Accipiter hiogaster	Variable Goshawk			X
Accipiter fasciatus	Brown Goshawk			X
Accipiter novaehollandiae	Grey Goshawk			X
Accipiter poliocephalus	Grey-headed Goshawk			X
Accipiter cirrocephalus	Collared Sparrowhawk			X
Megatriorchis doriae	Doria's Goshawk	NT		X
Harpyopsis novaeguineae	Papuan Eagle	VU	P	X
Aquila gurneyi	Gurney's Eagle	NT	R	X
Hieraaetus morphnoides	Little Eagle			X
Haliaeetus leucogaster	White-bellied Sea-eagle		R	X
Pandion cristatus	Eastern Osprey		P	X
Falco cenchroides	Nankeen Kestrel		R	
Falco severus	Oriental Hobby		R	
Falco longipennis	Australian Hobby		R	
Falco berigora	Brown Falcon		R	
Falco peregrinus	Peregrine Falcon		R	X
Butorides striatus	Striated Heron			
Zonerodius heliosylus	Forest Bittern	NT		
Dupetor flavicollis	Black Bittern			
Ardea alba	Great Egret			X
Egretta intermedia	Intermediate Egret			X
Nycticorax caledonicus	Nankeen Night-Heron			X
Pitta sordida	Hooded Pitta			X

Pitta erythrogaster	Red-bellied Pitta			X
Ailuroedus buccoides	White-eared Catbird			X
Chlamydera cerviniventris	Fawn-breasted Bowerbird			X
Malurus alboscapulatus	White-shouldered Fairywren			X
Myzomela eques	Ruby-throated Myzomela			X
Myzomela cruentata	Red Myzomela			X
Myzomela nigrita	Papuan Black Myzomela			X
Timeliopsis griseigula	Tawny Straightbill			X
Melilestes megarhynchus	Long-billed Honeyeater			X
Glycichaera fallax	Green-backed Honeyeater			
Meliphaga albonotata	Scrub Honeyeater			X
Meliphaga aruensis	Puff-backed Honeyeater			X
Meliphaga analoga	Mimic Honeyeater			X
Meliphaga gracilis	Graceful Honeyeater			X
Meliphaga flavirictus	Yellow-gaped Honeyeater			
Xanthotis flaviventer	Tawny-breasted Honeyeater			X
Pycnopygius ixoides	Plain Honeyeater			X
Pycnopygius stictocephalus	Streak-headed Honeyeater			X
Philemon meyeri	Meyer's Friarbird			X
Philemon novaeguineae	New Guinea Friarbird			X
Crateroscelis murina	Rusty Mouse-warbler			X
Sericornis spilodera	Pale-billed Scrubwren			X
Gerygone chloronotus	Green-backed Gerygone			X
Gerygone palpebrosa	Fairy Gerygone			X
Gerygone chrysogaster	Yellow-bellied Gerygone			
Gerygone magnirostris	Large-billed Gerygone			X
Monachella muelleriana	Torrent Robin			X
Microeca flavigaster	Lemon-bellied Flyrobin			X
Microeca flavovirescens	Olive Flyrobin			X
Poecilodryas hypoleuca	Black-sided Robin			X
Drymodes superciliaris	Northern Scrub-Robin			X
Ptilorrhoa geislerorum	Brown-headed Jewel-babbler			X
Pachycephala hyperythra	Rusty Whistler			X
Pachycephala simplex	Grey Whistler			X
Pachycephala aurea	Golden-backed Whistler			
Pachycephala monacha	Black-headed Whistler			X
Colluricincla megarhyncha	Little Shrike-thrush			X
Colluricincla harmonica	Grey Shrike-thrush			X
Pitohui dichrous	Hooded Pitohui			X
Pitohui ferrugineus	Rusty Pitohui			X
Corvus tristis	Grey Crow			X
Corvus orru	Torresian Crow			X
Manucodia atra	Glossy-mantled Manucode		P	X
Manucodia chalybata	Crinkle-collared Manucode		P	X
Ptiloris magnificus	Magnificent Riflebird		P	X
Cicinnurus magnificus	Magnificent Bird-of-paradise		P	X
Cicinnurus regius	King Bird-of-paradise		P	X
Paradisaea raggiana	Raggiana Bird-of-paradise		P	X
Cracticus cassicus	Hooded Butcherbird			X
Cracticus quoyi	Black Butcherbird			X
Artamus leucorynchus	White-breasted Woodswallow			X
Peltops blainvillii	Lowland Peltops			X
Oriolus szalayi	Brown Oriole			X
Coracina novaehollandiae	Black-faced Cuckooshrike			
Coracina caeruleogrisea	Stout-billed Cuckooshrike			
Coracina lineata	Barred Cuckooshrike			X
Coracina boyeri	Boyer's Cuckooshrike			X
Coracina papuensis	White-bellied Cuckooshrike			X
Coracina tenuirostris	Common Cicadabird			X

Coracina incerta	Black-shouldered Cicadabird			X
Coracina melas	Black Cicadabird			X
Lalage tricolor	White-winged Triller			X
Lalage leucomela	Varied Triller			X
Rhipidura leucophrys	Willie-wagtail			X
Rhipidura rufiventris	Northern Fantail			X
Rhipidura threnothorax	Sooty Thicket-Fantail			X
Rhipidura leucothorax	White-bellied Thicket-Fantail			X
Rhipidura rufidorsa	Rufous-backed Fantail			X
Dicrurus bracteatus	Spangled Drongo			X
Monarcha guttulus	Spot-winged Monarch			X
Monarcha melanopsis	Black-faced Monarch			X
Monarcha manadensis	Hooded Monarch			X
Monarcha chrysomela	Golden Monarch			X
Arses insularis	Ochre-collared Monarch			X
Arses telescophthalmus	Frilled Monarch			X
Myiagra rubecula	Leaden Flycatcher			X
Myiagra cyanoleuca	Satin Flycatcher			X
Myiagra alecto	Shining Flycatcher			X
Machaerirhynchus flaviventer	Yellow-breasted Boatbill			X
Saxicola caprata	Pied Bushchat			X
Aplonis cantoroides	Singing Starling			X
Aplonis metallica	Metallic Starling			X
Mino dumontii	Yellow-faced Myna			X
Hirundo rustica	Barn Swallow			
Hirundo tahitica	Pacific Swallow			X
Hirundo daurica	Red-rumped Swallow			
Hirundo nigricans	Tree Martin			
Cisticola exilis	Golden-headed Cisticola			X
Zosterops minor	Black-fronted White-eye			X
Mirafra javanica	Horsefield's Bushlark			X
Acrocephalus australis	Australian Reed Warbler			
Dicaeum geelvinkianum	Red-capped Flowerpecker			X
Nectarinia aspasia	Black Sunbird			X
Nectarinia jugularis	Olive-backed Sunbird			X
Melanocharis nigra	Black Berrypecker			X
Oedistoma pygmaeum	Pygmy Longbill			X
Passer domesticus	House Sparrow			X
Motacilla tschutschensis	Eastern Yellow Wagtail			
Lonchura tristissima	Streak-headed Mannikin			X
Lonchura grandis	Great-billed Mannikin			X
Lonchura spectabilis	Hooded Mannikin			
Lonchura castaneothorax	Chestnut-breasted Mannikin			X
REPTILES				
Elseya novaeguineae	New Guinea Snapping Turtle			
Crocodylus porosus	Saltwater Crocodile		R	
Varanus indicus	Mangrove monitor		R	
Varanus jobiensis	Peach-throated Monitor		R	X
Varanus prasinus	Emerald Tree Monitor		R	X
Hypsilurus modestus	Modest Forest Dragon			X
Hemidactylus frenatus	Common House Gecko			X
Gehyra vorax	Voracious Gecko			X
Gymnodactylus novaeguineae				X
Gekko vittatus				X
Hemidactylus frenatus				X
Tribolonotus gracilis	Red-eyed Crocodile Skink			X
Emoia caeruleocauda				X
Emoia obscura				X
Emoia pallidiceps				X

Emoia physicae				X
Emoia longicauda	Shrub whiptail-skink			X
Lipinia pulchra				X
Sphenomorphus simus				X
Sphenomorphus cf *jobiensis*				X
Sphenomorphus megaspilus				
Sphenomorphus microtympanus				
Lamprolepis smaragdina	Emerald Tree Skink			X
Dendrelaphis calligastra	Coconut Tree Snake			X
Tropidonophis multiscutellatus	Many-scaled Keelback			X
Stegonotus parvus	Common Ground Snake			X
Acanthophis laevis	New Guinea Death Adder			X
Micropechis ikahaka	New Guinea Small-eyed Snake			X
Boiga irregularis	Brown Tree Snake			X
Candioa aspera	New Guinea Ground Boa		R	X
Candoia carinata	Pacific Boa		R	
Morelia viridis	Northern Emerald Python		R	X
Leiopython bennettorum	Bennett's White-lipped Python		R	X
Leiopython albertisii	White-lipped (D'Albertis) Python		R	X
Python amethistinus	Amethystine Python		R	X
Typhlops mcdowelli	Blind Snake sp.			
AMPHIBIANS				
Bufo marinus	Cane Toad			X
Papurana arfaki				X
Papurana daemeli				X
Papurana garritor				X
Papurana cf grisea				X
Papurana papua				X
Platymantis papuensis				X
Litoria amboinensis				
Litoria cf. *bicolor* Type 'B'				
Litoria eucnemis	Fringed Tree Frog			X
Litoria genimaculata	New Guinea Tree Frog			
Litoria thesaurensis				X
Litoria nigropunctata				X
Litoria infrafrenata	White-lipped Tree Frog			X
Nyctimystes cheesmani				X
Cophixalus pipilans				
Copiula fistulans				
Genyophryine thomsoni				X
Oreophryne geislerorum				X
Oreophryne wolterstorffi				
Austrochaperina parkeri				X
Sphenophryne cornuta				
Callulops doriae				
Callulops robustus				
Hylophorbus rufescens				
Mantophryne sp. (lateralis complex)				X
Xenobatrachus subcroceus				X
Xenorhina subcrocea				X

[1] IUCN threat status indicates species listed as globally threatened (CR – Critically Endangered; EN – Endangered; VU – Vulnerable) or near threatened (NT). [2] PNG status includes species listed as Protected (P) or Trade Restricted (R) under the *PNG Fauna (Protection & Control) Act 1966, 1978*.
[3] Reference sources include: Bishop Museum (2016), IUCN (2016), Smith (1991), Eastwood (1995), and previous BAAM survey records from the local region.

Appendix G

Terrestrial vertebrate fauna species list and survey data

APPENDIX G: Terrestrial Vertebrate Fauna Species List and Survey Data

Table G.1 Terrestrial vertebrate fauna species list from the field survey, their Wampar language (Tok ples) name, their extinction risk status under the IUCN Red List (IUCN), their protection status under the Papua New Guinea *Fauna (Protection and Control) Act 1966* (PNG), the frequency of occurrence of bird species (Freq., percentage of timed surveys in which the species was detected), and the habitats they are associated with, namely forest/woodland (Forest), grassland (Grass) or wetlands and watercourses (Wet).

Abbreviations: VU = vulnerable; NT = Near Threatened; P = Protected; R = Restricted; X = species detected during the BAAM field survey by sight or call; L = reliable account from local informants as being currently present; LH = reliable account from local informants as being present historically, but no longer present; P = previous survey record of ECO Care Engineering Limited (2013).

Family	Scientific name	English name	Wampar name	Status		Record	Freq.	Habitat		
				IUCN	PNG			Forest	Grass	Wet
Mammals										
Peramelidae	*Echymipera/Peroryctes* spp.	Unidentified bandicoots	Siri			L		X	X	
Peramelidae	*Echymipera kalubu*	Common Echymipera				P		X	X	
Phalangeridae	*Phalanger intercastellanus*	Eastern Common Cuscus	Barofose			L		X		
Phalangeridae	*Spilocuscus maculatus*	Common Spotted Cuscus	Gwanang			L		X		
Petauridae	*Petaurus breviceps*	Sugar Glider	Senes			L		X		
Macropodidae	*Thylogale browni*	New Guinea Pademelon	Porep	VU		LH		X		
Muridae	*Melomys/Paramelomys* spp.	Unidentified rats (rufous fur)	Maziaz			L		X	X	
Muridae	*Rattus* spp.	Unidentified rats (grey fur)	Moangom			L		X	X	
Muridae	*Uromys* sp. *caudimaculatus* group	Giant White-tailed Rat	Ngayar			L		X		
Miniopteridae	38 st.cFM *Miniopterus* sp. cf. *magnater*	Unidentified bent-winged bat	Ngaropiz			X		X		
Miniopteridae	45 st.cFM *Miniopterus* sp. cf. *medius*	Unidentified bent-winged bat	Ngaropiz			X		X		
Miniopteridae	55 st.cFM *Miniopterus* sp. cf. *australis*	Unidentified bent-winged bat	Ngaropiz			X		X		
Vespertilionidae	*Nyctophilus* sp.	Unidentified long-eared bat	Ngaropiz			X		X		
Emballonuridae	*Emballonura* sp. cf. *raffrayana*	Unidentified sheath-tailed bat	Ngaropiz			X		X		
Emballonuridae	*Mosia nigrescens*	Lesser Sheath-tailed Bat	Ngaropiz			X				
Hipposideridae	*Hipposideros diadema*	Diadem Leaf-nosed Bat	Ngaropiz			X		X		
Hipposideridae	*Aselliscus tricuspidatus*	Trident Leaf-nosed Bat	Ngaropiz			X				
Pteropodidae	*Pteropus hypomelanus*	Variable Flying-fox				P				
Pteropodidae	*Nyctimene* sp. A *'albiventer'* group	Common Tube-nosed Fruit Bat	Bibip			P				
Muridae	*Melomys lutillus*	Grassland Melomys	Maziaz			P				
Suidae	*Sus scrofa*	Feral Pig	Pi			L		X		
Birds										
Casuariidae	*Casuarius bennetti*	Dwarf Cassowary	Kuwik	NT		LH		X		

Family	Scientific name	English name	Wampar name	Status		Record	Freq.	Habitat		
				IUCN	PNG			Forest	Grass	Wet
Megapodiidae	*Megapodius decollatus*	New Guinea Scrubfowl	Kerong			X		X		
Phasianidae	*Coturnix ypsilophora*	Brown Quail	Gompeg			L				
Anatidae	*Anas superciliosa*	Pacific Black Duck	Sowe			X	9			X
Ardeidae	*Ardea modesta*	Great Egret	Ngayasu		P	X	18			X
Ardeidae	*Ardea ibis*	Cattle Egret	Ngayasu			X	0			
Ardeidae	*Ardea intermedia*	Intermediate Egret	Ngayasu		P	X	9			X
Ardeidae	*Egretta picata*	Pied Heron				X	9			
Ardeidae	*Egretta garzetta*	Little Egret	Ngayasu		P	X	9			X
Phalacrocoracidae	*Phalacrocorax sulcirostris*	Little Black Cormorant				X	9			X
Accipitridae	*Aviceda subcristata*	Pacific Baza	Waitzwaitz			X	27	X		
Accipitridae	*Haliastur sphenurus*	Whistling Kite				X	9	X		X
Accipitridae	*Haliastur indus*	Brahminy Kite	Pamawafo			X	27	X		X
Accipitridae	*Milvus migrans*	Black Kite	Pungumping			X	73	X	X	X
Accipitridae	*Circus spilothorax*	Papuan Harrier			R	X			X	
Accipitridae	*Accipiter fasciatus*	Brown Goshawk				X	27	X		
Accipitridae	*Accipiter cirrocephalus*	Collared Sparrowhawk				X	9	X		
Falconidae	*Falco cenchroides*	Nankeen Kestrel	Ngebengeb			L			X	
Rallidae	*Porphyrio melanotus*	Australasian Swamphen	Ngareo			X	9			X
Charadriidae	*Actitis hypoleucos*	Common Sandpiper	Eregereg			X	9			X
Charadriidae	*Vanellus miles*	Masked Lapwing	Utzikekrek			X	9			X
Columbidae	*Chalcophaps longirostris*	Pacific Emerald Dove	Ngaregimpup			X	27	X		
Columbidae	*Geopelia placida*	Peaceful Dove				X	64		X	
Columbidae	*Ptilinopus perlatus*	Pink-spotted Fruit Dove				X	55	X		
Columbidae	*Ptilinopus superbus*	Superb Fruit Dove	Marib			X	9	X		
Columbidae	*Ptilinopus iozonus*	Orange-bellied Fruit Dove				X	27	X		
Columbidae	*Ducula pinon*	Pinon's Imperial Pigeon	Didiring			X	9	X		
Columbidae	*Ducula spilorrhoa*	Torresian Imperial Pigeon	Balus			X	36			
Cacatuidae	*Probosciger aterrimus*	Palm Cockatoo			P	X	9	X		
Cacatuidae	*Cacatua galerita*	Sulphur-crested Cockatoo	Urim		R	X	18	X		
Psittacidae	*Trichoglossus haematodus*	Coconut Lorikeet	Zazaman			X	73	X		
Psittacidae	*Lorius lory*	Black-capped Lory	Zazaman			L				
Psittacidae	*Geoffroyus geoffroyi*	Red-cheeked Parrot	Gakiang			X	82	X		
Psittacidae	*Eclectus roratus*	Eclectus Parrot	Damping			X	82	X		
Cuculidae	*Centropus menbeki*	Ivory-billed Coucal				X	9	X		
Cuculidae	*Centropus phasianinus*	Pheasant Coucal				X	27		X	

Family	Scientific name	English name	Wampar name	Status IUCN	Status PNG	Record	Freq.	Habitat Forest	Habitat Grass	Habitat Wet
Cuculidae	*Eudynamys orientalis*	Pacific Koel	Toa			X	9	X		
Cuculidae	*Scythrops novaehollandiae*	Channel-billed Cuckoo				X	9	X		
Cuculidae	*Cacomantis variolosus*	Brush Cuckoo				X	27	X		
Cuculidae	*Cuculus saturatus*	Oriental Cuckoo				X	18	X		
Podargidae	*Podargus ocellatus*	Marbled Frogmouth	Wampon			X	9	X		
Apodidae	*Aerodramus vanikorensis/A. hirundinaceus*	Uniform/Mountain Swiftlet	Ngaopea			X	73	X	X	X
Tytonidae	*Tyto tenebricosa*	Greater Sooty-Owl	Kukuk			L				
Tytonidae	*Tyto delicatula*	Eastern Barn Owl	Wampiwampi			L				
Strigidae	*Ninox theomacha*	Papuan Boobook	Kukuk			L				
Aegothelidae	*Aegotheles bennettii*	Barred Owlet-Nightjar	Aidoron			L				
Coraciidae	*Eurystomus orientalis*	Dollarbird	Ngayakak			X	36	X	X	
Alcedinidae	*Dacelo gaudichaud*	Rufous-bellied Kookaburra	Krok			X	55	X		
Alcedinidae	*Todirhamphus macleayii*	Forest Kingfisher	Nafes			X	9	X		
Alcedinidae	*Todiramphus sanctus*	Sacred Kingfisher	Nafes			X	36	X		X
Meropidae	*Merops ornatus*	Rainbow Bee-eater	Iribirib			X	9	X	X	X
Meropidae	*Merops philippinus*	Blue-tailed Bee-eater	Iribirib			X	64		X	
Bucerotidae	*Rhyticeros plicatus*	Blyth's Hornbill	Dangir		P	X		X		
Meliphagidae	*Meliphaga sp(p).*	Honeyeater sp(p).	Tuk			X	73	X		
Meliphagidae	*Pycnopygius stictocephalus*	Streak-headed Honeyeater				X	18	X		
Meliphagidae	*Philemon novaeguineae*	New Guinea Friarbird	Owang			X	91	X		
Acanthizidae	*Gerygone chloronota*	Green-backed Gerygone				X	0	X		
Cracticidae	*Cracticus cassicus*	Hooded Butcherbird	Gogorob			X	82	X		
Artamidae	*Artamus leucorynchus*	White-breasted Woodswallow				X	0			
Campephagidae	*Coracina papuensis*	White-bellied Cuckooshrike				X	36	X		
Campephagidae	*Coracina tenuirostris*	Common Cicadabird				X	27			
Pachycephalidae	*Colluricincla megarhyncha*	Little Shrike-thrush				X	27	X		
Oriolidae	*Oriolus szalayi*	Brown Oriole				X	9	X		
Dicruridae	*Dicrurus bracteatus carbonarius*	Spangled Drongo	Zarazer			X	36	X		
Rhipiduridae	*Rhipidura leucophrys*	Willie-wagtail	Zazafra			X	9		X	X
Rhipiduridae	*Rhipidura leucothorax*	White-bellied Thicket Fantail	Piziang			X	36	X		
Rhipiduridae	*Rhipidura rufiventris*	Northern Fantail	Zufagek			L				
Monarchidae	*Myiagra alecto*	Shining Flycatcher				X	55	X		
Corvidae	*Corvus orru*	Torresian Crow	Ngaokngaok			X	64	X		X
Petroicidae	*Microeca flavigaster*	Lemon-bellied Flyrobin				X	9	X		
Hirundinidae	*Hirundo tahitica*	Pacific Swallow				X			X	

Family	Scientific name	English name	Wampar name	Status		Record	Freq.	Habitat		
				IUCN	PNG			Forest	Grass	Wet
Cisticolidae	*Cisticola exilis*	Golden-headed Cisticola				X	36		X	
Alaudidae	*Mirafra javanica*	Horsefield's Bushlark				X	9		X	
Sturnidae	*Aplonis cantoroides*	Singing Starling				X	9			X
Sturnidae	*Mino dumontii*	Yellow-faced Myna	Ngaogwara			X	82	X		
Nectariniidae	*Leptocoma sericea*	Black Sunbird	Ngaregemo			X	64	X		
Nectariniidae	*Cinnyris jugularis*	Olive-backed Sunbird	Zabain			X	55	X		
Reptiles										
Crocodylidae	*Crocodylus porosus*	Saltwater Crocodile	Foa		R	L				X
Gekkonidae	*Hemidactylus frenatus*	Common House Gecko	Gigri			L, X		X		
Gekkonidae	*Gehyra vorax*	Voracious Gecko	Ngaroro			L		X		
Scincidae	*Tribolonotus gracilis*	Red-eyed Crocodile Skink	Ngarafo			L				
Scincidae	*Emoia* sp. 1					X		X		
Scincidae	*Sphenomorphus* sp.	Unidentified skink (black-spotted)	Senap			L		X		
Scincidae	*Lamprolepis smaragdina*	Emerald Tree Skink	Mugumig			L, X		X		
Varanidae	*Varanus prasinus*	Emerald Monitor	Gwam		R	L				
Amphibians										
Bufonidae	*Bufo marinus*	Cane Toad				X		X		
Hylidae	*Litoria infrafrenata*	White-lipped Tree Frog				X		X		

Table G.2. Point location data for ecological features. Co-ordinate data in WGS84 datum.

Latitude	Longitude	Ecological feature
-6.56902	146.5362	Scrubfowl nest mound
-6.56938	146.5364	Scrubfowl nest mound
-6.56949	146.5367	Scrubfowl nest mound
-6.62634	146.5587	Scrubfowl nest mound

Appendix H

Anabat bat detector acoustic analysis technical report of Specialised Zoological

Bat call identification

from the Markham Valley, PNG

Type:	Acoustic analysis
Prepared for:	Biodiversity Assessment and Management Pty Ltd
Date:	15 October 2016
Job No.:	SZ417
Prepared by:	Kyle Armstrong and Yuki Konishi Specialised Zoological ABN 92 265 437 422 Tel 0404 423 264 kyle.n.armstrong@gmail.com http://szool.com.au

SUMMARY

Bat identifications from acoustic recordings are provided from the Markham Valley, near Lae in Papua New Guinea. Eight species of bat were identified from their echolocation calls (**Table 1**). Further data are available should verification be required.

METHODS

Data for analysis were provided in the form of AnaBat zero crossings files (1,595 files from three nights). Each file was inspected in AnalookW version 4.2g software. Bat species were recognised, where possible, based on information in Armstrong and Aplin (2011, 2014), Leary and Pennay (2011), Robson et al. (2012), Armstrong et al. (2015) and K.N. Armstrong and K.P. Aplin (unpublished data).

RESULTS

Eight species were recognised from the recording made on the night of 2016-09-07 (1,128 AnaBat zero crossings files; **Table 1**), however a species name could not be attributed unambiguously in all cases because of both taxonomic ambiguity in some groups and the lack of information about the source of some call types. Candidate species names are provided, but these would need to be confirmed following capture and further morphological and genetic investigation. No bat calls were observed in the recordings made on 2016-09-04 (466 AnaBat zero crossings files) or 2016-09-06 (1 only AnaBat zero crossings file).

The *Miniopterus* spp. could not be identified to species level because of issues with taxonomy. At present, the *Miniopterus* species in Asia and Australasia have numerous taxonomic issues and are difficult to distinguish based on morphological characters. In addition, the distribution limits of each *Miniopterus* species in Papua New Guinea are not well known. Attributing unambiguous identifications in the context of these two constraints is not possible. The identifications provided here are potential candidates based on their size, given both the shape of calls (typical of *Miniopterus*) and the general pattern of increasing call characteristic frequency with body size.

Similar constraints limit species-level identifications for two other echolocation call types. The identification of long-eared bats *Nyctophilus* species is also problematic given taxonomic issues, a lack of information on species distributions, and the general similarity of calls amongst species in this genus. Also, the calls attributable to a species of sheath-tailed bat *Emballonura* are within the range of Raffray's Sheath-tailed Bat *Emballonura raffrayana*, but maximum values are higher than elsewhere suggesting the possibility of either geographic variation or a different source.

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TABLE 1. Species identified in the present survey.

HIPPOSIDERIDAE	
Temminck's Leaf-nosed Bat (Trident Leaf-nosed Bat)	*Aselliscus tricuspidatus*
Diadem Leaf-nosed Bat	*Hipposideros diadema*
EMBALLONURIDAE	
Unidentified sheath-tailed bat	*Emballonura* sp. cf. *raffrayana*
Lesser Sheath-tailed Bat	*Mosia nigrescens*
VESPERTILIONIDAE	
Unidentified long-eared bat	*Nyctophilus* sp.
MINIOPTERIDAE	
Unidentified bent-winged bat 'small' (call type *55 st.cFM*)	*Miniopterus* sp. cf. *australis*
Unidentified bent-winged bat 'medium' (call type *45 st.cFM*)	*Miniopterus* sp. cf. *medius*
Unidentified bent-winged bat 'large' (call type *38 st.cFM*)	*Miniopterus* sp. cf. *magnater*

Appendix 7
Aquatic Ecology Characterisation and Impact Assessment

PNG Biomass Markham Valley Project

Markham Valley Biomass Limited

Aquatic Ecology Characterisation and Impact Assessment

Report to ERIAS Group Pty Ltd

1 March 2017

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PNG Biomass Markham Valley Project

Aquatic Ecology Characterisation Study

Report to ERIAS Group Pty Ltd

Document Control Sheet

Author(s) Adrian Flynn (Fathom Pacific), Justin Cutajar (Hydrobiology), Simon Drummond (Hydrobiology)

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2	1-6 & 8	13 Jan 17	Impact Assessment chapter	AF	1.2
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Distribution

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1	MS Word	Michelle Clark	ERIAS Group
2	MS Word	Simon Drummond	Hydrobiology

Executive Summary

This report describes the results of an aquatic ecological study completed by Fathom Pacific Pty Ltd and Hydrobiology Pty Ltd to inform an Environmental Impact Assessment for the proposed PNG Biomass Markham Valley (PBMV) Project. The project involves the establishment of an electricity generation plant that will be fueled by biomass supplied from eucalypt plantations in the Markham Valley.

The broad objectives of the study were to characterise the aquatic fauna and flora of, and ecosystem services provided by, the watercourses of the project area, ascertain sensitivities, recommend management and mitigation measures and complete an assessment of the potential residual impacts of the project. This study was able to draw on existing contextual data from previous studies in the Watut and wider Markham River catchment. The field study involved sampling of fishes, macrocrustaceans (freshwater prawns), macroinvertebrates (mainly comprising the aquatic larval stages of terrestrial insects), assessment of in-stream and riparian habitats, and *in-situ* physicochemical measurements. The study also made observations of villager aquatic resource use.

The geomorphology of the Markham Valley region dictates that the majority of watercourses traversing the PBMV project area are characterised by high energy, high sediment loads and ephemeral flows in some upstream reaches. Riparian vegetation in the project area is generally dominated by grasses and there is a history of agricultural practice throughout the Markham Valley. Under these environmental conditions, aquatic species diversity and biomass is generally limited. The recent introduction and spread of exotic fish species in the Markham River catchment has brought about potentially significant but unquantified change in aquatic communities. Under these baseline conditions, and with the mitigation measures adopted by the PBMV project that are described herein, the potential impacts to aquatic species, communities and ecosystem services associated with high sediment load, high energy watercourses with ephemeral reaches, are expected to be low to negligible.

Another watercourse type exists in the PBMV project area, that being clearwater streams of the Maralumi River and a stream known as Klin Wara (literally translated to ‘Clean Water’). These two streams were recorded as having the highest diversity and abundance of aquatic species, relatively high in-stream and riparian habitat diversity, and potentially the highest

levels of aquatic resource use in the project area. Further, these two streams appear to originate in lowland, flat areas that receive inflows from streams draining the Finisterre and Saruwaged ranges. Therefore, it is possible that flow in these two clearwater streams is maintained via surface water, soil water or ground water contributions stemming from these receiving areas. Maralumi River and Klin Wara are classified as 'inflow depended ecosystems' and are slated as 'sensitive areas' herein. The key mitigation measure that is recommended is for no plantation establishment in MOU areas overlaying the receiving areas. Recommendations are also made to further investigate groundwater contributions to these watercourses. Under the assumption that the recommended mitigation measures are adopted, the impacts to clearwater streams are expected to be low.

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3. Fish and macrocrustacean specimen photo collection
4. Macroinvertebrate raw data (can be provided electronic format upon request)

1. Introduction

1.1. Objectives

The objectives of this study are to:

- Characterise the freshwater aquatic fauna, communities and key ecological processes within the vicinity of the project area and contextualise these at the local, national and international scale.
- Identify and describe any significant aquatic fauna and flora species, communities and habitats (i.e., those of conservation significance and/or importance to the local community, or areas that can otherwise be classified as 'sensitive environmental areas').
- Identify and describe freshwater aquatic ecosystem services.
- Describe the potential impacts of the project on aquatic ecology during construction and post-construction periods.
- Recommend appropriate measures to avoid or mitigate potentially significant adverse impacts on aquatic ecology that may occur as a result of the project.
- Assess residual impacts on aquatic ecology as a result of the proposed project (i.e., those impacts that are still likely to occur following effective implementation of management/mitigation measures.

This study was conducted to satisfy the relevant assessment requirements of PNG legislation, the Forest Stewardship Council (FSC) National Forest Management Standards for PNG (2010, and 2016 drafted amendments) and International Finance Corporation (IFC) Environmental and Social Performance Standards (2012), particularly Performance Standard 6: Biodiversity Conservation and Sustainable Management of Living Natural Resources.

1.2. Background

1.2.1. Project Setting

Markham Valley Biomass Limited is investigating the feasibility of developing the PNG Biomass Markham Valley (PBMV) project in Morobe Province, Papua New Guinea (PNG). The project will involve growing *Eucalyptus* species tree plantations to provide biomass that will fuel a new 30 MW power plant. The project is advancing on the basis of plantation areas described as "Area A", these being areas that are under Memoranda of Understanding (MOU) with relevant stakeholders, and a power plant as shown in Figure 1-1. Of the total area covered by the MOU (approximately 17,940 ha), the net stocked area of plantation will be 16,000 ha.

The Markham Valley has had a long history of commercial agriculture with sugarcane, beef cattle and oil palm being the major activities. The Markham Valley is characterised by broad alluvial deposits and is bounded to the northwest and north by the Finisterre and Saruwaged ranges respectively, and is bounded to the south by the Owen Stanley Range and the Central Range. The headwaters of the Markham River, the fourth largest river in PNG, and the major tributaries that originate in these ranges, can generally be described as high gradient, shallow, fast-flowing turbid rivers. Several major tributaries entering the Markham River from the north, with headwaters at high altitude in the Finisterre or Saruwaged ranges, are highly braided (e.g. Erap River, Rumu River) and some create large low-gradient alluvial fans in the valley (e.g. Leron River). The Markham River mainstream is highly braided and subject to significant course alterations in sporadic high flow events. The Markham River discharges into the head of the Huon Gulf, where coastal waters and the subsea Markham Canyon receive high sediment loads (Renagi et al. 2010).

In northern Papua New Guinea, the Sepik and Ramu[1] rivers are hydraulically connected (Loffler 1977). There was likely to have been connectivity between the Markham and Ramu rivers at some time during their geomorphological history (Loffler 1977) but today the connectivity between these two systems is unconfirmed. However, lowlands in the Gusap and Watarais areas may provide avenues for headwater tributaries to be connected during extreme flood events. Further information on the environmental setting of the project area is presented in the results of the literature review (see Section 3.1).

[1] The Ramu River referred to here is located to the west of the Markham River and is differentiated from the Rumu River within the project area.

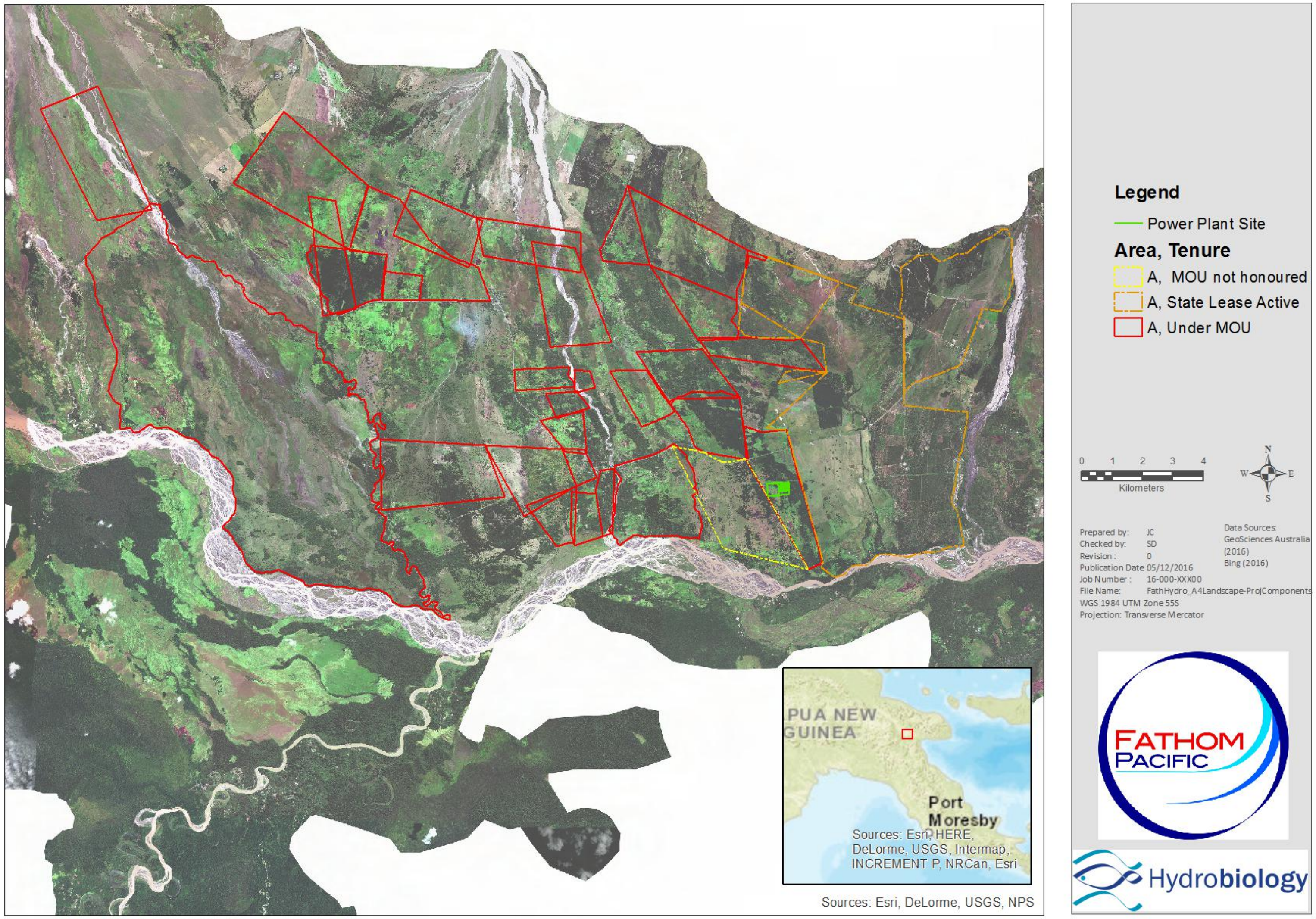


Figure 1-1 Location of project components in the Markham Valley.

1.2.2. Aquatic Ecology

The freshwater fish fauna of northern PNG is broadly separated from that of southern PNG by the central dividing range. Only species with a marine life history phase occur in both northern and southern PNG. Allen (1991) postulated that most of the northern half of PNG represents a single zoogeographic zone with considerable uniformity among the Ramu and Markham systems. On a global scale, freshwater fish diversity in PNG is comparatively low because there are no native primary freshwater fish species (species originally evolved in freshwater) and the fauna belong in, or are recently derived from, marine families (Allen and Coates 1986, Coates 1989). However, there is considerable freshwater radiation among these secondary forms in PNG (Allen et al. 2002). Freshwater fish diversity in northern PNG is further limited by the fact that, unlike southern PNG and northern Australia, northern PNG has no extensive estuaries. Therefore, some species that have a life history stage involving estuaries (e.g. barramundi) do not occur in the north of the country. Several marine migratory species, notably mullet (family Mugilidae) and eels (family Anguillidae) do migrate into northern PNG rivers. Freshwater prawns (*Macrobrachium* spp.) form a significant component of the diversity and biomass of aquatic fauna in northern PNG rivers.

In the fast flowing turbid rivers that typify the Markham River catchment, and the watercourses intersecting with the PBMV project area, high sediment loads and high flow conditions are important drivers of assemblage composition. Fauna may make use of refugia such as backwater eddies, clearwater tributaries and other microscale structures such as the lee side of logs and cobbles/boulders and during times of intolerably high flow or sediment loading. Sediment and flow conditions are also key factors to foodweb functioning in these rivers. In general, allochthonous[2] sources of organic matter are more dominant than autochthonous[3] production in high flow-high sediment load watercourses. Macroinvertebrates, dominated by the aquatic life stages of terrestrial insects, and prawns play a role in breaking down allochthonous organic matter through successive reprocessing in the foodweb. Macroinvertebrates also provide prey for fishes.

The New Guinea crocodile (*Crocodylus novaeguineae*) is likely to occur in the Markham River and during this survey, sampling at one site near the confluence of a clearwater tributary and the Markham River was abandoned and the site moved further upstream on the

[2] Production derived from terrestrial systems that is transported into watercourses in the form of organic matter.
[3] Production derived within the aquatic system itself, the opposite of allochthonous production.

tributary after a landowner cautioned about potential for crocodiles to be present. The estuarine (or "saltwater") crocodile (*Crocodylus porosus*) is likely to occur only near the mouth of the Markham River. The New Guinea snapping turtle (*Elseya novaeguineae*) is known from permanent off-river water bodies in the Markham catchment.

1.2.3. Northern PNG Exotic Fish Species Migrations and Introductions

Since the 1950s, a number of freshwater fish species have been intentionally introduced to, or have migrated to, Papua New Guinea (Table 1-1).

Table 1- 1 Freshwater fish species intentionally introduced or naturally migrated to PNG.

Common name	Species name	Location/Habitat	Potentially occurs in PBMV project area or downstream
Tilapia	*Oreochromis mossambica*	Nation-wide, most prevalent in off-river water bodies.	Yes
Common carp	*Cyprinus carpio*	Widespread throughout PNG	Yes
Snakehead	*Channa striata*	Apparently migrating or translocated from western borders	Yes
Walking catfish	*Clarius batrachus*	Introduced to Lake Sentani (Irian Jaya) and now present throughout northern PNG.	Yes
Guppy	*Poecilia reticulata*	Nation-wide, most prevalent in off-river water bodies, temporary pools, or backwater edges of streams.	Yes
Swordtail	*Xiphophorus helleri*	Nation-wide, most prevalent in off-river water bodies, temporary pools, or backwater edges of streams.	Yes
Mosquitofish	*Gambusia affinis*	Nation-wide, most prevalent in off-river water bodies, temporary pools, or backwater edges of streams.	Yes
Climbing perch	*Anabas testinudeus*	Western Province and possibly further east and south.	Unlikely
Snakeskin gouramy	*Trichogaster pectoralis*	Western Highlands, Central and Gulf provinces. Self-sustaining populations uncertain. Also present in Irian Jaya so translocations possible.	Unlikely
Giant gourami	*Osphronemus goramy*	Introduced to off-river water bodies in a number of districts, unknown as to whether populations are self-sustaining.	Unlikely
Threespot gourami	*Trichogaster trichopterus*	Apparently Central Province around NCD only.	Unlikely
Brown trout	*Salmo trutta*	Upland streams generally >1,600 m altitude.	No
Rainbow trout	*Oncorhynchus mykiss*	Upland streams generally >1,600 m altitude.	No

Some of these species, such as tilapia (*Oreochromis mossambica*) and common carp (*Cyprinus carpio*), have become widespread and are common in most subsistence inland fisheries. Others are either too small to be eaten (e.g. guppy, swordtail and mosquitofish), or are not found in significant numbers in self-sustaining populations and therefore do not feature prominently in the diets of lowland peoples. The ecological effects of these introductions and migrations are largely unquantified but generally until the 1990s, these introductions, migrations and translocations were considered to be either so widespread and accepted by the culture that they have become part of the PNG fisheries identity (e.g. tilapia, common carp and trout) or were spatially limited and not of widespread ecological concern. However, as will be described further in this report, in light of subsequent introductions the cumulative effects of exotic species on the ecology of PNG freshwater systems are likely to now be significant.

Between 1987 and 1993, a collaborative project between the government of Papua New Guinea, the United Nations Development Programme (UNDP) and The Food and Agriculture Organization (FAO) investigated the feasibility of introducing fish species to the Sepik and Ramu river systems. Known as the Sepik River Fish Stock Enhancement Project (SRFSEP), the ultimate objective was to improve people's access to fish protein and socio-economic opportunities in northern PNG, where fisheries potential of native freshwater species is relatively low (see Section 1.1.2). That program resulted in the introduction of only one species, Rendall's tilapia (*Tilapia rendalli*) into selected locations in the Sepik-Ramu system. Native to Africa and in the same family as the Mozambique tilapia (*Oreochromis mossambica*) that was introduced to PNG in the 1950s, *T. rendalli* appears to have become well established in off-river water bodies in the Sepik-Ramu system and has become one of the most commonly caught species in Yonki Reservoir (van der Heijden 2002).

Subsequent to the SRFSEP, the Fisheries Improvement by Stocking at High Altitudes for Inland Development (FISHAID) project was initiated. This project investigated the feasibility of a broader range of species introductions into higher altitudes where it was deemed that the largest human populations co-occurred with the lowest fish stocks (FAO 1997). The intentional fish introductions made in PNG on the basis of the findings and recommendations of the FISHAID project, and general comments on known distributions from subsequent surveys, are summarised in Table 1-2.

Table 1- 2 Freshwater fish species intentionally introduced to PNG during the FISHAID project.

Common name	Species name	Location/Habitat	Potentially occurs in PBMV project area or downstream
Common carp	*Cyprinus carpio*	Yonki Reservoir	Yes
Golden mahseer	*Tor putitora*	Upland streams in Sepik-Ramu system	Yes
Chocolate mahseer	*Neolissocheilus hexagonolepis*	Upland streams in Sepik-Ramu system	Yes
Snow trout	*Schizothorax richardsonii*	Purari River, Upland streams in Sepik-Ramu system	Unlikely
Pirapatinga	*Piaractus brachypomus*	Unconfirmed	Unlikely
Sabalo, curimbata, Emily's fish	*Prochilodus margravii*	Unconfirmed	Unlikely
Java carp, tawas, silver barb	*Barbonymus gonionotus*	Unconfirmed	Unlikely
Pacu	*Colossoma bidens*	Unconfirmed but probably lowland off-river water bodies	Unlikely
Lesser baril	*Barilius bendelisis*	Unconfirmed	Unlikely
Carp	*Labeo* spp.	Unconfirmed	Unlikely
Snakeskin gouramy	*Trichogaster pectoralis*	Central Province	Unlikely
Giant gourami	*Osphronemus goramy*	Unconfirmed but probably lowland off-river water bodies	No
Rainbow trout	*Oncorhynchus mykiss*	Upland streams in northern PNG, aquaculture facilities in Goroka, Yonki Reservoir	No

Footnote: Table includes species that are possible "contaminants" in the introduced brood stock.

Further still, a collaborative Australia-PNG project is currently investigating the feasibility of Genetically Improved Farmed Tilapia (GIFT). The tilapia species in use is *Oreochromis niloticus* and there have been cage-based husbandry projects in Yonki Reservoir (Ramu valley) since 2001, where cage-based aquaculture of common carp (*Cyprinus carpio*) and two tilapia species (*Oreochromis mossambica* and *Tilapia rendalli*) has been operating since 1998 (Hair et al. undated). Cage culture of GIFT in Yonki Reservoir saw operational declines soon after 2001 for a variety of reasons and recently the Australian Centre for International Agriculture Research (ACIAR) and the government of PNG began a program to investigate husbandry in experimental pondage in the lowlands of the Markham Valley (ACIAR 2016). At this time, we are unaware of intentional releases into northern PNG, although as described below, GIFT has been identified in monitoring surveys in the Lower Watut/Markham area. There have been security concerns with reports of thefts and possible releases from aquaculture impoundments in the Erap and Lae facilities. There are reports of large numbers of GIFT in the Fly River, possibly originating from failed or flooded riparian pondage (R. Smith, Hydrobiology, pers. comm.) further illustrating the risks of accidental releases in the Markham Valley.

1.2.4. Northern PNG Freshwater Fisheries and Aquaculture

Inland fisheries resources are central to subsistence lifestyles for people in northern PNG with access to freshwater habitats. Access to motorised canoes and effective fishing equipment (e.g. monofilament gill nets) and as outlined above, access to populations of desirable species, are some of the main limitations faced by subsistence fishers in northern PNG. Poisoning, hook-and-line fishing, netting, spearing (in clear water) and trapping are some of the key methods by which subsistence fishers attempt to supplement a diet that in most cases is dominated by garden produce (Coates 1989, 1996). Fishes, freshwater prawns, turtles (and eggs), crocodiles (and eggs) are the main groups of subsistence significance and generally all species caught, regardless of size, are eaten.

Aquaculture has been recognised as a way to potentially enhance protein nutrition in remote areas and provide economic opportunities in PNG since the late 1950s. There is an aquaculture component to the fish introductions discussed in Section 1.1.3 as research into the viability of fingerling and brood stock continues. Key areas of activity for aquaculture research and trials in northern PNG have been the Highlands Aquaculture Development Centre (HAQDEC, formerly known as the Aiyura Fisheries Station) in Eastern Highlands Province and the Erap Research and Development Centre (National Department of Agriculture and Livestock) in Morobe Province. The latter governmental institution provides training and out-reach to semi-privatised aquaculture operations in the vicinity of Lae (Ponia and Mohiba 2002). Aquaculture research carried out for the FISHAID project was located primarily at the Christensen Research Institute in Madang Province, but this facility is currently non-operational.

Private aquaculture enterprises include the Lake Pindi Yaundo Trout Farm and Hatchery (Chimbu Province). Mainland Holdings Ltd, which operates the nations largest saltwater crocodile farm, located in the Sepik River catchment, is integrating GIFT fish farming into their practices. Bismark Barramundi Ltd operates a barramundi (*Lates calcarifer)* farming operation in Gulf Province (southern PNG) that may provide a brood stock for rearing in other areas of PNG.

Excluding aquaculture-based research activities associated with fish species targeted for introductions by the FISHAID project and other trial introductions, the species of most importance to aquaculture in PNG are rainbow trout (*Oncorhynchus mykiss*), common carp (*Cyprinus carpio*), tilapia (*Oreochromis mossambica*), Rendall's tilapia (*Tilapia rendalli*) and GIFT (*Oreochromis niloticus*). The establishment of aquaculture practices has been attempted in several areas of PNG and in some instances have been identified as potentially providing business development or environmental offset potential for development projects. A notable example is the establishment of a barramundi farming enterprise in the Fly River catchment. These projects have had varying levels of success and are susceptible to problems associated with cost of establishment, maintenance, flooding, security and sustainability of feed.

2. Methods

2.1. Literature review

Previous sampling at sites upstream and downstream of the Markham River Bridge and along the Watut River has been undertaken as part of the development of the Hidden Valley mine and these surveys provide the main basis of knowledge for the area. Most surveys focused on fish and macrocrustaceans, with relatively little information available on aquatic macroinvertebrates (Table 1-1). Monitoring surveys were most frequent in the period 2007 to 2012 and included the following key publications:

- Hydrobiology (2007). Hidden Valley Project. Construction Phase: Aquatic Fauna. Report Prepared for MMJV;
- Hydrobiology (2009). Hidden Valley Aquatic Ecology Study: Construction Phase. Report Prepared for MMJV;
- Hydrobiology (2010a). Hidden Valley Aquatic Ecology Gap Survey: Construction Phase. Report Prepared for MMJV;
- Hydrobiology (2010b). Hidden Valley Aquatic Ecology Gap Survey: Operational Phase (May 2010). Report Prepared for MMJV;
- Hydrobiology (2010c). Hidden Valley Aquatic Ecology Gap Survey: Operational Phase (November 2010). Report Prepared for MMJV;
- Hydrobiology (2011). Hidden Valley Aquatic Biology Gap Survey: Operations Phase Supplementary Sampling. Report Prepared for MMJV; and
- Hydrobiology (2012). Hidden Valley Aquatic Ecology Gap Survey: Operational Phase (June 2012). Report Prepared for MMJV.

The Hidden Valley mine aquatic biological monitoring program also includes sites along the Snake, Wafi and Bulolo rivers. However, these are considered less relevant to the PBMV study as they targeted higher elevations and as such have not been included in the summaries below . Sites sampled during the previous Hidden Valley monitoring surveys are shown in Figure 2-1. Other historical studies not part of the monitoring program have also been undertaken in the wider catchment and include:

- R&D Environmental (1997). Survey of Fishes in the Vicinity of the Morobe Consolidated Goldfields Project. Report prepared for NSR Environmental Consultants; and
- Powell and Powell (2000). Downstream ecological effects of mining development in the Watut River catchment, Markham Basin, Morobe District, Papua New Guinea: A review. Science in New Guinea, 25(1-3):74-115.
- Enesar (2003). Freshwater Downstream Impact Assessment. Report prepared for Morobe Consolidated Goldfields Limited.
- Enesar (2003). Rare Fish and Aquatic Fauna Survey. Report prepared for Morobe Consolidated Goldfields Limited.

While knowledge from all surveys has been incorporated into the present study, these four early studies are considered less relevant as the majority of sites are located in the Bulolo and Wau regions. Further, the scale and nature of impacts associated with the Hidden Valley project are not directly comparable to those associated with the PBMV project area. Therefore, information from the previous studies is useful to provide background and context only.

Table 2- 1 Historical survey sites in the Markham Valley region that provided input to the present study.

Site	Drainage	Easting	Northing	Hydrobiology Reference	Parameters Assessed
Bali Oxbow	Lower Watut River	446635	9261405	2011, 2012	F, FT, MC
Gabamatsung	Markham River	473801	9270352	2009, 2010b, 2011, 2012	F, FT, MC
Kayam	Lower Watut River	430832	9244335	2010b, 2010c, 2011, 2012	F, FT, MC
Koko (US Maus Watut)	Markham River	449515	9265966	2012	F, FT, MC
Kona Beach	Markham River	497568	9255214	2009	F, FT, MC
M.Wat.Oxbow	Lower Watut River	432922	9251966	2010c	F, FT, MC
Magereng (Maralinan)	Lower Watut River	433270	9238909	2011, 2012	F, FT, MC
Maralinan	Lower Watut River	433159	9239032	2010b, 2010c	F, FT, MC
Mare	Markham River	463095	9268542	2012	F, FT, MC
Mari	Markham River	463100	9264727	2009, 2010b, 2011	F, FT, MC
Markham Bridge	Markham River	487842	9260076	2010b, 2010c, 2011	F, FT, MC
Erap	Erap River	466804	9273267	2010a	F, FT, MC
Markham R. US Maus Watut	Markham River	447717	9265912	2010c, 2011	F, FT, MC
Maus Markham 1	Markham River	492263	9258419	2009	F, FT, MC
Maus Markham 2	Markham River	494474	9256429	2009	F, FT, MC
Maus Markham 3	Markham River	497016	9254550	2009	F, FT, MC
Maus Watut	Lower Watut River	447973	9263911	2010a, 2010b, 2010c, 2011, 2012	F, FT, MC
Uruf	Lower Watut River	433254	9251414	2010a, 2010c, 2011, 2012	F, FT, MC
Uruf Ck	Lower Watut River	431929	9250859	2010b, 2010c, 2011, 2012	F, FT, MC
Uruf Oxbow	Lower Watut River	431929	9250528	2010a, 2010b, 2010c, 2011, 2012	F, FT, MC
Uruf Village	Lower Watut River	432426	9250583	2010b	F, FT, MC

Footnote: F – fish; FT – fish tissue (both fish and macrocrustaceans); MC – macrocrustaceans

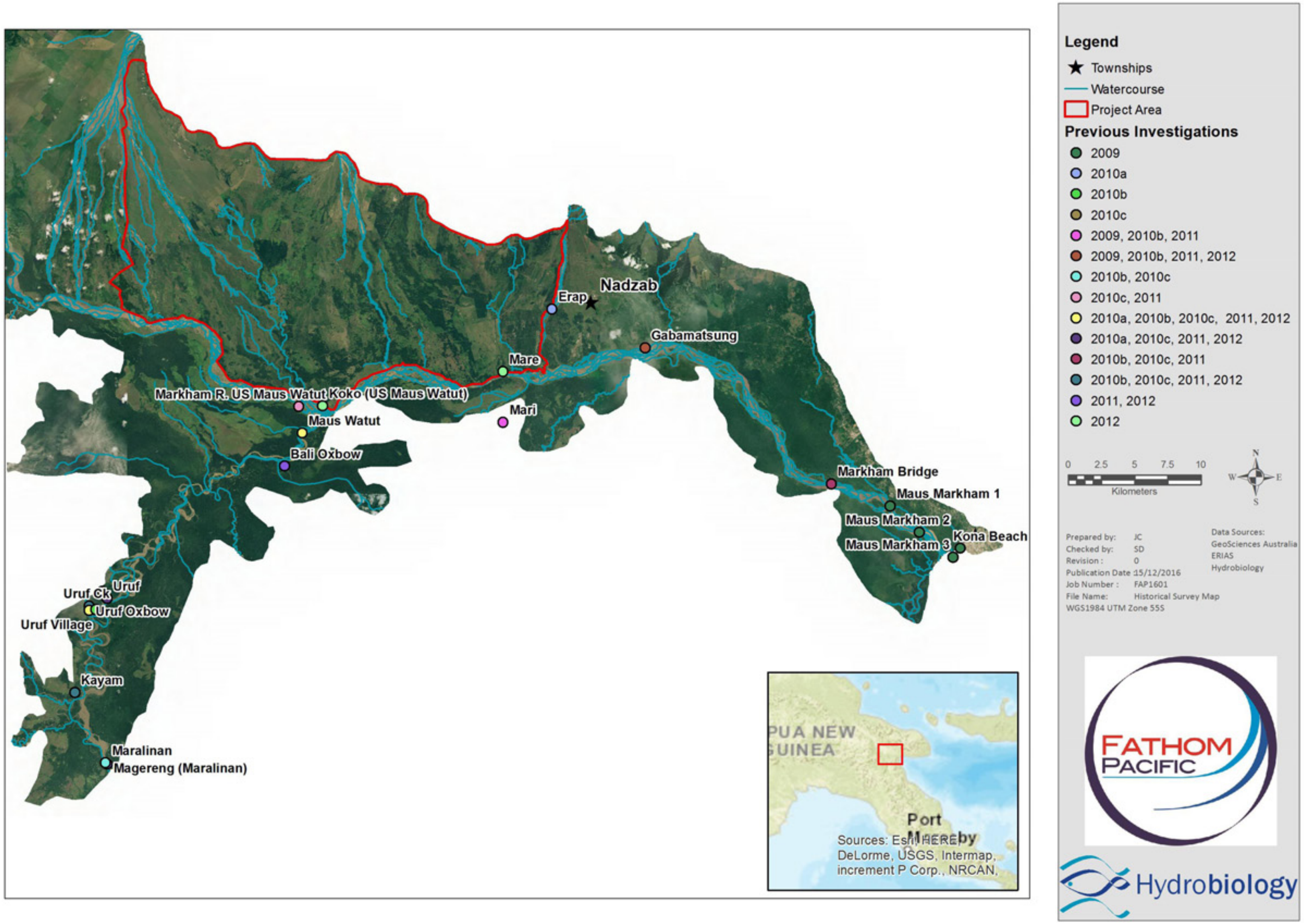


Figure 2-1 Location of historical surveys drawn upon for this study.

2.2. Field Survey

Fieldwork was completed at the project area from 25 September to 2 October 2016 and meetings were held with PNG National Fisheries Authority and CEPA on 3 and 4 October 2016 respectively in Port Moresby. In addition to the aquatic habitat and fauna sampling described here, water and sediment physicochemical samples and data relating to sediment and stream geomorphology were collected to inform separate studies. Methods relating to those activities are not described here.

2.2.1. Site Access and Navigation

Sampling sites were accessed by four-wheel drive vehicle and by walking (see Figure 2-2). During the fieldwork planning phase, potential sites at representative watercourses within the project and upstream and downstream of the project area were identified that appeared to be accessible from the Highlands Highway and from un-named tracks through the project area that were apparent in satellite imagery. Some of these pre-selected potential sites were found to be inaccessible or not able to be safely sampled. Sampling sites were iteratively rationalised in the field with due consideration to representativeness of watercourse types in the area and accessibility in all seasons for future monitoring.

Real-time navigation on un-marked tracks was achieved using a GPS antenna connected to a Samsung Series 7 slate computer running off 12-volt power from the vehicle. Global Mapper® software was used to overlay target and achieved sites on a satellite image and record the GPS track daily. A member of the landowner group from Bampu Village accompanied the sampling team and consultation with community members to gain access to sampling sites occurred as required. Selected community members were also engaged to conduct informal aquatic resource use surveys.

Sampling activities completed at each site, and status of water flow at each site, are listed in Table 2-2.

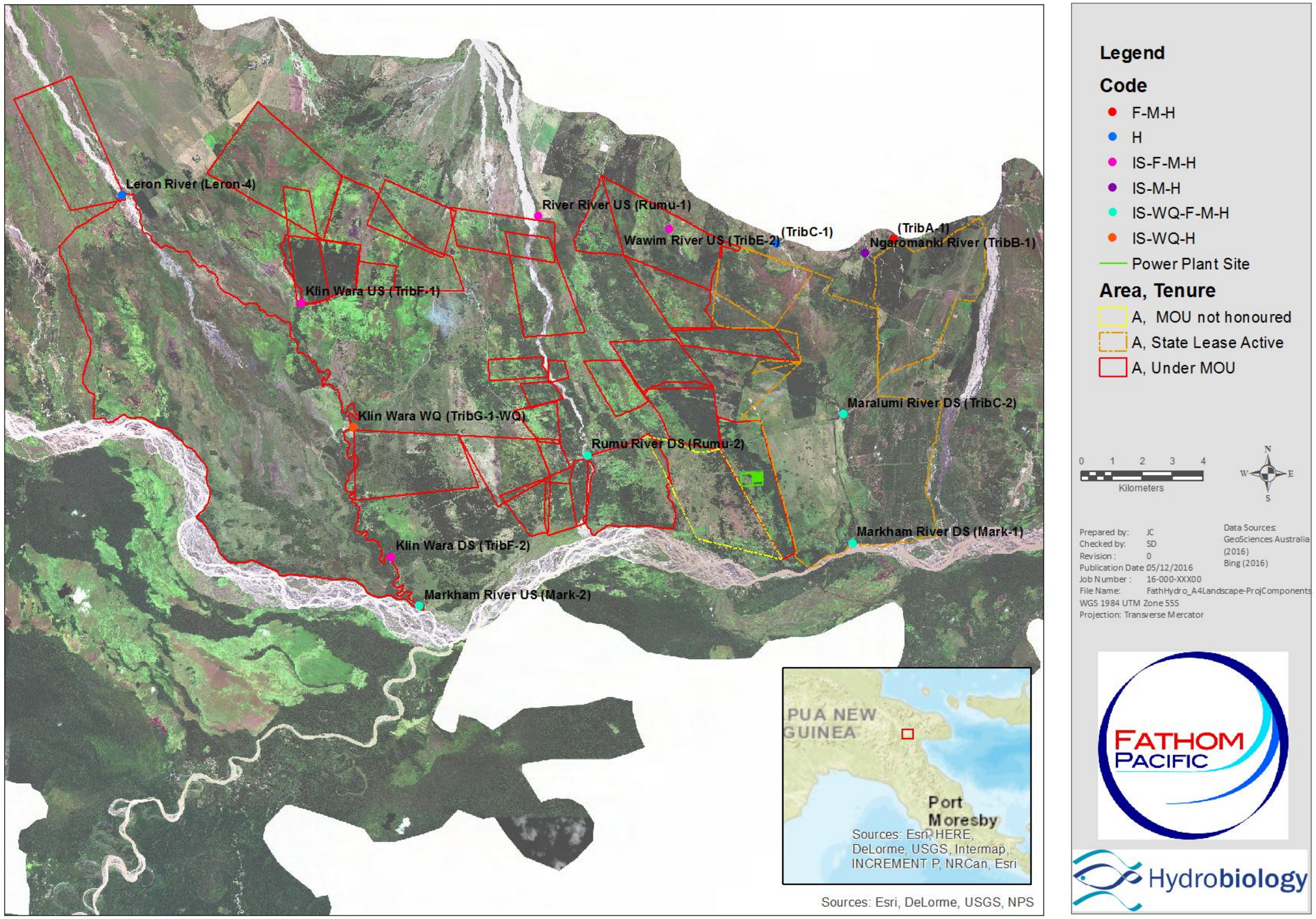


Figure 2-2 Location of sampling sites in relation to project components. Method codes: F = fish and macrocrustacea sampling, M = macroinvertebrates, H = habitat assessment, IS = in-situ water quality measurements, WQ = water quality sampling

Table 2- 2 Sampling activities completed

Site code	Site name	Easting	Northing	Latitude	Longitude	IS	EF	GN	M	H
Mark-1	Markham River DS	463108	9268453	6.61813S	146.66626E	✓			✓	✓
Mark-2	Markham River US	448849	9266387	6.63671S	146.53725E	✓	✓		✓	✓
Rumu-1	Rumu River US	452752	9279239	6.52049S	146.57265E	✓	✓		✓	✓
Rumu-2	Rumu River DS	454376	9271350	6.59186S	146.58728E	✓	✓		✓	✓
TribB-1#	Ngaromanki River	463536	9278028	6.53152S	146.6702E	✓			✓	✓
TribA-1		464454	9278470	6.52752S	146.6785E		✓		✓	✓
TribC-1*		460602	9278333	6.52874S	146.64365E					✓
TribC-2	Maralumi River DS	462807	9272710	6.57961S	146.66356E	✓	✓	✓	✓	✓
TribE-2	Wawim River US	457070	9278804	6.52445S	146.61169E	✓	✓		✓	✓
TribF-1	Klin Wara US	444964	9276381	6.54628S	146.50218E	✓	✓	✓	✓	✓
TribF-2	Klin Wara DS	447922	9267997	6.62214S	146.52887E	✓	✓		✓	✓
TribG-1-WQ	Klin Wara Mid	446672	9272278	6.58341S	146.51761E	✓				✓
Leron-4*	Leron River	439045	9279927	6.51415S	146.44867E					✓

Footnotes:

Coordinate datum is WGS84. Easting and Northing listed in UTM, Zone 55S. IS= In-situ water quality probe, EF = fish, GN = opportunistic gillnet sampling (villager use), M = Macroinvertebrate sampling, H = aquatic habitat assessment.

* Watercourses that were dry at time of sampling.

Very low flow. Villagers reported that the watercourse ceased flowing ~200 meters downstream from this location and that no fish occur in the watercourse as a result. There appeared to be two names ascribed to this watercourse: Ngaromanki River and Harisisi Creek. It is unclear whether one of these names relates to the settlement.

2.2.2. Habitat Assessments

2.2.2.1. In-situ measurements

At each site, an Aquaread® AP-2000 multimeter was used to take measurements of the following physicochemical parameters in the water column: oxidation-reduction potential, temperature, dissolved oxygen, conductivity, pH, total dissolved solids and turbidity. These data also contributed to a water and sediment quality assessment study that is not included in this report.

Measurements were taken at a location central to the habitat assessment and macroinvertebrate sampling site that was associated with riffle habitat at all locations. Water depth was less than 1 m at all in-situ locations and measurements were taken at a single depth mid-water column.

2.2.2.2. Habitat Assessment Forms

Queensland State of Rivers standard riverine habitat assessment forms (sheets 5, 9 and 10) were completed at each site. These sheets qualitatively score in-stream and riparian habitat features to provide a basis for assessing overall stream "condition".

2.2.2.3. Photographs and Site Observations

The watercourse, banks, riparian zone and substrates were photographed using a standardised approach with a camera linked with a GPS. These images also contributed to a detailed assessment of geomorphology and sediment transport that is not included in this report.

2.2.3. Fishes and Macrocrustaceans

2.2.3.1. Electrofishing

Electrofishing (Smith-Root LR24 model) was used to sample fishes and macrocrustaceans from wadable streams (see Figure 2-3). The electrofisher introduces an electrical current into the water that elicits galvanotaxis – a muscular response that draw organisms towards the hand-held anode – or temporary stunning. Specimens were collected using a net sewn into the hand-held anode pole and an assistant used a dip net to collect any specimens washed downstream from the operator. At each site, five replicate stream sections were sampled and the "on-time" of electrical discharge was recorded as a proxy for sampling effort.

Fishes and macrocrustaceans were identified to species level, enumerated and weighed (wet weight) in the field. A photographic record of each species was retained.

2.2.3.2. Opportunistic Villager Gill Net Sampling

At two locations (Klin Wara US and Maralumi River), slow-flowing deep pool habitats that are conducive to gill net sampling were encountered. Two 19 mm and two 25 mm (knot-to-knot mesh size) gill nets were left with villagers at these locations for overnight fishing. The catch was retained by fishers and inspected by the sampling team the following day. The catch was identified, enumerated and weighed.

Figure 2-3. Electrofishing

2.2.3.3. Opportunistic Subsistence Catch Observations

Subsistence fishing activity was observed at sites Klin Wara US, Maralumi River and in the Markham River. At these sites, catches and fishing equipment were inspected and fishers were questioned about fishing practices.

2.2.3.4. A note on sampling in the Markham River

The Markham River is a dynamic, fast-flowing, turbid, shallow braided river. Sampling fishes and macrocrustaceans safely and effectively in this river is notoriously difficult. Indeed, local people observed fishing in the Markham River during this study, and in previous studies, focus efforts on known locations of backwater eddies, log jams or the confluence of tributaries.

Electrofishing was used at one sampling site in the Markham River. The effectiveness of electrofishing in this type of habitat is severely limited by the accessibility of suitable habitats, visibility, and the size of the water body being sampled. Electrofishing in the Markham River was therefore restricted to areas of riffles close to the bank, bank undercuts, areas of log/branch accumulations and any small backwater habitat able to be accessed. Catches were low and not deemed to be representative of the diversity and biomass of fishes and macrocrustaceans in this river. At this site, local fishers assisted the sampling team to attempt seine net sampling, however these attempts were unsuccessful. At a second site visited on the Markham River (sampled for water and sediment quality), electrofishing was not attempted. Information for the Markham River is therefore supplemented with the results of previous sampling efforts and literature review.

2.2.4. Macroinvertebrates

In-stream benthic macroinvertebrates were collected by kick-net sampling (Figure 2-4). This is the most effective means of collection in wadable, relatively fast flowing streams with pebble-cobble-boulder substrates. Macroinvertebrates are sensitive to water quality perturbations and are generally abundant, thus providing a sensitive and robust measure of stream quality and functioning. Five replicate samples were taken at each site and preserved in 95% ethanol. Samples were delivered a specialist in Australia for identification and enumeration.

Identifications were to family level of taxonomic organisation as a minimum. Genus and species level identifications were made for well described types. Where lower-level formal identifications were not feasible, but distinct forms were observable, morphotype identifications were made. This allowed for analyses to consider taxonomic levels (and therefore effort) required for detecting change in future monitoring. A reference collection of preserved representatives of each type was retained (70% ethanol).

Figure 2-4. Macroinvertebrate kick net sampling.

2.2.5. Training and Capacity Building

This project actively sought to involve PNG nationals in scientific sampling and data management in the field. Further, daily discussions were had regarding the species encountered, the methods used and the ecology of the aquatic systems. An Aligned Energy (PNG) field guide was trained in the principals of aquatic fauna sampling and had a hands-on role in data collection, skills that are transferable to other sectors of the company's work and to the wider community.

Detailed discussions about the preliminary findings of the study and considerations about the ecological functioning of the aquatic systems in the project area were had with the principal landowner from Bampu Village - Kelly Jim Onogore. Mr. Onogore also had a hands-on role in daily sampling activities. The way in which this study contributed to the characterisation of the aquatic environment, against which future changes will be compared, and how this study interacted with the principals of Ecologically Sustainable Development were discussed. This awareness and knowledge is transferable to the collective landowner group and thus their wider community.

In-water sampling activities, particularly those that involve fishing, inevitably attract the interest of people. At most sites, particularly those where villagers took part in gill net sampling, the team had conversations about aquatic resources and the studies being undertaken. Taking water samples (with the sampler wearing rubber gloves), using an in-situ water quality probe and using equipment such as an electrofisher were novel to most individuals and discussions were held at most sites about these methods and the reasons behind the sampling effort. These interactions yielded useful information and were appreciated by the audience that included children and adults.

2.3. Data Analysis

2.3.1. Habitats

Qualitative habitat assessment sheets were digitised and along with photos and field observations, supported a narrative assessment of in-stream and riparian habitat types. This information is used to contextualise results of the aquatic fauna sampling and also provide a basis of monitoring.

2.3.2. Fishes and Macrocrustaceans

Species diversity and biomass are the key metrics used to describe fish and macrocrustacean communities. Total species richness was summarised from all methods and all sites. Electrofisher catches only were used to make quantitative comparisons of diversity and biomass (standardised to grams per 30 seconds of shock-time) between sites. For these analyses, replicate electrofisher samples were pooled because abundance in any one replicate was too low to provide meaningful assessments at the within site level. The conservation significance of fauna was assessed by reference to global databases and in-house knowledge of the distribution of species from previous studies in PNG.

2.3.3. Macroinvertebrates

Macroinvertebrate data were reviewed to first remove terrestrial arachnids, adult (terrestrial) dipterans and hymenopterans and decapod crustacean taxa from further analysis. Taxa richness and abundance was calculated at the replicate and site level. To examine site differences, watercourses were categorised into three types: (1) Cobble-pebble dominated streams with relatively high sediment load, ephemeral reaches or episodic high flows, (2) clearwater streams, and (3) Markham River.

The following were quantified:

- Taxa richness (number of taxa).
- abundance (number of individuals).
- Shannon-Wiener diversity (H'; Pielou 1966).
- Plecoptera, Ephemoptera, Trichoptera (PET) richness. These groups represent species known to be particularly sensitive to pollution.
- Abundance weighted Stream Invertebrate Grade Number – Average Level (SIGNAL) biotic index (a pollution scoring system for macroinvertebrates based on their pollution tolerances) (Chessman, 2003).

Replicates from each site were pooled according to habitat after first investigating within-site variation among replicates. There was significant variation among replicates only at the Markham River sites. This was likely to be attributed to the variability among accessible habitats and this result is explained further below. Overall, assemblage composition in the Markham River did not differ significantly from the other high sediment load streams and analysis proceeded at the habitat level.

Differences in assemblage indices among habitats were tested with a one-way Permutational ANOVA (PERMANOVA). Significant results ($\alpha = 0.05$) were investigated further by pairwise comparisons. Within-habitat variation was tested using a nested two-way PERMANOVA.

Differences in macroinvertebrate assemblages between habitats were also examined using non-parametric multidimensional scaling (nMDS), based on Bray-Curtis dissimilarity matrices. Differences between habitat types were tested using analysis of similarity (ANOSIM). Additionally, similarity percentage (SIMPER) analyses were used to identify which taxa contributed to any observed differences in community assemblages.

To improve homogeneity of variance, all data were log transformed prior to analysis. All statistical analyses were performed in Primer6+PERMANOVA (v.6.0) (Clark and Gorley 2006) and all analyses were conducted at the family level of taxonomic classification.

Macroinvertebrate families were also classified into functional feeding groups (FFGs) based on literature as follows:

- MC - Macrophyte Collector;
- MP - Macrophyte Piercer;
- P - Predator;
- GC - Gatherer Collector;
- SC - Scrapper;
- SH - Shredder;
- FC - Filter Feeder/Collector.

FFGs vary in their niche requirements and sensitivity to environmental stressors. For example, scrappers can be associated with benthic algae and biofilm growth that requires clean water conditions for sunlight penetration and low suspended sediment and bed sediment loads that do not scour surfaces. Filter feeders generally have delicate feeding structures that are sensitive to high suspended sediment concentrations and their presence can indicate stable clear water conditions. High abundance of macrophyte piercers and shredders can be indicative of systems with high terrestrial vegetation input. Therefore, the relative diversity and dominance of feeding types can be indicative of ecological functioning of watercourses and thus sensitivities. Any one family of macroinvertebrate may consist of multiple FFGs and at lower levels of taxonomic organisation, feeding types are not well known.

3. Existing Environment Literature Review

3.1.1. Physical Environment

The Markham River drains an area of about 13,000 km^2 with high rainfall (catchment mean annual rainfall of 2,100 mm) and high sediment supply rates (Renagi 2009). Headwaters originate in the Finisterre Range and the river flows for approximately 180 km (linear distance) to empty into the Huon Gulf at Lae. Mean annual discharges from the Markham River have been estimated at 350-400 m^3/s (Powell and Powell 2000). The Huon Gulf is a submarine canyon with little tidal movement, as such, the Markham River is almost fresh to the mouth of the river where it meets Huon Gulf. The Leron, Watut, Erap and Rumu rivers are among the most significant tributaries of the Markham River. The Leron, Erap and Rumu rivers are fed by numerous creeks draining the Finisterre and Saruwaged ranges that are largely ephemeral or semi-permanent systems.

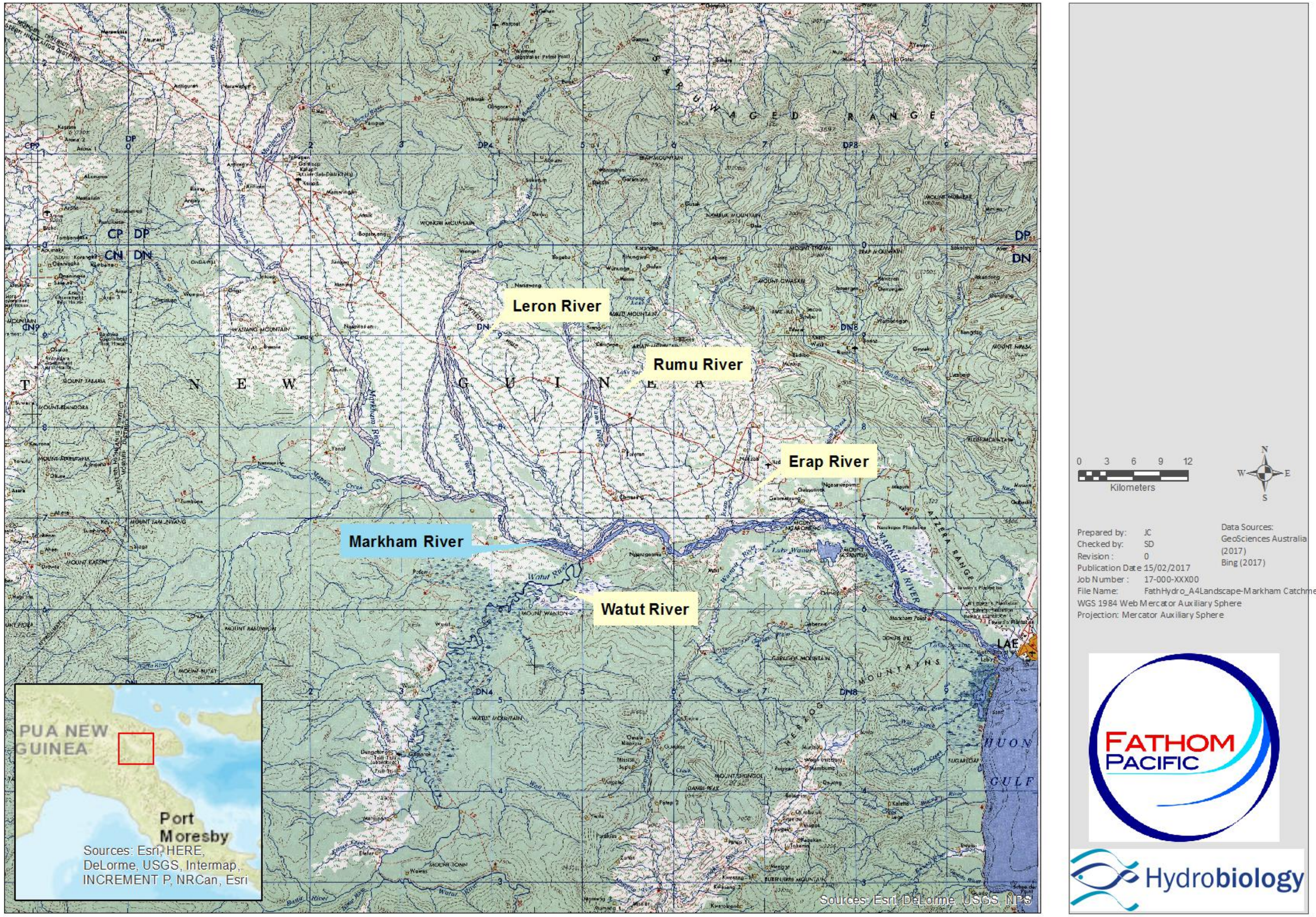


Figure 3-1. Location of the Markham River and major tributaries.

The Markham River catchment is characterised by large volumes of fluvial sediment which are supplied from high rainfall, landslide–prone mountains, and carried through a highly energetic floodplain to the coastline. The entire system is affected by long term tectonically-induced changes in relief and slope gradients, with mountain uplift and sea floor subsidence across a major plate boundary. There are frequent earthquakes which trigger landslides both in the mountains and on the sea floor. Of importance was the Finisterre Range Earthquake of 1993, which registered 7.1 on the Richter scale. The effects of the earthquakes included: damming of the upper Leron River – a major tributary of the Markham River on the western boundary of the PBMV project area – to a depth of 30 m which formed a large lake which breached three weeks later; damming of the Gusap River – a major tributary of the Ramu River – at four locations and the Bora River at two locations. One of the Gusap dams was breached on 26 November 1993, releasing about 40,000 ML of water (equivalent to about the size of a small to medium urban reservoir). The resulting floodwaters (with an estimated peak flow of 2,800 $m^{3/}s$) overtopped and destroyed the Gusap Bridge. The channel of the Gusap River that was originally 19 m wide and 11 m deep was widened to approximately 30 m while sediment deposition of about 9 m occurred under the bridge. Less than one month later, on 12 December 1993, the largest of the Bora River dams failed, releasing approximately 60,000 ML of water, destroying the Gusap bridge. Prior to the 1993 earthquake the Markham River was largely considered a clear-water environment. Today the river is characterised by high suspended sediment and bed loads and high turbidity.

Combinations of landslide damming of rivers, floods and dam breaching bring significant volumes of sediment to fan deltas on the coast. One landslide in the Markham catchment at Kaiapit mobilized 1.8 cubic km of rock with sufficient velocities and energy for air fluidization, (Peart, 1991). Haskoning and Maunsell, (1980) estimate that about 150 – 160 tons of sediment per km^2 is moved annually by the Markham River with an average annual bed-load of about 2 million tons. Subsequently the landslide debris has become an additional sediment supply to the Markham River. River sediments are mainly sand, gravel, pebbles and boulders up to 50 cm diameter (Deacon, 1993).

Alluvial fans are a characteristic feature of the Markham Basin. These features represent sediments deposited by river flows, and debris flows resulting from landslide activity. The fans contain alluvium to depths of up to 1,000 m. The largest fan is the Leron Fan (Loffler, 1977). The fans, and the rivers that flow over them are highly mobile and continuously change form due to ongoing fluvial processes and intermittent tectonic activity. The fan delta deposits overlie the Pleistocene Leron formation, comprising well–laminated mudstones, siltstones, pebbly sandstone and sandy conglomerates (Brierley et al. 1993).

Large areas of the Markham River floodplain have been cleared for agriculture. Oil palm, sugar and cattle grazing and chicken farming are the most prevalent agriculture in the region. Tracts of dense vegetation still occupy elevated areas, and these represent approximately 44% of land cover within the basin (Samanta 2016). Two mining projects occur in the Markham River catchment, both in upland areas to the south of the Markham River, in the sub-catchments of the Bulolo and Watut river systems, that report to the Markham River upstream of the PBMV project area: Hidden Valley Gold-Silver Mine (an operating mine) and the Wafi-Golpu Gold project (yet to be developed). Artisanal alluvial gold mining occurs throughout the catchment, though predominantly within the Wau-Bulolo area where artisanal, small-scale and large mining practices have occurred since at least the 1940s.

3.1.2. Native Fish Communities

In total, 38 native fish species have been recorded from sampling in the Markham River system (Table **3- 1**). Monitoring of fish populations in the catchment has been most intensive in the Watut River and these data, while representing generally higher altitude watercourses that those in the PBMV project area, provide some basis for understanding diversity and impacts in the catchment. Fish communities in the upper Watut declined severely in 2007 to 2009, probably as a result of sediment-related impacts (Hydrobiology 2009), and have not recovered since this time. In contrast, communities in the Lower Watut and Markham rivers have remained relatively stable, although fish abundance appears to have decreased, potentially due to fishing pressure and localised landslips (Hydrobiology 2009; 2010a; 2010b; 2010c; 2011; 2012). Several species in the Watut River system are likely maintaining their populations in off-river habitats including floodplains, oxbow lakes, and tributary streams (Hydrobiology 2010a, b). Native species that are likely to occur in off-river water bodies include *Glossamia gjellerupii, Melanotaenia affinis*, and *Mogurnda aurofodinae*.

Hydrobiology (2010a) sampled in the Erap River, at the eastern boarder of the PBMV project. A single *Chilatherina bulolo* was captured during the survey effort.

3.1.3. Non-native Species

Powell and Powell (2000) reported three non-native species in the Lower Watut River and today, seven non-native species are known to occur in the Lower Watut and Markham rivers (see Table **3-1**). Non-native species on average account for approximately 15% of total fish species diversity in the Lower Watut and Markham Rivers, though some watercourses are almost completely dominated by non-natives (Hydrobiology 2012).

At least three of the exotic fish species (*Tor putitora; Oreochromis niloticus* and *Clarias batrachus*) in the Watut-Markham have the potential to negatively impact native fish communities, particularly in floodplain habitat. The introduced golden mahseer, *T. putitora*, is successfully breeding in the Watut and continuing to disperse upstream (Hydrobiology 2012). The dietary range of the species (herbivorous as juveniles, carnivorous/piscivorous as adults) is likely to result in negative impacts on resident fish communities through resource competition and predation. The walking catfish, *C. batrachus*, can dominate small creeks and waterbodies and have a similar negative impact on native species. The GIFT tilapia is genetically 'improved' stock of the Nile tilapia, *O. niloticus*, originally introduced locally for aquaculture, but has now entered open waters. This species, with wider ecological tolerances and more vigorous growth and preferring floodplain habitat, may also negatively impact resident communities through resource competition.

Table 3- 1 Fish recorded during surveys in the Lower Watut and Markham rivers

Species	Common name	Powell and Powell 2000	Hydrobiology							
			2007	**2009**	**2010a**	**2010b**	**2010c**	**2011**	**2012**	**IUCN Listed**
Ambassis interruptus	Long-spined glass perchlet						X			LC
Ambassis macrocanthus	Estuarine glass perchlet			X						
Anguilla megastoma	Pacific long-finned eel			X				X		DD
Anguilla reinhardtii	Marbled eel		X							
Anguilla sp.	Eel								X	
Awaous melanocephalus	Largesnout goby			X			X		X	
Chilatherina bulolo	Bulolo rainbowfish		X	X	X	X		X		DD
Chilatherina crassispinosa	Silver rainbowfish	X		X	X		X		X	
Chilatherina fasciata	Barred rainbowfish					X			X	
Liocranium pleurostigma	Blackspot waspfish			X						
Glossamia gjellerupi	Gjellerup's mouth almighty	X			X	X	X	X	X	
Glossogobius torrentis	White water goby		X			X	X	X	X	
Glossolepis kabia	Sepik River rainbowfish					X	X	X	X	
Glossolepis sp.	Rainbowfish				X					
Hephaestus transmontanus	Sepik grunter	X	X						X	
Johnius amblycephalus	Bearded croaker			X		X				
Lamnostoma kampeni	Freshwater snake-eel			X			X			
Lentipes watsoni	Watson's goby		X	X				X	X	
Liza sp.	Mullet			X						
Liza subviridis	Greenback mullet		X			X			X	
Liza tade	Rock mullet			X						DD
Melanotaenia affinis	North New Guinea rainbowfish	X	X	X		X	X	X	X	
Mesopristis cancellatus	Grunter			X		X				

Microphis mento	Red pipefish			X	X	X				LC
Mogurnda aurofodinae	Northern Mogurnda		X							
Mogurnda nesolepis	Yellowbelly budgeon		X			X	X	X		
Mugil sp.	Mullet				X	X	X			
Neosilurus idenburgi	Idenberg tandan	X				X			X	
Nibea sp.	Croaker						X			
Ophieleotris aporos	Snakehead gudgeon	X		X	X	X	X	X	X	
Bunaka gyrinoides	Greenback gudgeon	X	X	X		X			X	LC
Potamosilurus coatesi	Coates’ catfish			X						
Potamosilurus velutinus	Papillate catfish	X			X	X	X	X	X	
Rhyacichthys aspro	Loach goby		X							DD
Schismatogobius sp. cf. insignus	Goby								X	
Stenogobius laterisquamatus	Goby			X						LC
Valamugil buchanani	Bluetail mullet					X				
Native species richness		**8**	**11**	**18**	**8**	**16**	**13**	**10**	**16**	
Clarias batrachus	Walking catfish					X			X	LC
Xiphophorus helleri	Swordtail	X		X	X	X	X	X	X	
Tor putitora	Golden mahseer					X	X	X	X	E
Cyprinus carpio	Common carp	X			X	X		X	X	
Gambusia holbrooki	Mosquitofish			X		X	X		X	
Oreochromis mossambica	Tilapia	X		X	X	X	X	X	X	
Oreochromis niloticus	GIFT (tilapia)								X	
Non native species richness		**3**	**0**	**3**	**3**	**6**	**4**	**4**	**6**	

Footnote: LC: Least Concern; E: Endangered; DD: Data Deficient

3.1.4. Threatened Fish Species

A previous survey in the Watut River catchment recorded only one threatened native species listed on the IUCN Red List, the Critically Endangered freshwater sawfish *Pristis microdon* (Gwyther 1988, cited in Powell and Powell 2000). The sawfish is generally found in shallow near-shore marine environments and estuaries, but also in large, turbid rivers. Adults breed in estuarine or marine conditions and use freshwater reaches as nursery grounds (Thorburn et al. 2007). It is unknown how many individuals were associated with this record of *P. microdon* in the Watut catchment, but the record was from the lower Watut River below the Wafi River junction. This species was not recorded in the numerous subsequent surveys between 2007 and 2012.

According to the IUCN Red List, the golden mahseer, *Tor putitora*, is endangered in its natural range (Jha and Rayamajhi 2010). *T. putitora* was introduced to PNG from India in 1995 for the purpose of fisheries enhancement. It inhabits the montane and submontane regions, in streams and rivers, particularly rapid streams with rocky substrates, riverine pools and/or lakes. Its natural range extends across the Himalayan region and elsewhere in south Asia and southeast Asia, ranging from Afghanistan, Pakistan, India (Darjeeling to Kashmir), Nepal, Bangladesh, Bhutan, Sri Lanka, Myanmar, western Iran to eastern Thailand. The IUCN conservation status is not deemed to apply to populations of this species outside of its natural range and therefore does not apply to this species in PNG.

Four species recorded from the Lower Watut and Markham rivers are listed in the *data deficient*[4] category of the IUCN Red List: *Anguilla megastoma, Chilatherina bulolo, Liza tade* and *Rhyacichthys aspro*. A further four species are in the *of least concern* category: *Ambassis interruptus, Microphis mento, Bunaka gyrinoides* and *Clarias batrachus* (the latter species being non-native to PNG).

[4] Data deficient means that there is inadequate information to make a direct or indirect assessment of its risk of extinction based on its distribution and/or population status. A taxon in the category may be well studied, and its biology well known, but appropriate data on abundance and/or distribution is lacking.

3.1.5. Threatened Aquatic Reptiles

The New Guinea snapping turtle (*Elseya novaeguineae*) has been recorded from off-river water bodies in the Markham River catchment (P. Lloyd, Biodiversity Assessment and Management Pty Ltd, pers. comm.). This species is listed in the *lower risk/least concern* category of the IUCN Red List (ATTWG 2000).

The New Guinea crocodile (*Crocodylus novaeguineae*) is listed in the *lower risk/least concern* category of the IUCN Red List (CSG 1996). This species may occur in the Markham River in the vicinity of the PBMV project area.

The saltwater crocodile (*Crocodylus porosus*) is listed in the *lower risk/least concern* category of the IUCN Red List (CSG 1996). If present in the Markham River valley, it is most likely restricted to the narrow estuarine zone of the Markham River mainstream near the mouth.

3.1.6. Fishes with Restricted Distributions

A native rainbow fish (*Glossolepsis kabia*) collected from an oxbow lake in the Uruf creek (a tributary of the Lower Watut River) was found to be genetically distinct from other populations in the Sepik and Ramu Rivers (Hydrobiology 2010b). The population was classified as an evolutionarily significant unit, and represents a population in the process of becoming a new species which, if its habitat remains isolated, will be endemic to the lower Watut-Markham catchment. The genetic differences suggest that the populations have been isolated for a reasonably long period prior to migration of the main channel and formation of the oxbow lakes.

While this water body is well outside the PBMV project area, this finding elevates the importance of off-river water bodies such as floodplain swamps, oxbow lakes and other permanent pools as potential habitats of significance in the catchment. Indeed, it is such habitats that are also commonly associated with sites of cultural significance (e.g. spiritual *masalai* sites).

Several species collected in the Watut-Markham catchment are understood to be endemic to northern New Guinea (i.e. north of the Central Range): *Hephaestus transmontanus,* *Glossamia gjellerupi, Glossogobius bulmeri, Mogurnda aurofodinae* and *Neosilurus novaeguineae*.

3.1.7. Species of Fisheries Significance

Most fish species, including small-bodied species, are important food species for local villagers in the Markham River catchment and generally, people eat whatever is caught. Similar to other areas in PNG, the tilapia (*Oreochromis mossambica*) has become a key species for inland subsistence fisheries.

It has been estimated that there are approximately 300 active fish farms in the Morobe region (Smith, 2007). Locations of fish farms in the vicinity of the Ramu, Erap and Markham rivers are shown in Figure 3-2. No detailed information on the farmed species is available, but carp, GIFT tilapia and rainbow trout, and to a lesser extent crocodiles are commonly farmed in northern PNG catchments (Smith, 2007).

Several commercial significant freshwater species found elsewhere in PNG, such as barramundi (*Lates calcarifer*) and Saratoga (*Scleropages jardinii*), do not occur in the Markham River catchment. Several eels (*Anguilla marmorata, Anguilla bicolor pacifica*) have been recorded from the Markham catchment that form an important component of subsistence fisheries in PNG, particularly in high altitude areas (Coates, 1996). Eels have also been the subject of aquaculture attempts in PNG, albeit with apparently limited success (FAO 2010).

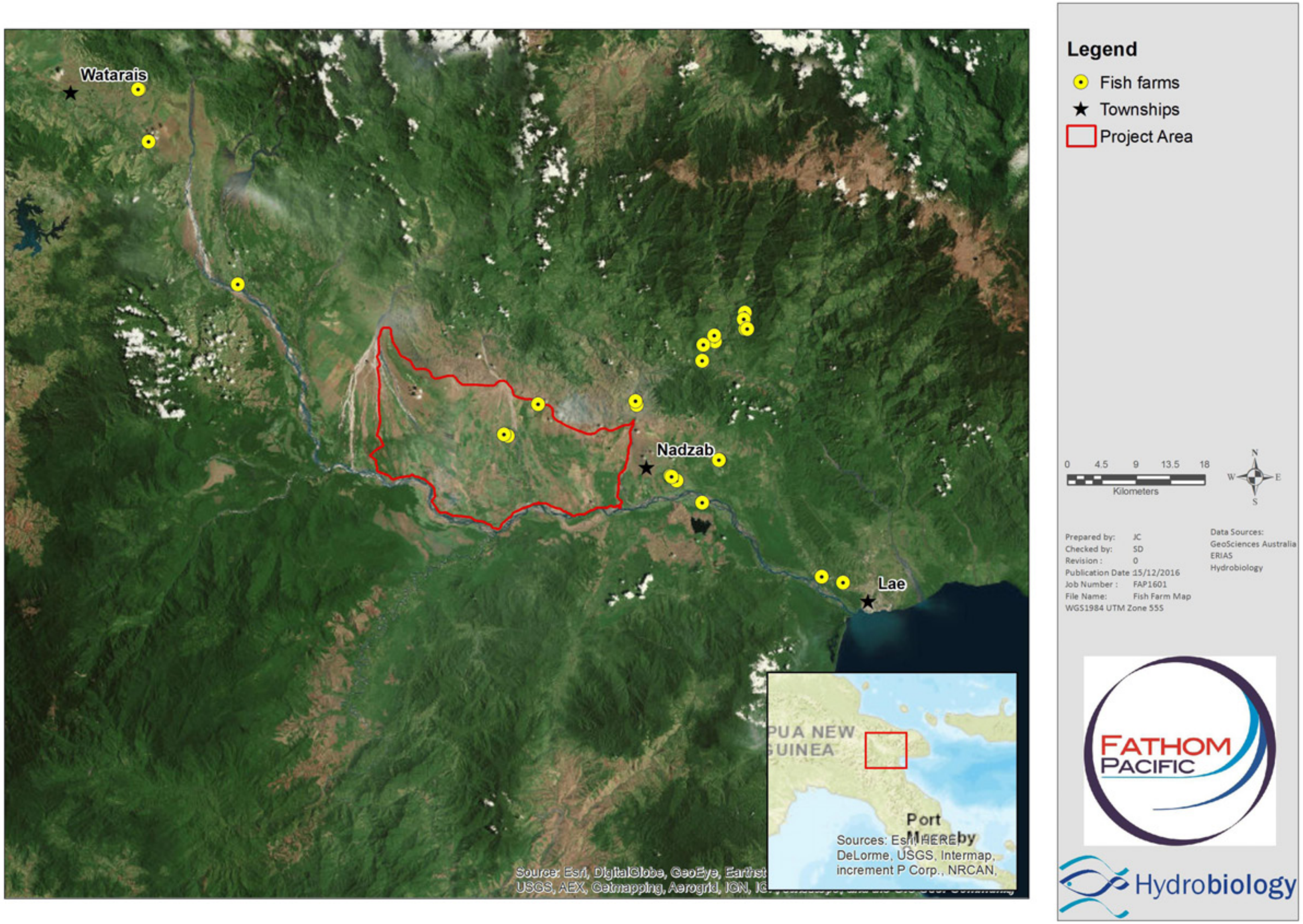


Figure 3-2 Location of fish farms in the Ramu-Markham valleys.

3.1.8. Macrocrustacean Communities

Freshwater prawns communities in the Lower Watut-Markham are diverse, though still not well-documented taxonomically (Table 3- 2). Five species have been recorded in the Watut-Markham system that are undescribed and possibly endemic to the Watut-Markham.

Prawns are detritivores and many species are tolerant of high levels of suspended sediments, while others prefer clear water conditions. However, lower abundance of prawns was recorded downstream from the junction of the Markham and Erap rivers at a time when the Erap River had a very heavy sediment load, possibly from a landslip in the river's catchment (Hydrobiology 2011; 2012).

3.1.9. Macroinvertebrate Communities

Aquatic macroinvertebrate communities are dominated by the aquatic larval stages of terrestrial insects. A number of macroinvertebrate surveys have previously been carried out in the Watut River system, primarily in conjunction with the development and operation of the Hidden Valley mine (Hydrobiology 2009; 2010c; 2011; 2012) and Wafi-Golpu prospect (BMT WBM 2013). Macroinvertebrate sampling for the Hidden Valley mine was largely limited to the Upper Watut, Bulolo and Snake rivers, and associated tributaries. While these sites are not necessarily analogous to the PBMV study area, this summary provides some context to the results that will be presented from the study area. The feeding guilds of macroinvertebrates are used as one indicator of assemblage diversity and ecosystem functioning. In a healthy system, with good water quality and stable, diverse micro-habitats, a broad range of feeding guilds may be present. Filter-feeders are particularly vulnerable to sediment-related water quality impacts.

Table 3- 2. Macrocrustaceans (prawns and shrimps) recorded in the Lower Watut and Markham rivers

Species	Hydrobiology							Red List category
	2007	2009	2010a	2010b	2010c	2011	2012	
Caridina sp.		X	X	X				
Macrobrachium idae							X	LC
Macrobrachium. sp. nov *(cf. papuanum)*							X	
Macrobrachium. sp. nov *(nr. placidulum)*							X	
Macrobrachium. sp. nov *C5*							X	
Macrobrachium. sp. nov *1*						X		
Macrobrachium. sp. nov 2 *(nr latimanus)*						X	X	
Macrobrachium. sp. nov. A		X			X			
Macrobrachium. sp. nov. C					X			
Macrobrachium australe		X	X	X				LC
Macrobrachium bariense	X				X			LC
Macrobrachium equidens		X		X				LC
Macrobrachium gracilirostris						X		
Macrobrachium hirtimanus				X				E
Macrobrachium hostii		X	X	X				
Macrobrachium lar		X	X	X	X	X		LC
Macrobrachium latidactylus	X							LC
Macrobrachium latimanus		X					X	LC
Macrobrachium lorentzi	X							LC
Macrobrachium mammillodactylus	X	X		X	X	X	X	LC
Macrobrachium rosenbergii		X						LC
Macrobrachium weberi		X	X	X	X	X	X	LC
Macrobrachoim oenone		X		X				
Macrobrachium sp.	X	X	X	X				
Total Species Richness	**5**	**11**	**5**	**9**	**6**	**6**	**8**	

Footnote: LC: Least Concern; E: Endangered; DD: Data Deficient

The likely factors influencing the diversity and abundance of aquatic macroinvertebrates in the Watut River system are:

- Suspended sediment and sedimentation regimes. The main channel environments of the upper Watut are generally more turbid and may be more exposed to higher levels of sedimentation than tributary streams. Powell and Powell (2000) sampled sites along the lower Watut River and reported the area from Tsili Tsili downstream to be virtually devoid of aquatic macroinvertebrates. Powell and Powell (2000) suggest this was due to severe sedimentation of the streambed caused by land disturbance in the upper Watut River. As will be discussed further below, an analogous situation appears to occur in the watercourses with naturally high sediment loads (and contrasting with clearwater tributaries) in the PNG Biomass Markham Valley project area.

- Flows and structural habitat conditions. Tributary streams can support higher levels of micro-habitat complexity compared to main river channel environments, thereby providing a broader range of niches for aquatic fauna. This is especially true of streams with extensive riffle and run systems (see below).
- Biological processes and interactions. This includes differences in, for example, recruitment, competition and predation.

Riffle Habitat

A total of five phyla and 82 taxa (typically family-level identifications) were recorded during the monitoring in the Watut River (Table 3- 3). The most abundant taxa were:

- Baetidae mayfly larvae, which represented 33% of the total abundance;
- Hydropsychidae caddisfly larvae, which represented 16% of the total abundance;
- Chironominae midge larvae, which represented 12% of the total abundance; and
- Orthocladinae midge larvae, which represented 7% of the total abundance.

Baetide had the highest recorded abundances in all years and abundance was highest in the Upper Watut reaches and tributary reference sites. As will be discussed further below, this was also the most abundant macroinvertebrate in the PBMV project area. This taxa is common in fast flowing riffle zones waters but are also found less commonly in lower flows in rivers, wetlands, billabongs and farm dams (Gooderham and Tsyrlin 2002). In the Watut River, sites downstream of mining-related impacts were dominated by predators representing on average 90% of the individuals recorded at impacted Upper Watut sites, with collector-scrapers representing the remaining invertebrates presents. By comparison, reference sites contained assemblages that consisted of a broader range of feeding guilds that included (in addition to predators and collector-scrapers), deposit feeders, filter feeders collectors/collector-scrapers and gatherer-scrappers.

Pool Habitat

Sampling for the Wafi-Golpu Project (BMT WBM 2013) included upland pool habitats. Sampling sites were largely located along tributaries east of the Lower Watut (i.e. the Wafi River). Pools supported a range of aquatic macroinvertebrates that were unique to this habitat, but also several taxa that were also recorded in riffle habitats. Pool communities included:

- Psychodidae: recorded at three sites in pool habitat only. This family prefers still or slow-flowing waters (Gooderham and Tsyrlin 2002).
- Bivalve molluscs: recorded at four sites in pool habitat only. Representatives of this group occur in a range of habitats, but most freshwater representatives occur in soft sediments such as found in pool habitats.
- Gastropoda (unidentified)/Physidae: very abundant in pool habitats, particularly at Ziriruk Creek, but recorded in riffle habitat at one site only in low numbers. Physidae snails prefer still waters (Gooderham and Tsyrlin 2002), such as found in pool habitats.

It was noted that the pools in ephemeral or semi-permanent streams provided dry season refugia. During dry periods, the upper-most and lower-most reaches of tributaries can dry out, while deeper pools found in the middle reaches of the tributaries can provide important permanent refugia for most aquatic fauna species. An analogous situation may exist in the watercourses of the PBMV project area that is known to have ephemeral streams.

Table 3- 3. Macroinvertebrates recorded in riffle habitat during historical surveys within the Upper Watut River and tributaries.

Taxa	Common Name	Hydrobiology			
		2009	2010c	2011	2012
Aeshnidae	dragonfly larvae	X			
Baetidae	dragonfly larvae	X			
Caenidae	dragonfly larvae	X			
Ephemerellidae	dragonfly larvae	X			
Ephemeridae	dragonfly larvae	X			
Eustheniidae	stonefly larvae	X			
Heptageniidae	dragonfly larvae	X			
Lebellulidae	dragonfly larvae	X	X	X	X
Leptophlebiidae	mayfly larvae	X			
Limnaeidae	snail	X			
Potamanthidae	mayfly larvae	X			
Prosopistomatidae	mayfly larvae	X	X	X	X
Tipulidae	crane fly larvae	X	X	X	X
Athericidae	fly larvae			X	
Baetidae	mayfly larvae		X	X	X
Belostomatidae	giant waterbug			X	
Caenidae	mayfly larvae		X	X	X
Calamoceratidae	caddisfly larvae		X	X	X
Capniidae	stonefly larvae	X			
Ceratopogonidae	biting midge	X	X	X	X
Chironomidae	non-biting midge larvae	X			
Chironominae	non-biting midge larvae		X	X	X
Coenagrionidae	damselfly larvae				
Conoesucidae	caddisfly larvae				X
Corixidae	water boatman		X	X	
Crambidae	aquatic caterpillars		X	X	X
Curculionidae	weevil	X			
Dixidae	fly larvae	X			
Dolichopodidae	fly larvae	X		X	
Drosophilidae	fly larvae	X			
Dytiscidae	diving beetle		X	X	X
Ecnomidae	caddisfly larvae	X	X	X	
Elmidae	riffle beetle	X	X	X	X
Empididae	fly larvae	X	X		X
Epiproctophora	dragonfly larvae		X		
Gerridae	water strider		X		X
Glossosomatidae	caddisfly larvae		X	X	X
Helicopsychidae	caddisfly larvae		X		
Hemicorduliidae	dragonfly larvae			X	
Heteroceridae	variegated mud-loving beetles		X		

Hydraenidae	aquatic beetle			X	
Hydrophilidae	water scavenger beetle		X		
Hydropsychidae	caddisfly larvae	X	X	X	X
Hydroptilidae	caddisfly larvae	X	X	X	X
Hygrobiidae	aquatic beetle	X			
Leptoceridae	long-horned caddisfly larvae		X	X	X
Leptophlebiidae	prong-gilled mayfly larvae		X	X	X
Limoniinae	long-palped crane fly	X			
Nannochoristidae	scorpionfly larvae	X			
Naucoridae	saucer bug	X	X	X	X
Nemouridae	stonefly larvae	X			
Notoligotomidae	webspinner larvae	X			
Notonectidae	backswimmer				
Odontoceridae	caddisfly larvae	X			
Oligochaeta	segmented worm	X	X	X	
Orthocladiinae	non-biting midge larvae		X	X	X
Perlidae	stonefly larvae	X			
Philopotamidae	finger-net caddisfly larvae	X	X	X	X
Physidae	bladder snail		X		
Pleidae	pygmy backswimmer	X			
Psychodidae	drain fly larvae			X	
Ptilodactylidae	beetle		X	X	X
Ryachophilidae	caddisfly larvae	X			
Sciaridae	fly larvae	X			
Scirtidae	marsh beetle		X	X	X
Simuliidae	black fly larvae	X	X	X	X
Acarine sp.	mite		X	X	
Staphylinidae	rove beetle		X	X	
Stratiomyidae	soldier fly larvae			X	
Tabanidae	horse fly larvae	X	X	X	
Tanyderidae	crane fly larvae			X	
Tanypodinae	non-biting midge larvae		X	X	X
Thaumaleidae	solitary midge larvae				
Therevidae	stiletto fly larvae	X			
Thiaridae	thiarid snail				
Veliidae	riffle bug		X	X	X
Zygoptera	damselfly larvae			X	
Species Richness		**41**	**37**	**39**	**27**

4. Field Survey Results

4.1. Aquatic and Riparian Habitats of the Project Area

A compilation of habitat photographs is presented in Attachment 1. The in-stream bed habitats of most reaches sampled in this study are dominated by the rock category of boulder-cobble-pebble sediments (Figure 4-1). The clearwater tributaries of Klin Wara and Maralumi River and the Markham River had low contributions of other bed structural forms, with significant pool habitat recorded at Maralumi River.

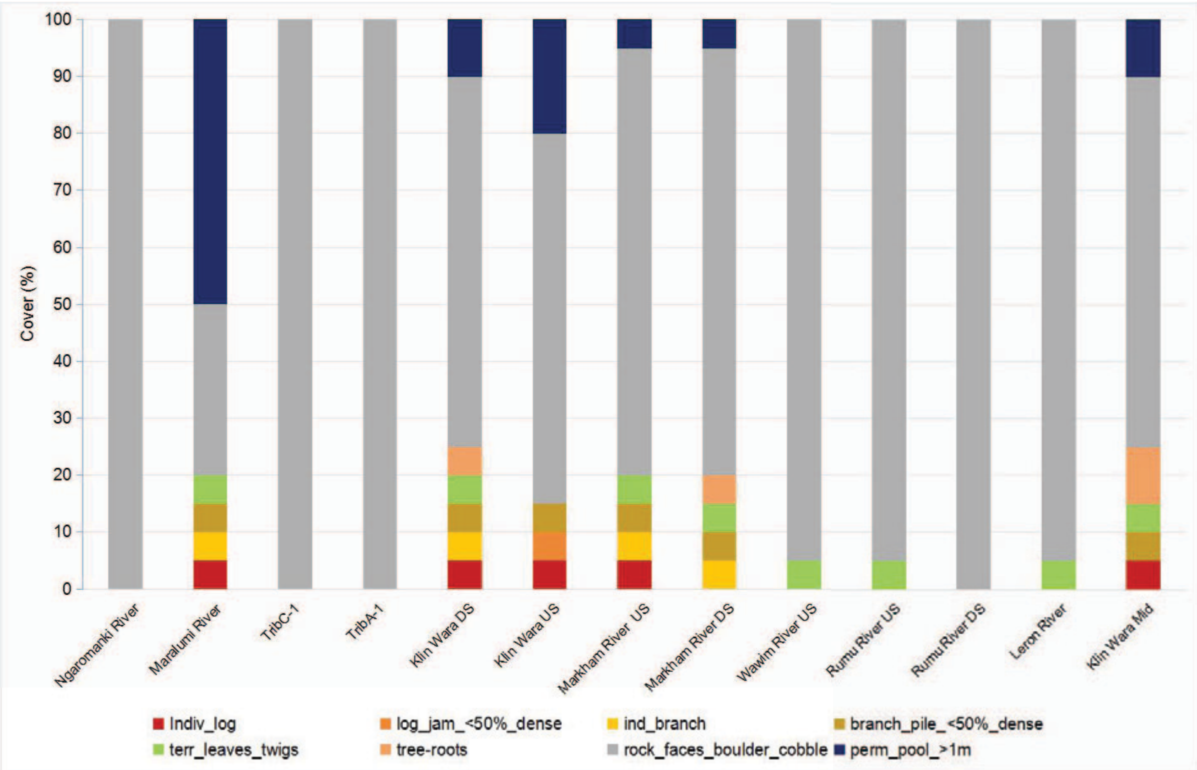


Figure 4-1 Percentage cover of structural types occupying the bed of watercourses.

Aquatic habitat types were similarly low in diversity at most sites (Figure 4-2). Riffle, run and glide habitats that typically have depths of <0.5 m, were most prevalent, with minor contributions of deeper pool and backwater habitat.

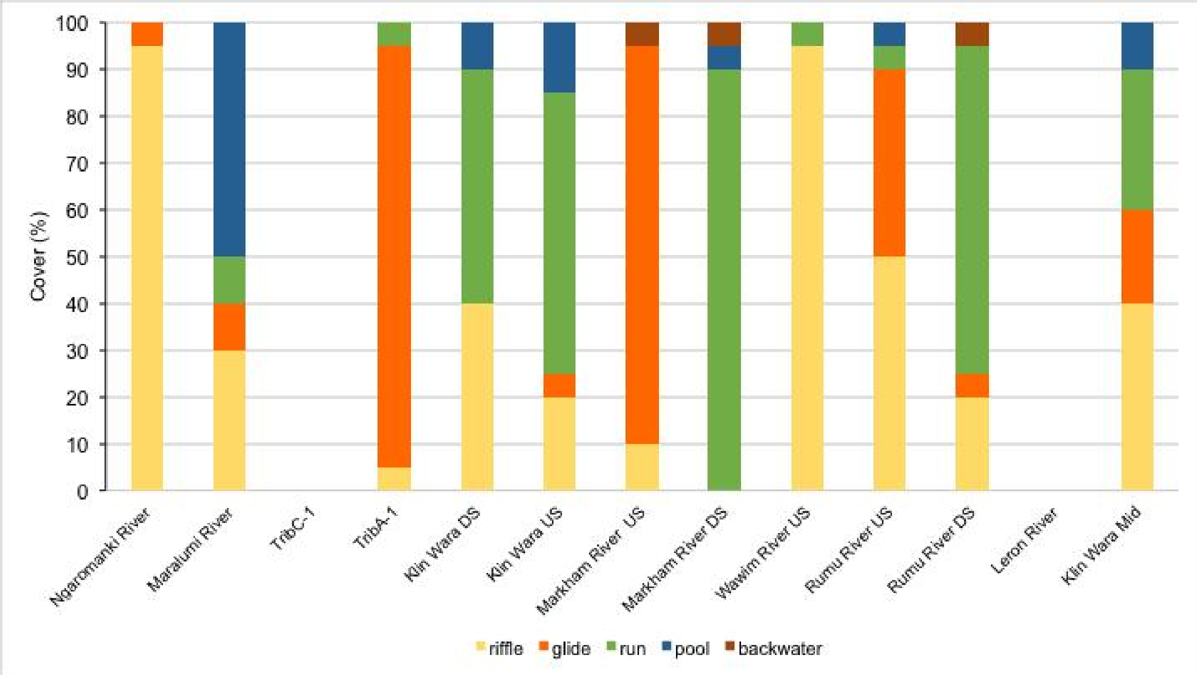


Figure 4-2 Percentage cover of aquatic habitats. Sites with no data had no flowing water at the time of sampling.

Figure 4-3 and Figure 4-4 shows the cover and width of riparian vegetation classes overhanging the stream channel on the left and right banks. This is an indicator of shading, terrestrial organic input (e.g. falling leaves and fruits), bank habitat complexity and stability. Only the Markham River DS site and Klin Wara Mid (TribG-1 water quality site) had significant tree canopy cover overhanging the channel. Most sites had a riparian zone dominated by vegetation that did not create any canopy cover over the channel. Small overhanging banks, formed by streamflow undercutting the bank sediments, were present at Ngaromanki River, TribC-1 and at the Markham River US site and likely represent microhabitat and high-flow refugia for prawns and other aquatic species.

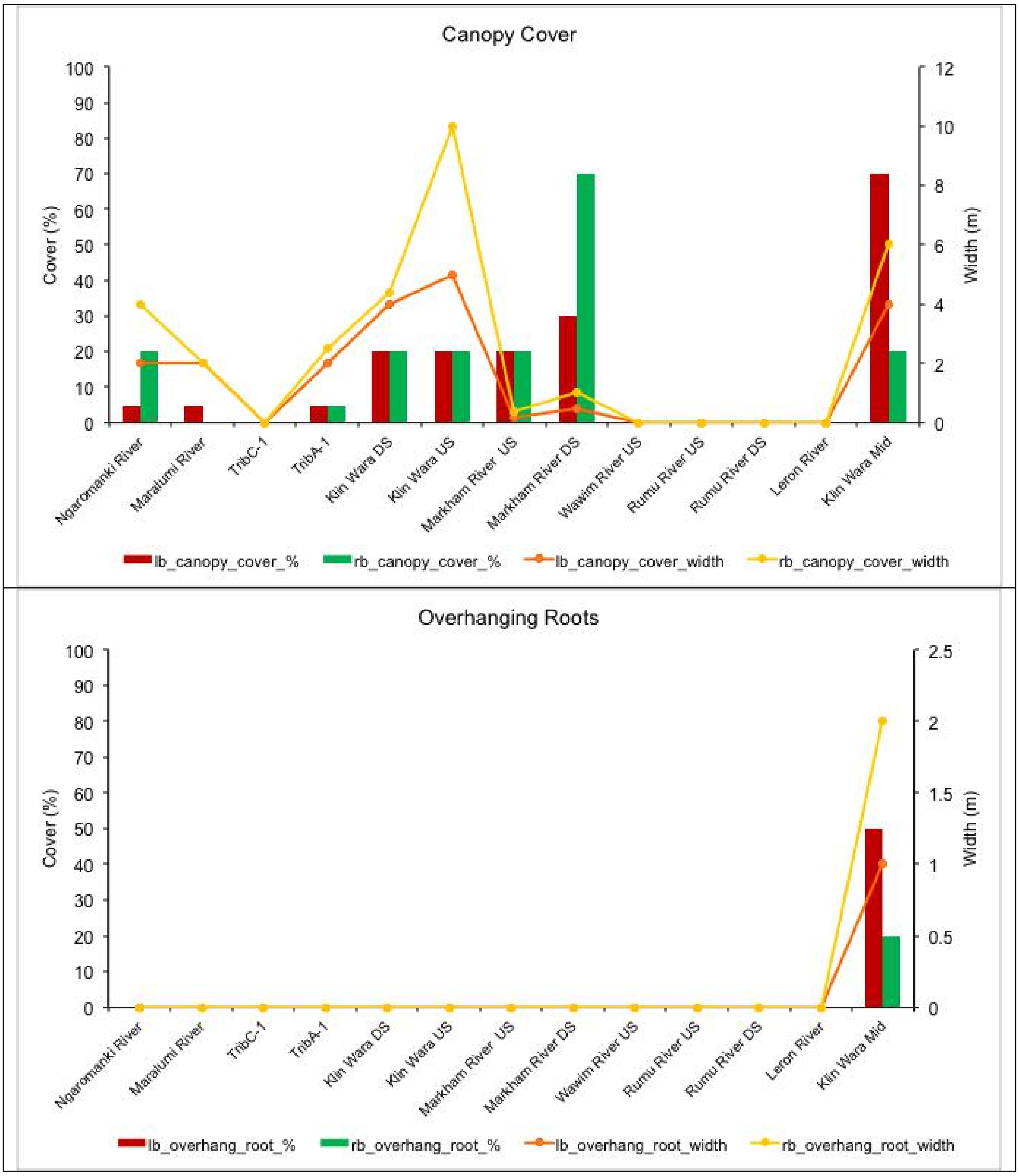


Figure 4-3 Percentage cover (left axis) and width (right axis) of riparian tree canopy and roots overhanging the watercourse channel. lb = left bank looking downstream (red), rb = right bank looking downstream (green).

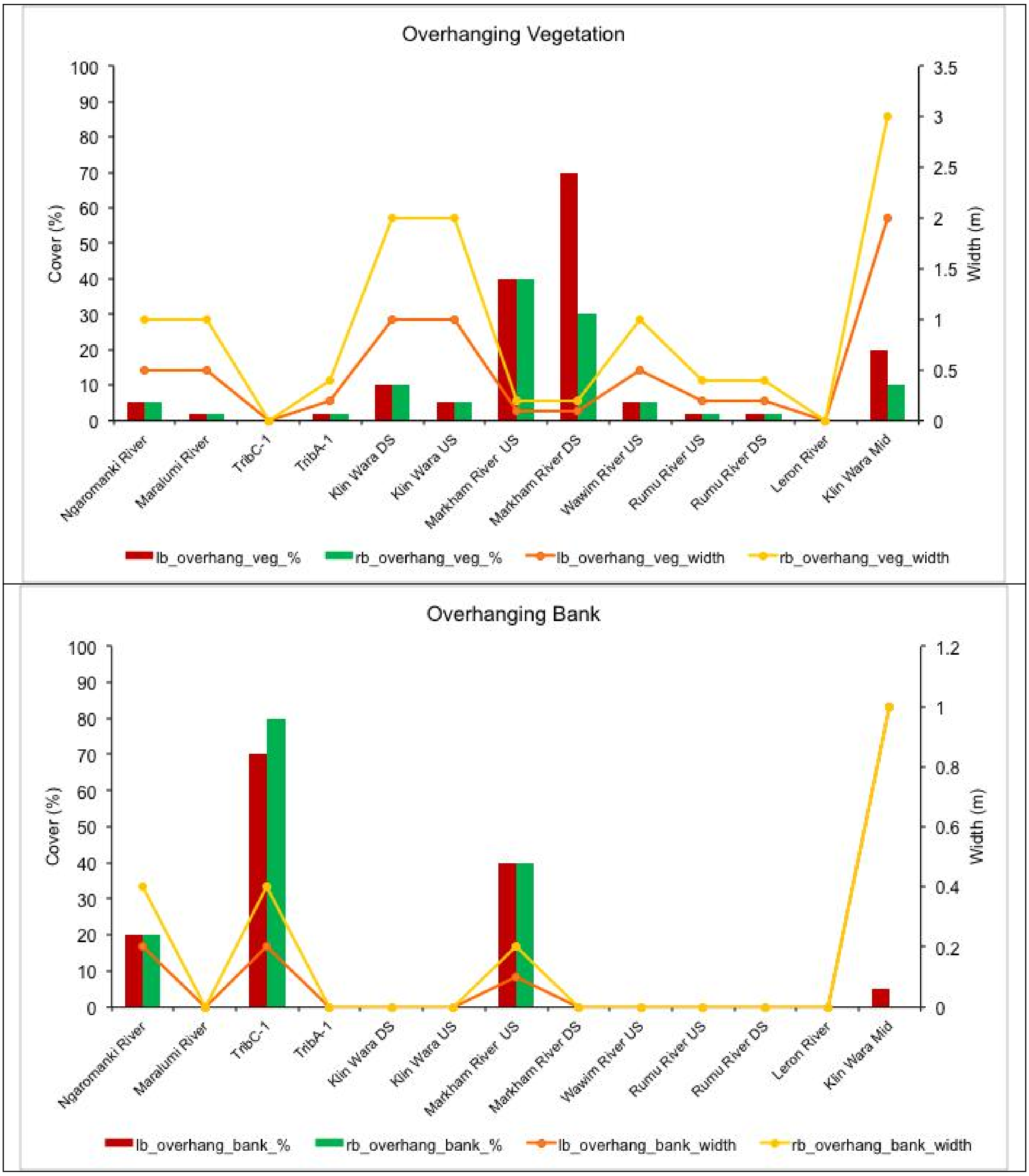


Figure 4-4 Percentage cover (left axis) and width (right axis) of riparian vegetation and bank overhanging the watercourse channel. lb = left bank looking downstream (red), rb = right bank looking downstream (green).

Riparian vegetation was dominated by grasses at most sites (Figure 4-5). Woody shrubs were common in the riparian zone in low abundance at most sites. For reaches of the Leron River, Ngaromanki River, Trib C-1, TribA-1 and the Rumu River, that traverse wide, shallow, braided channels, these riparian vegetation classes are likely to be flooded or uprooted during high flow events. Only the sites on Klin Wara and the Markham River DS had significant cover of large and mid-sized trees.

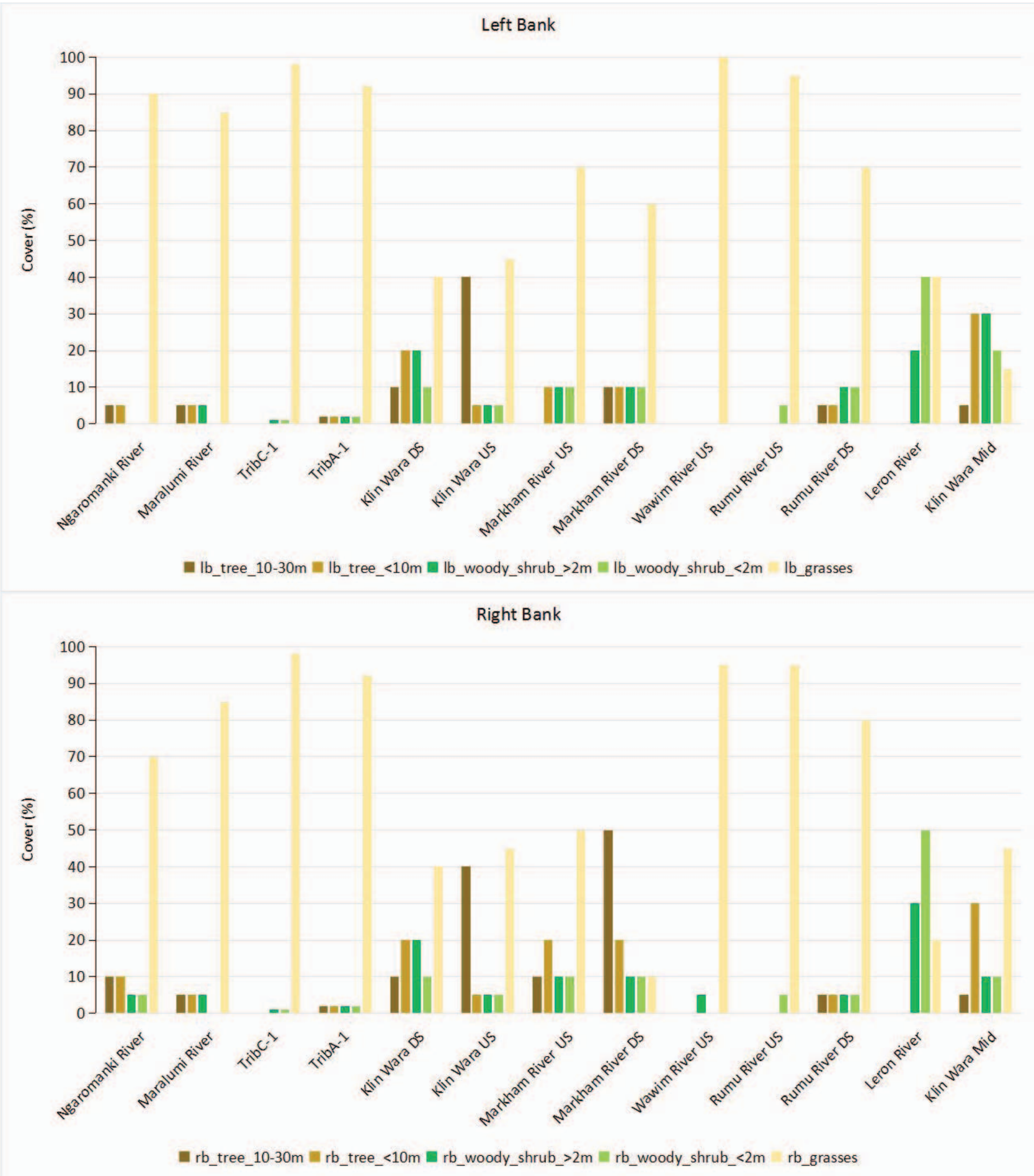


Figure 4-5 Percentage cover of vegetation structural classes in the left bank (lb, top) and right bank (rb, bottom) riparian zones.

In-situ physicochemical properties of sampled watercourses indicate high turbidity conditions in the Markham and Rumu rivers (Table 4- 1). Ngaromanki River had intermediate turbidity while low turbidity was recorded in Maralumi River and Klin Wara. High total dissolved solids (TDS) concentration was recorded at Maralumi River and this coincided with high conductivity, a related parameter (Table 4- 1). This indicates a high concentration of organic or inorganic compounds that probably include salts and minerals that are conductive. This could indicate unique conditions or water sources in the Maralumi River. Dissolved oxygen concentrations were relatively low in the Maralumi River (see Table 4- 1). Some 100-200 m upstream of the sampling site, the Maralumi River mainstream was dominated by relatively deep, slow flowing pools that may have contributed to low dissolved oxygen conditions.

Table 4- 1. In-situ physicochemical data.

Site name	Site code	ORP	Temp		DO		DO		EC		pH	TDS		Turb	
Ngaromanki River	TribB-1	121.9	33	deg C	110	%	7.69	mg/L	517	µS/cm	9.8	337	mg/L	242	NTU
Maralumi River	TribC-2	170.4	27.1	deg C	39.7	%	3.05	mg/L	982	µS/cm	8.59	637	mg/L	11.3	NTU
Klin Wara DS	TribF-2	116.9	30.3	deg C	117.8	%	8.72	mg/L	515	µS/cm	11.47	335	mg/L	0	NTU
Klin Wara US	TribF-1	165.3	27.5	deg C	106.5	%	8.28	mg/L	543	µS/cm	8.28	352	mg/L	0	NTU
Markham River US	Mark-2	162.5	28.5	deg C	110.5	%	8.46	mg/L	471	µS/cm	9.07	306	mg/L	393	NTU
Markham River DS	Mark-1	126.6	28	deg C	108.5	%	*1.37*	mg/L	296	µS/cm	9.1	192	mg/L	1494	NTU
Wawim River US	TribE-2	127.4	35.4	deg C	112.4	%	7.58	mg/L	494	µS/cm	9.03	312	mg/L	13	NTU
Rumu River US	Rumu-1	*-371.2*	30.1	deg C	109.8	%	8.07	mg/L	329	µS/cm	9.6	211	mg/L	1002	NTU
Rumu River DS	Rumu-2	175.5	32.95	deg C	110.1	%	7.75	mg/L	362	µS/cm	9.13	235	mg/L	640	NTU
Klin Wara Mid	TribG-1-WQ	50.6	28.9	deg C	117	%	8.87	mg/L	519	µS/cm	11.8	331	mg/L	0	NTU

Footnote: Dissolved oxygen (DO) value in italics at site Markham River DS (1.37 mg/L) is likely to be a spurious value as percentage concentration is high. Oxidation-reduction potential value in italics at Rumu River US (-371.2) may be spurious. Measurement of ORP can be affected by temperature among other factors. However, at this site significant in-stream aggregate extraction works were observed that may have released reducing agents into the water column.

Landscape-scale regimes of sediment and water flow are two key environmental controls of aquatic habitats in the project areas. These environmental controls act to establish broad habitat types that can be described as follows:

Type 1: Boulder-cobble-pebble dominated bed structure and moderate to high sediment loads with high gradient headwaters and ephemeral or episodic flows that dictate relatively low aquatic fauna diversity. Riparian vegetation dominated by grasses. This class describes the aquatic habitats in much of the northern sector of the project area bordering the foothills and the Leron River. These watercourses support aquatic fauna only when flowing and diversity of aquatic fauna is limited by sediment tolerances and habitat connectivity that enables movement of fishes and prawns into the area from perennial downstream reaches.

Type 2: Perennial high flow energy, high sediment supply rivers with boulder-cobble-pebble bed structures and low diversity aquatic habitats. This class describes the Erap and Rumu rivers. Riparian vegetation dominated by grasses and low shrubs but some larger trees and canopy cover. These watercourses support aquatic fauna at all times and diversity of aquatic fauna is limited by tolerances to sediment conditions and habitat availability (e.g. refugia from high flow).

Type 3: Clearwater streams (Klin Wara and Maralumi River) that appear to have origins in lowland areas that receive waters from high-energy streams draining the foothills of the Finisterre and Saruwaged ranges (Figure 4-6 and Figure 4-7). These flat receiving areas may buffer potentially high sediment loads and contribute outflows in surface water, soil water and/or groundwater. The buffering of flow energy and settlement of sediment loads in these receiving areas may contribute to clearwater conditions in Klin Wara and Maralumi River. Streams characterised by riparian vegetation with a relatively high diversity of structural forms including large trees. These streams support a relatively high diversity of aquatic species and at downstream reaches, are likely to provide important refugia for populations of mobile species in the Markham River during times of high sediment conditions that exceed tolerances.

Type 4: The Markham River. High sediment supply and flow with moderate aquatic habitat diversity. Moderate diversity of riparian vegetation with some intact forest. Supports a higher diversity of aquatic fauna and supports migratory species.

Sites classified by these four habitat categories are listed in Table 4-2. While these four habitat types appear to be morphologically distinct, macroinvertebrate assemblage data (see Section 4.3) indicated that there was no differentiation between habitats 2 and 4 above.

Table 4- 2 Sites classified into habitat types (see text for description)

Site code	Site name	Habitat Type
Mark-1	Markham River DS	4
Mark-2	Markham River US	4
Rumu-1	Rumu River US	2
Rumu-2	Rumu River DS	2
TribB-1#	Ngaromanki River	1
TribA-1		1
TribC-1*		1
TribC-2	Maralumi River DS	3
TribE-2	Wawim River US	1
TribF-1	Klin Wara US	3
TribF-2	Klin Wara DS	3
TribG-1-WQ	Klin Wara Mid	3
Leron-4*	Leron River	1

Footnote: * watercourse completely dry at the time of sampling. # watercourse had running water at the sampling location, but villagers reported that the flow terminated a short distance downstream of the sampling site.

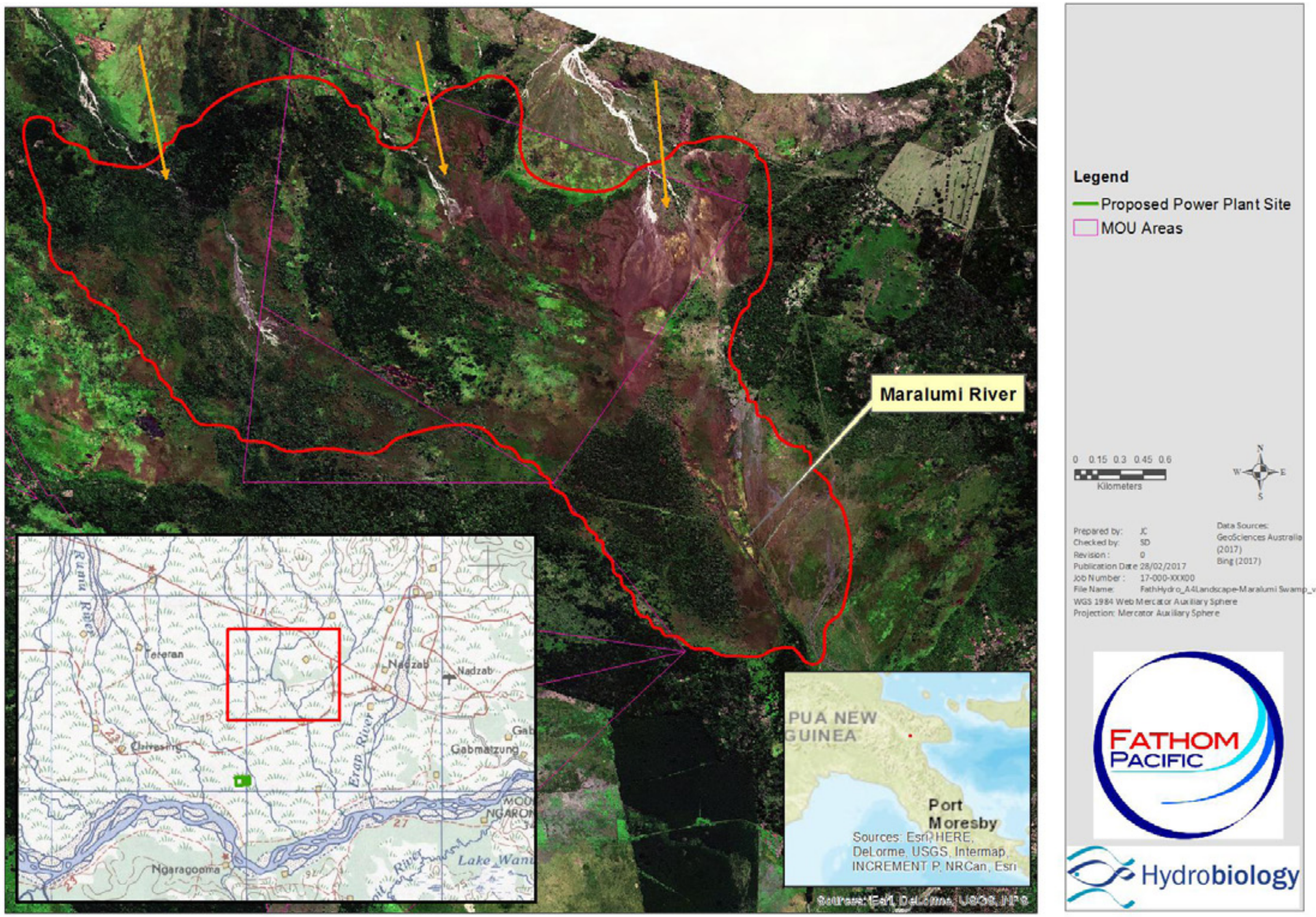


Figure 4-6 Aerial image and digital elevation model showing the headwater region of the Maralumi River (red polygon) that apparently originates in an area that receives inflows from a number of high energy, high sediment load streams (orange arrows) draining the foothills of the Finisterre Range.

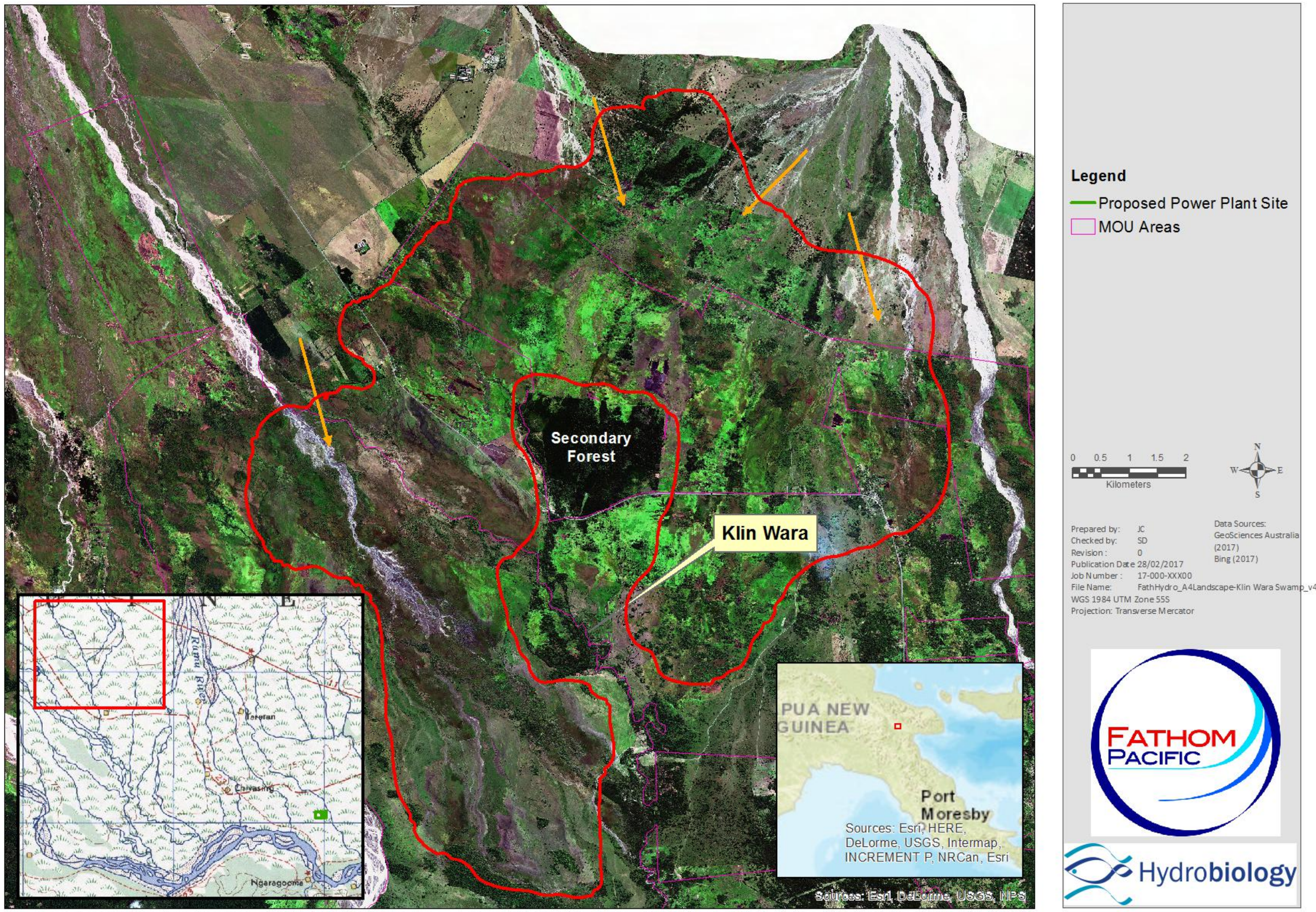


Figure 4-7 Aerial image showing the headwater region of Klin Wara (red polygon) that apparently originates in an area that receives inflows from a number of high energy, high sediment load streams (orange arrows) draining the foothills of the Finisterre Range.

4.2. Fish and Macrocrustacean Communities of the Project Area

4.2.1. Species Richness

Nine native and seven introduced or translocated fish species and one native macrocrustacean species were recorded from electrofishing, opportunistic gill-net sampling, macroinvertebrate sampling and observations of villager catches (Table 4-3). Those species sampled by electrofishing, and therefore represented in analysis of the standardised catches in Section 3.3.2, are identified in Table 4-3. Raw data are presented in Attachment 2 and a photographic record of recorded species is presented in Attachment 3.

Fish species recorded from the project area are characteristic of lowland rivers and tributaries in northern PNG. Fish species richness (16 species total) in the project area is within the range of that recorded from previous surveys in the Lower Watut and Markham rivers (11–21 species). More extensive surveys in the PBMV project area and sampling in other flow conditions may record additional species. However, the generally reduced diversity of in-stream and off-river habitats and the turbid and semi-ephemeral nature of streams in the PBMV project area are expected to limit fish species diversity compared to the larger and more diverse Watut River system.

Notable distinctions in fish species richness compared to that reported from the Lower Watut River and other areas of the Markham River catchment are as follows:

- Reduced diversity of mullet species (family Mullidae) and other large-bodied marine/estuarine migratory species (e.g *Johnius amblycephalus, Nibea* sp. and *Mesopristis cancellatus* in the PBMV project area.
- Reduced diversity of rainbowfishes (family Melanotaenidae) in the PBMV project area.
- Reduced diversity of goby species (family Gobiidae) in the PBMV project area.
- Absence of *Mogurnda* species (family Eleotridae) in the PBMV project area.
- Absence of fork-tailed catfishes (family Ariidae) and native eel-tailed catfishes (family Plotosidae) in the PBMV project area.

Table 4- 3 Fish and macrocrustacean species sampled and observed in the PBMV project area.

Species name	Common name	Sampled by electrofishing	Sampled by gill net	Sampled by kick net	Observed villager catch
Native Fishes					
Anguilla bicolor pacifica	Short-finned eel	✓			
Awaous melanocephalus	Largesnout goby	✓			
Chilatherina bulolo	Bulolo rainbowfish	✓			
Chilatheria crassispinosa	Silver rainbowfish	✓			
Glossamia gjellerupi	Mouth almighty	✓	✓		
Hephaestus transmontanus	Sepik grunter	✓			
Kuhlia marginata	Spotted flagtail				✓ D
Melanotaenia affinis	North New Guinea rainbowfish	✓			✓ D
Valamugil buchanani	Bluetail mullet	✓	✓		
Introduced/Translocated Fishes					
Clarius batrachus	Walking catfish	✓			✓ D
Cyprinus carpio	Common carp				✓ D
Gambusia affinis	Mosquitofish	✓			
Oreochromis mossambica	Tilapia	✓	✓		✓
Tor putitora	Golden mahseer	✓	✓		✓ D
Xiphophorus helleri	Swordtail	✓			
Macrocrustacea					
Caridina sp. 1	Atyid prawn			✓	
Macrobrachium australe	Freshwater prawn	✓		✓	
Palaemon sp. 1	Freshwater prawn			✓	
Palaemonidae sp. 1	Freshwater prawn			✓	
Palaemonidae sp. 2	Freshwater prawn			✓	

Footnotes: N = villager catch observed from gill net catch, D = villager catch observed from *Derris* root poisoning (known locally as “poison rope”).

Additional sampling effort may lead to additional species being recorded from the PBMV project area. The differences between these results and those from other studies in the region may be seasonal (note that the presence of some species in the Lower Watut listed in Table 3- 1 is variable between sampling events). Species that are highly migratory (e.g. mullets, catfishes and gobies) may occur in the PBMV project area under different seasonal/flow conditions. However, some of these differences are likely to be related to three key environmental drivers in the PBMV project area:

- Reduced diversity of suitable habitat and ephemeral status of some streams;
- Water quality (specifically, suspended sediment and sedimentation regimes) in some streams (particularly relevant for species that are clearwater species such as *Mogurnda* species and benthic species such as gobies); and
- The potential adverse effects of increasing dominance of exotic species.

Analysis of standardised electrofishing catches showed that species richness was highest in clearwater tributaries (Klin Wara and Maralumi River) (Figure 4-8). These rivers were also the watercourses with the most diversity in aquatic habitats. It should be noted that electrofishing results from the Markham River are not considered representative of the full species diversity of that river.

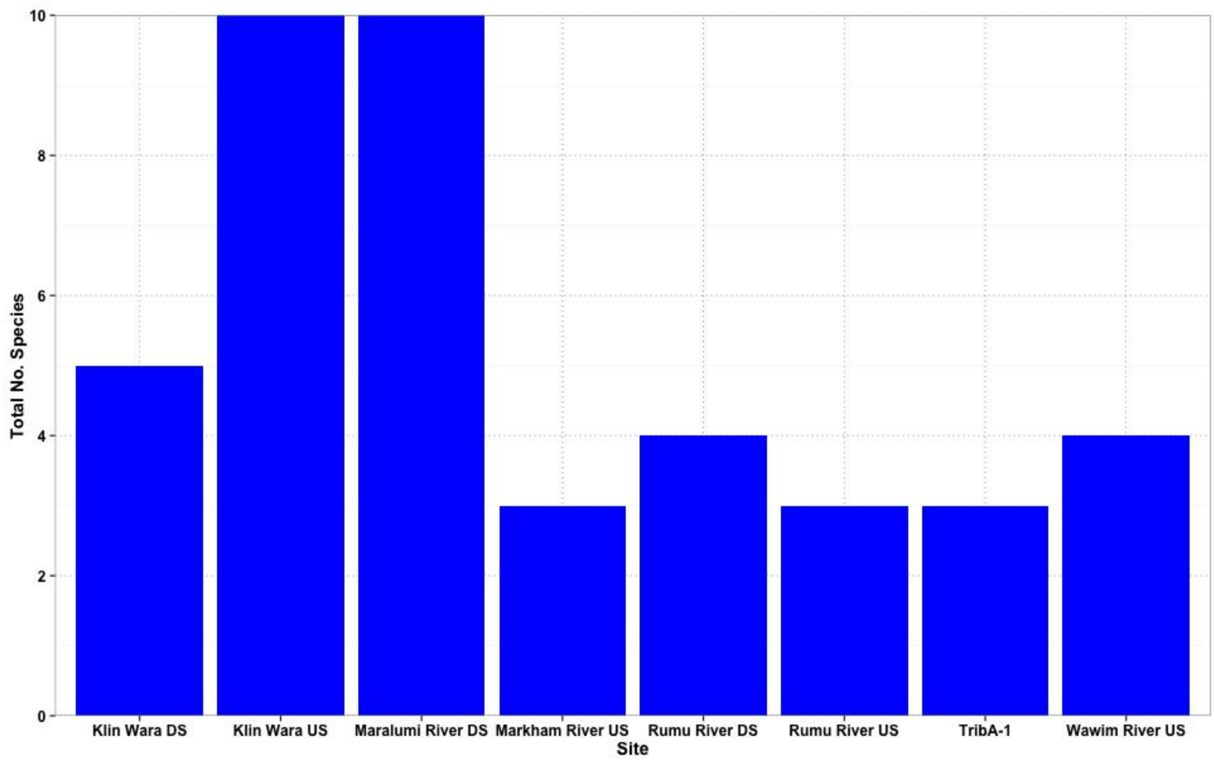
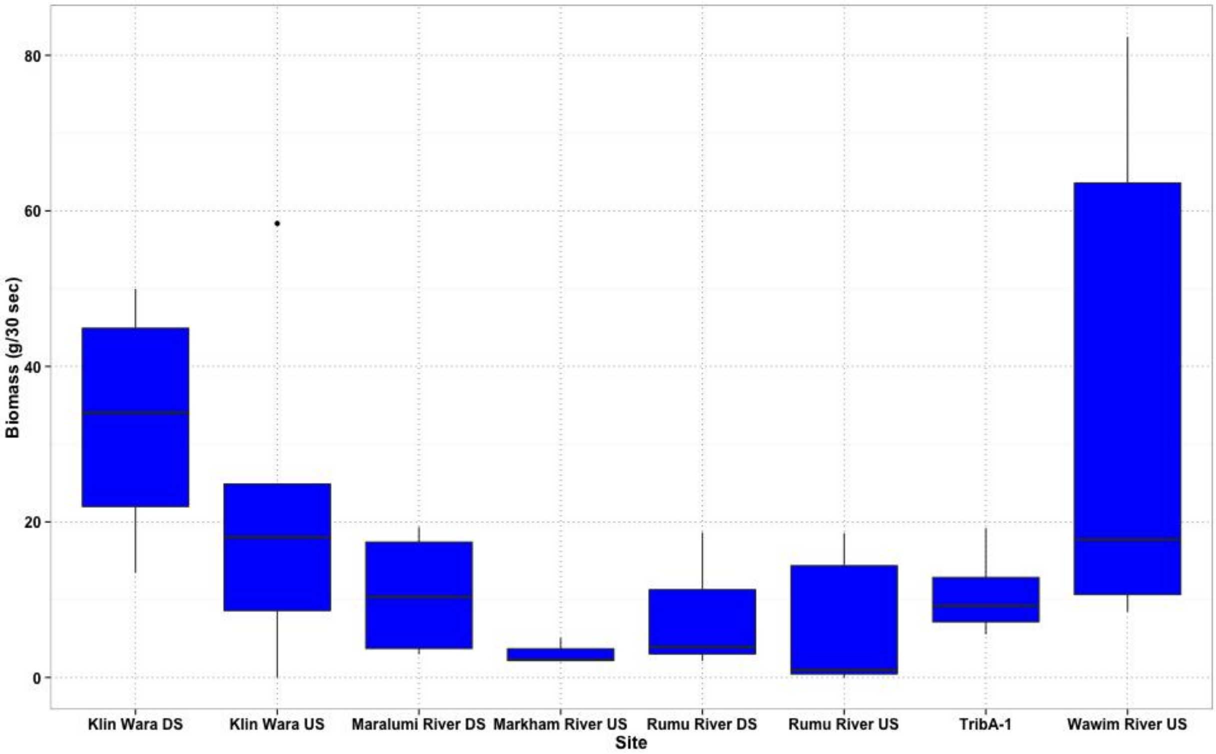


Figure 4-8 Fish and macrocrustacean species richness from electrofishing catches.

4.2.2. Biomass

Fish and macrocrustacean electrofished standardised biomass was highest in the clearwater tributary sites of Klin Wara and Maralumi River (Figure 4-9). Biomass at Wawim River was influenced strongly by a single specimen of eel (*Anguilla bicolor*). Electrofishing efficiency was not optimal in the Markham River and results for this site are not considered representative of fish and macrocrustacean biomass in this river.



Note: Boxes show inter-quartile ranges (IQR, 25% to 75%), median values denoted by horizontal line inside boxes, whiskers represent ranges largest or smallest values (+/- 1.5 × IQR), dot represents greater than 1.5 × IQR.

Figure 4-9 Boxplots of mean standardised fish and macrocrustacean biomass from replicate electrofishing catches per site.

Introduced fish species dominated the total electrofished biomass at Klin Wara US, Rumu River US and DS and at Wawim River US (Figure 4-10). Biomass from gill net catches was dominated by introduced species at both sites sampled using this method (Figure 4-11). While not weighed in the field, opportunistic observations made of villager catches from gill netting (Markham River tributary confluence) and poisoning (Maralumi River) (see Table 4- 3) revealed a dominance of introduced species.

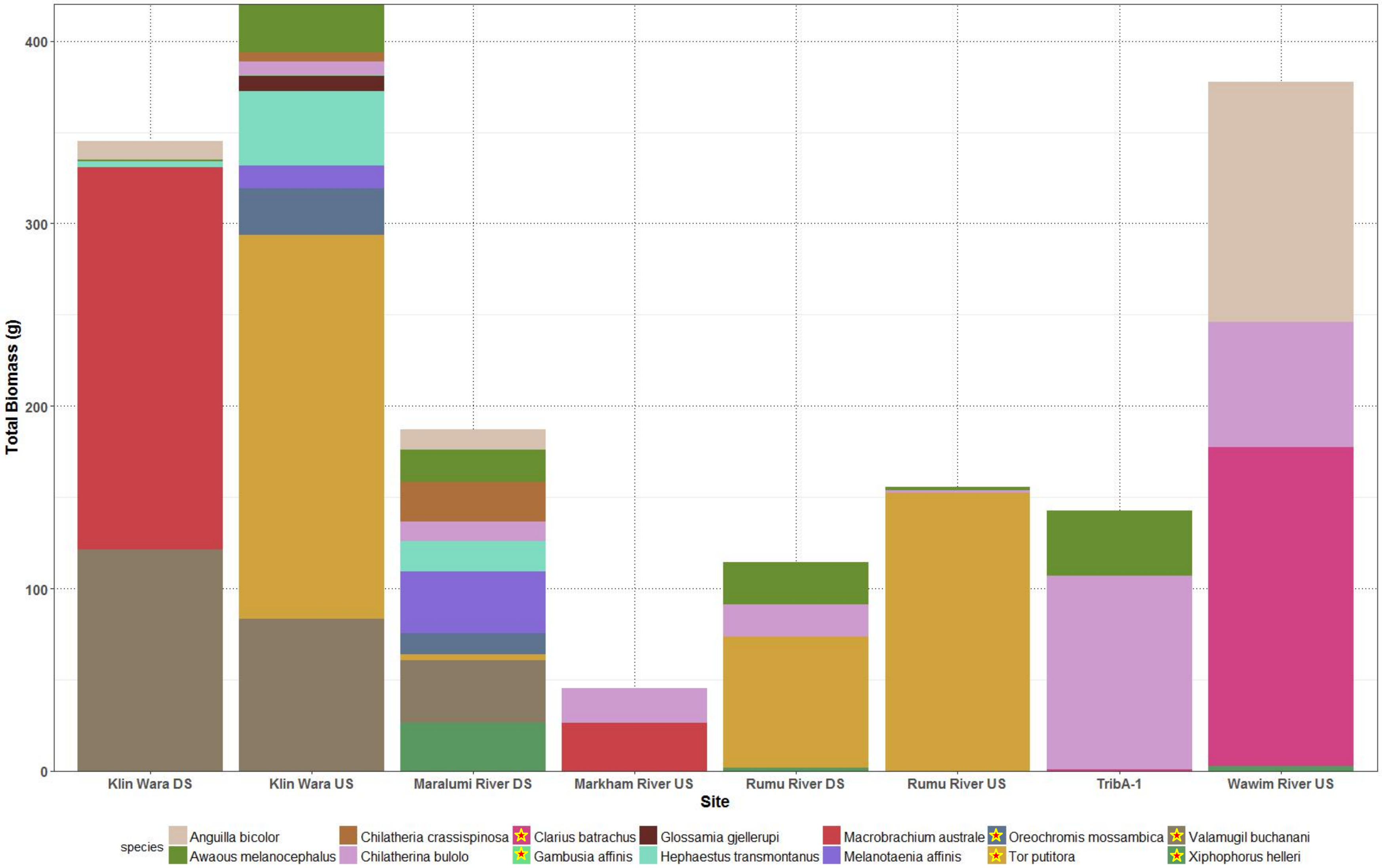


Figure 4-10 Species contribution to total electrofishing catch biomass. Introduced species denoted by star symbol.

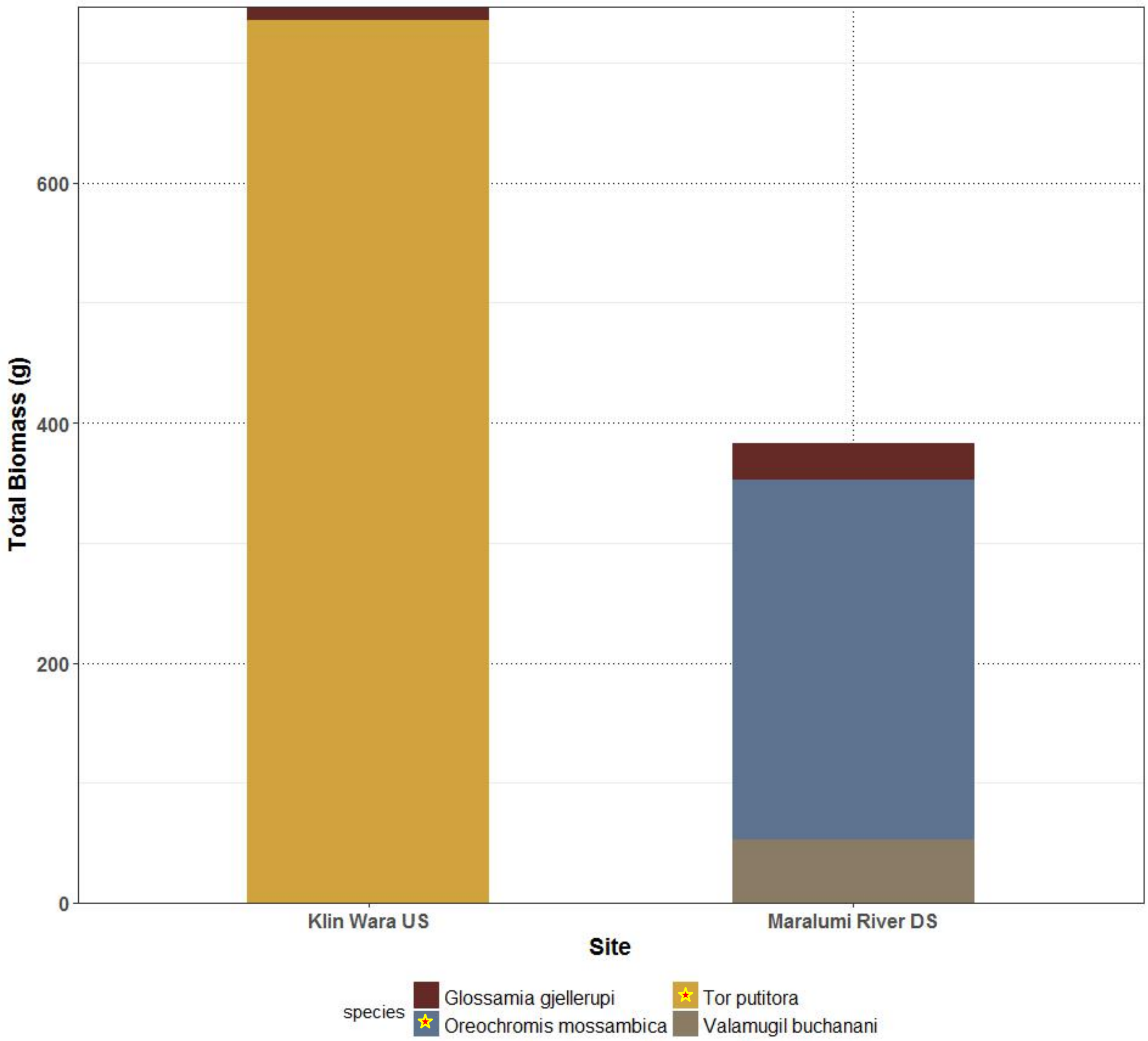


Figure 4-11 Species contribution to total gill net catch biomass. Introduced species denoted by star symbol.

4.3. Macroinvertebrate Communities of the Project Area

4.3.1. Species Richness and Abundance

A total of 59 macroinvertebrate taxa were identified from 11 sites and 3 habitats (Table 4-4). This is higher than total taxa richness recorded in previous surveys in the Lower Watut River catchment (maximum of 48 taxa, BMT WBM 2013). Raw data are presented in Attachment 4[5].

The site Markham River US yielded the highest number of taxa (30), consisting predominantly of two mayfly taxa Caenidae and Baetidae. Klin Wara DS (28) and Ngaromangki River (28) yielded slightly fewer taxa, though Klin Wara DS contained considerably more individuals (3778). Markham River DS yielded the lowest number of taxa (9) and individuals (31), dominated by a single mayfly taxa Baetidae. The site Maralumi River DS yielded the highest number of individuals (7065).

Macroinvertebrate taxa diversity recorded in the project area is within the range of that recorded from previous surveys within the Lower Watut River (BMT WBM 2013). However, taxa richness per site (maximum of 30 taxa) in the PBMV project area is higher than that recorded in the Lower Watut and tributaries (maximum of 320 taxa).

Other historical surveys undertaken within the wider Markham River catchment for the Hidden Valley mine recorded considerably lower macroinvertebrate richness. However, these surveys have only occurred in the Upper Watut catchment which is at a higher altitude and not considered analogous to the watercourses sampled in the PBMV project area. Lower species richness recorded in the Upper Watut catchment has also been attributed to the impacts from Hidden Valley mine (Powell and Powell 2000).

[5] Can be provided in electronic format upon request.

Table 4- 4 Total numbers of macroinvertebrates (individuals) according to site (pooled replicates).

Habitat	**Type 1 & 2**					**Type 3**			**Type 4**	
Taxa	**Ngaromangki River**	**Ramu River DS**	**Ramu River US**	**TribA-1**	**Wawim River US**	**Klin Wara DS**	**Klin Wara US**	**Maralumi River DS**	**Markham River DS**	**Markham River US**
Nematoda										
Nematoda	0	1	0	0	0	1	1	0	0	0
Nemertea										
Nemertea	0	1	0	0	0	0	0	0	0	0
Gastropoda										
Lymnaeidae	0	0	2	0	1	0	0	0	0	0
Planorbidae	0	0	0	0	1	0	12	12	0	0
Thiaridae	0	0	0	0	0	0	1	2	0	0
Clitellata										
Lumbriculidae	0	1	0	0	0	1	0	4	0	0
Oligochaeta	4	1	3	0	0	12	2	724	1	2
Naididae	0	0	0	1	0	12	0	4	2	0
Arachnida										
Orbatida	0	0	1	6	4	0	1	0	0	0
Mesostigmata	1	0	1	1	1	0	0	0	0	0
Hydracarina	0	0	0	1	0	2	1	4	0	2
Trombidiidae	1	0	0	0	0	0	0	0	0	0
Pisauridae	0	0	0	0	0	0	0	0	0	1
Ostracoda										
Ostracoda	2	0	0	0	0	0	0	0	0	0
Entognatha										
Isotomidae	5	1	1	1	1	0	0	0	0	2
Sminthurididae	2	0	0	0	0	0	0	0	0	0

Habitat	Type 1 & 2					Type 3			Type 4	
Taxa	**Ngaromangki River**	**Ramu River DS**	**Ramu River US**	**TribA-1**	**Wawim River US**	**Klin Wara DS**	**Klin Wara US**	**Maralumi River DS**	**Markham River DS**	**Markham River US**
Insecta										
Caenidae	9	39	0	14	124	652	446	3906	8	327
Baetidae	43	68	35	174	1132	795	127	180	13	293
Leptophlebiidae	1	2	0	0	4	15	3	1	1	18
Calopterygidae	0	0	0	0	0	0	0	0	0	1
Libellulidae	0	0	0	3	6	1	4	0	0	0
Epiprocta	16	0	0	8	7	1	2	0	0	0
Hemiptera	60	1	1	4	5	5	0	0	0	3
Naucoridae	0	0	0	7	6	4	52	0	0	1
Mesovelidae	1	0	0	0	0	1	1	0	0	2
Velidae	0	1	0	0	0	0	0	0	0	2
Gerridae	0	0	0	0	0	0	0	1	0	0
Elmidae	1	1	2	0	1	2	14	7	0	4
Psephenidae	0	0	0	0	0	0	0	0	0	3
Hydrophilidae	0	0	0	5	0	0	1	0	0	1
Hydraenidae	0	0	0	6	0	3	0	0	0	0
Chrysomelidae	0	1	0	0	0	0	0	0	0	0
Haplidae	0	0	0	0	0	0	0	0	0	1
Hydrochidae	0	0	0	0	0	1	0	0	0	0
Coleoptera	1	2	1	1	1	0	0	0	0	0
Simulidae	0	0	0	3	11	0	0	0	0	2
Tipulidae	0	1	0	0	0	0	0	0	0	2
Culicidae	1	0	0	0	0	0	0	0	0	0
Stratiomyidae	0	0	0	0	0	0	0	0	0	1

Habitat	**Type 1 & 2**					**Type 3**			**Type 4**	
Taxa	**Ngaromangki River**	**Ramu River DS**	**Ramu River US**	**TribA-1**	**Wawim River US**	**Klin Wara DS**	**Klin Wara US**	**Maralumi River DS**	**Markham River DS**	**Markham River US**
Chironomidae	7	7	4	56	28	334	260	292	0	2
Chironominae	13	11	6	139	57	216	123	1022	2	29
Tanypodinae	0	1	0	2	30	36	61	122	0	10
Orthocladinae	0	2	1	11	1	138	374	612	0	7
Ceratopogoninae	0	1	0	0	0	1	0	0	1	2
Forcipomyiinae	0	0	0	1	0	0	0	0	0	0
Ceratopogonidae	2	0	0	0	0	0	0	0	0	0
Psychodidae	6	0	0	23	0	0	0	0	0	0
Dolichopodidae	1	0	0	1	1	0	1	0	0	0
Ephydridae (cf.)	1	0	0	0	0	0	0	0	0	0
Muscidae	1	0	0	0	0	0	0	0	0	0
Diptera	2	0	0	0	0	0	0	0	0	0
Calamoceratidae	0	0	0	0	1	0	0	0	0	0
Ecnomidae	0	0	0	0	0	2	1	0	0	4
Leptoceridae	1	0	0	0	0	5	6	0	0	7
Hydropsychidae	0	70	19	0	84	1026	1687	168	1	5
Hydroptilidae	0	0	0	0	0	3	1	0	0	31
Glossosomatidae	0	0	0	0	0	0	1	0	0	0
Tricoptera	5	4	4	25	17	365	151	4	2	9
Crambidae	2	0	1	5	6	143	56	0	0	0
Species Richness	**28**	**21**	**15**	**26**	**25**	**28**	**27**	**17**	**9**	**30**
Abundance	**193**	**217**	**82**	**500**	**1531**	**3778**	**3390**	**7065**	**31**	**776**

4.3.2. Habitat Comparisons

Macroinvertebrate taxa richness was approximately 40% higher in the clearwater tributaries of Klin Wara and Maralumi River (Habitat Type 3) (PERMANOVA, p=0.004) (Figure 4-12). PET richness also differed significantly among habitats (p=0.001) with PET richness in clearwater streams significantly higher than that in other watercourses (see Figure 4-12). Mean total abundance of macroinvertebrates showed the same pattern with significantly higher abundance in clearwater streams compared to the other watercourses (PERMANOVA, p=0.001) (see Figure 4-12).

There were no significant differences in Shannon-Wiener diversity among habitats (PERMANOVA, p=0.118). This diversity index takes into account both species richness and abundance. High abundances can reduce overall calculated diversity and in this case the high abundance in clearwater habitats is down-weighting the diversity index. There were no significant differences in weighted SIGNAL 2 scores among habitats (PERMANOVA, p=0.076) (see Figure 4-12).

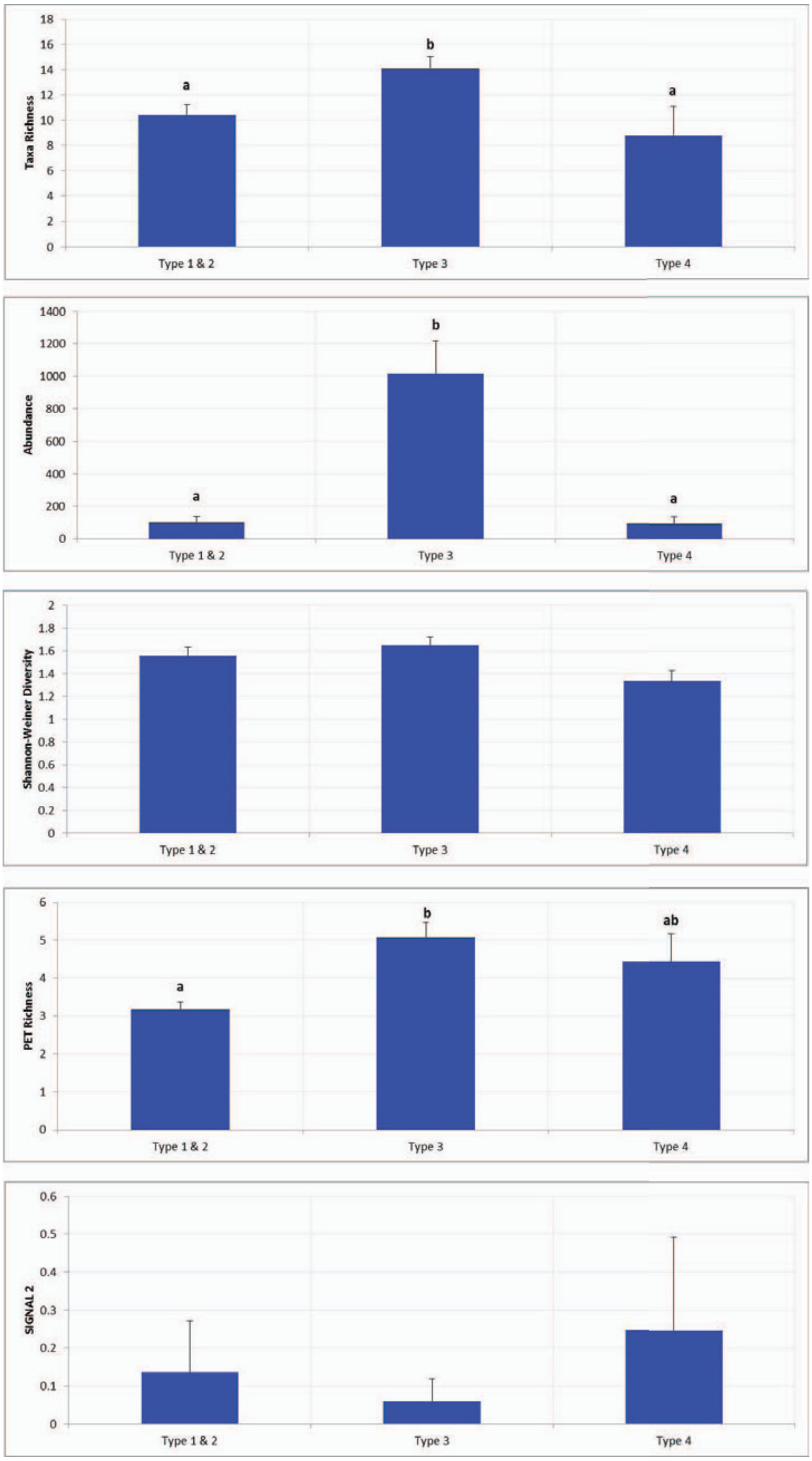


Figure 4-12 Mean (± SE) taxa richness, abundance, Shannon-Weiner diversity, PET richness and SIGNAL 2 values for each habitat type. In each panel, "a" and "b" denotes significantly different means (p<0.05 in pairwise comparisons) and "ab" is significantly different from both "a" and "b".

An nMDS ordination of the macroinvertebrate assemblages indicated that assemblages from clearwater streams (Habitat Type 3) clustered together and were separated from the other habitats (Figure 4- 13). ANOSIM and SIMPER tests confirmed significant dissimilarity between the clearwater streams (Type 3) and the high sediment load watercourses (Types 1 and 2) (dissimilarity of 65%, ANOSIM R = 0.6, p = 0.001) and between the clearwater streams and the Markham River (dissimilarity of 71%, R = 0.8, p = 0.001) (Type 4). .

The Markham River sites (Type 4) and other watercourses that are also characterised by high sediment loads and high energy (Type 1 and 2) clustered in a dispersed group (Figure 4- 13).

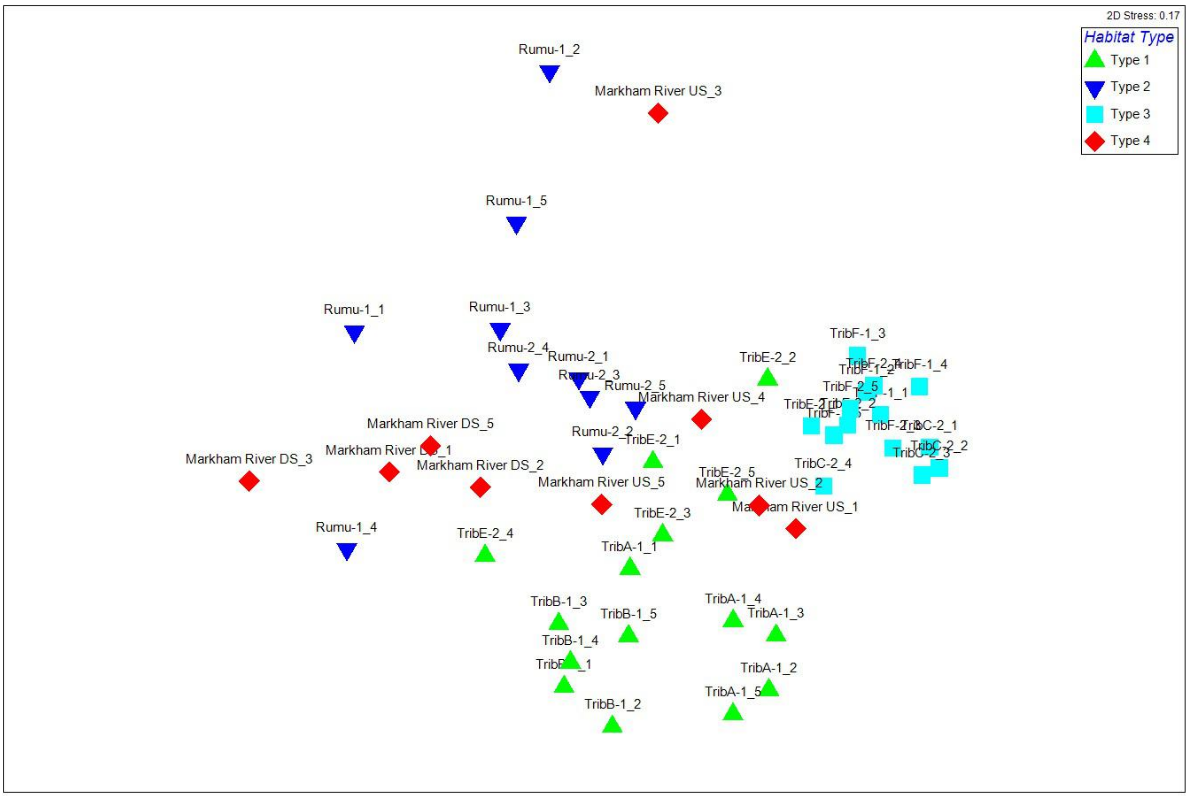


Figure 4- 13 MDS ordination of species abundance in replicate samples, based on the 59 macroinvertebrate taxa identified from four habitat types.

4.3.3. Functional Feeding Groups

Predators, gathering collectors, scrappers and shredders were the most dominant functional feeding group in turbid habitats and these were dominated (>50%) by two taxa: Caenidae (gathering collectors) and Baetidae (scrappers and gathering collectors) (Figure 4- 14). Macrophyte piercers and macrophyte collectors represented a small proportion of overall taxa contribution and these groups consisted of three taxa: Hemiptera, Coleoptera and Haliplidae. These results indicate that in the generally high energy streams with high sediment load, macroinvertebrates that feed directly on the input of large intact macrophyte material are in relatively low abundance and this food source is of lower importance than subsequent phases of vegetative breakdown. Shredders reprocess vegetative material, that in this case is principally allochthonous, into successive smaller size fractions that subsequently makes this material available to gathering collectors and other feeding types. The gathering collector feeding type is one of the most dominant types in all watercourses. The predator group is typically dominated by worms that inhabit unconsolidated sediments and their relatively high abundance in turbid, high sediment load watercourses suggests potentially higher sediment stress in these systems and increased habitat availability.

In the clearwater streams, gathering collectors and scrappers (that feed on biofilms, algae or bacteria on benthic substrates) were also dominant. Pure filtering collectors (represented by the family Hydropsychidae) were more dominant in clearwater streams. Filtering collectors are known to be sensitive to suspended sediment due to the finely structured morphology of feeding apparatus.

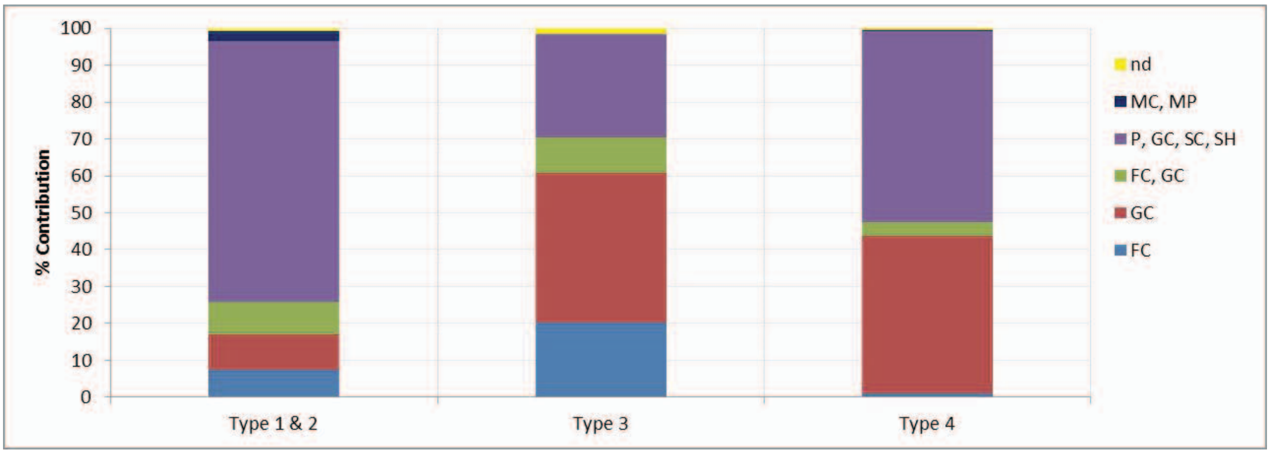


Figure 4- 14 Functional feeding group contribution (%) among habitats. nd= not defined; MC= Macrophyte Collector; MP= Macrophyte Piercer; P= Predator; GC= Gatherer Collector; SC= Scrapper; SH= Shredder; FC= Filter Feeder/Collector.

4.4. Aquatic Flora of the Project Area

No aquatic flora were observed at sites sampled in the project area.

4.5. Aquatic Reptiles of the Project Area

No aquatic reptiles were recorded at sites sampled in the project area and sampling methods did not target these fauna. Anecdotal evidence presented herein suggests that crocodiles (deemed to be most likely the New Guinea crocodile, *Crocodylus noveaeguineae*) occurs in the Markham River and possibly a short distance upstream into the major tributaries.

The New Guinea snapping turtle (*Elseya novaeguineae*) has been recorded from off-river water bodies in the Markham River catchment. The absence of such habitats in the project area dictates that its presence in the PBMV project area is considered highly unlikely (P. Lloyd, Biodiversity Assessment and Management Pty Ltd, pers. comm.).

4.6. Species of Conservation Significance

Three confirmed fish species were recorded in sampling that are listed in the IUCN Red List:

- Golden mahseer, *Tor putitora*. The status of this species is *endangered* in its natural range (Jha and Rayamajhi 2010). However, this categorisation, and all categorisations of the IUCN Redlist only apply to wild populations inside their natural range and so the conservation status is not deemed to apply to populations of this species in PNG[6]. Its natural range extends across the Himalayan region and elsewhere in south Asia and southeast Asia, ranging from Afghanistan, Pakistan, India (Darjeeling to Kashmir), Nepal, Bangladesh, Bhutan, Sri Lanka, Myanmar, western Iran to eastern Thailand. This species was introduced to PNG for the purpose of fisheries enhancement and has become widespread in the Markham-Ramu-Sepik systems. The ecological effects to native species are unquantified in PNG but data available from project-specific sampling programs indicate that the effects are likely to be significant. In its natural range, over-fishing and habitat fragmentation are key threatening processes. It is interesting to note that, on a global scale, the survival of the species may be supported by maintenance of populations in non-native ranges. However, development projects in PNG are not required to make assessments as if this was a native endangered species.
- Bulolo rainbowfish, *Chilatherina bulolo*. The status of this species is *data deficient*[7] (WCMC 1996). The species was originally described from collections made in the Erap River[8] and was once considered to have a potentially restricted distribution. The species has since been recorded from multiple areas in the Ramu-Markham River system and is now known to be widespread, although knowledge of newly appreciated distributions is gained principally from the work cited in this report and not necessarily transmitted to global databases. This species is considered one of the native species in streams of the PBMV project area that is potentially under threat from the impacts of exotic species. The habitat of *C. bulolo* is under threat of alteration from exotic species and the eggs, juveniles and adults of this species are

[6] http://www.iucnredlist.org/static/categories_criteria_3_1

[7] Data deficient means that there is inadequate information to make a direct or indirect assessment of its risk of extinction based on its distribution and/or population status. A taxon in the category may be well studied, and its biology well known, but appropriate data on abundance and/or distribution is lacking.

[8] In the parlance of taxonomic species descriptions, the Erap River is known as the *type locality* for *Chilatherina bulolo*.

under threat of direct predation by exotic species. While the formal conservation status of this species is in need of updating given the new understandings of its distribution, in light of the threats of exotic species impinging on populations in the PBMV project area, the current maintenance of local populations of this species in the project area (particularly in clearwater streams), and the use of this species by local people (see Section 4.6.1), *C. bulolo* is considered a species of informal conservation significance at the scale of the PBMV project area. The threats of exotic species to this and other native species are beyond the control of the PBMV project. However, through best practice environmental management, the project has an opportunity to avoid or mitigate compounding impacts to this species.

- The walking catfish, *Clarias batrachus*. This species is in the *of least concern* category of the IUCN Red List. The native has a wide native range across Asia and appears to have entered PNG from Indonesia either by natural migration or via intentional translocation. The Red List categorisation does not apply to populations in PNG and again, the adverse ecological effects of this species to native populations is unquantified. Its presence in the PBMV project area signifies a rapid colonisation of northern PNG since its first recording in Western Province in 1995 if indeed its expansion across that range has been natural. However, Smith (2007) indicates that intentional introductions for aquaculture purposes may have contributed to this range expansion.

While unconfirmed, two reptile species potentially occur in the PBMV project area:

- The New Guinea snapping turtle (*Elseya novaeguineae*) has been recorded from off-river water bodies in the Markham River catchment (P. Lloyd, Biodiversity Assessment and Management Pty Ltd, pers. comm.). This species is listed in the lower risk/least concern category of the IUCN Red List (ATTWG 2000) and may occur in the PBMV project area.
- The New Guinea crocodile (*Crocodylus novaeguineae*) is listed in the lower risk/least concern category of the IUCN Red List (CSG 1996). This species may occur in the Markham River in the vicinity of the PBMV project area.

There are no freshwater species listed as “protected” in the national Fauna (Protection and Control) Act 1976 (Kula and George 1996). This list is in need of revision but lists only brown trout and rainbow trout (both introduced species). The Fauna (Protection and Control)

Act 1976 grants the Minister powers to declare any fauna as "protected" and to our knowledge no such declarations have been made for any species encountered in the project area. No species recorded from the PBMV area are listed in the Australian Environment Protection and Biodiversity Conservation Act (1999) List of Threatened Fauna.

4.7. Sensitive Areas

Clearwater streams in the project area had a higher diversity of aquatic fauna and are likely to be refugia for species that are intolerant of high sediment loads that may occur in other watercourses. Klin Wara and Maralumi River are considered sensitive areas at the scale of the PBMV project area due the following attributes:

- They are the only reportedly permanent clearwater streams in the project area with relatively high diversity instream and riparian habitats;
- There is limited representation of these watercourse types in the project area and in this mid-reach region of the Markham River more generally;
- They appear to support a range of ecosystem services as described in Section 4.8;
- They are characterised by relatively high biodiversity, and the predominance of taxa that are adapted to clearwater conditions;
- They appear to have a relationship with flat, lowland receiving areas that play a role in flood mitigation.

These watercourses appear to have origins in broad flat areas in the landscape that receive inflows from several streams draining the mountainous region to the north of the project area (see Figure 4-6 and Figure 4-7). At the scale of the project area, these receiving areas are considered sensitive areas. The lowland flat receiving areas are understood to be dry during most times and do not form permanent swamps (ERIAS Group, pers. comm.). However, they may have standing water temporarily during periods of high rainfall at which time wetland conditions may attract aquatic and terrestrial species that use aquatic habitats (e.g. frogs, birds, turtles). As described in Section 4.1, water quality in Maralumi River downstream of the receiving areas was characterised by high total dissolved solids (TDS) concentration and high conductivity, indicating a high concentration of organic or inorganic compounds that probably include salts and minerals that are conductive. Further, ERIAS Group (2017) reported that water samples from Maralumi River were classified as having 'very high hardness' with relatively high concentrations of magnesium, calcium, potassium, sodium and high alkalinity. These conditions may be indicative of soil water or groundwater contributions to surface waters in Maralumi River. Therefore, Maralumi River and Klin Wara are classified as 'inflow dependent ecosystems (IDEs)' according to the following definition by BOM (2012):

> *Inflow dependent ecosystems: describes ecosystems that are likely to be using another source of water in addition to rainfall. IDEs include groundwater dependent ecosystems as well as ecosystems which use sources of water other than rainfall (e.g. surface water, soil water, irrigation).*

The stand of intact secondary forest vegetation at the headwaters of Klin Wara (see Figure 4-7) appears to represent a habitat type that is not represented elsewhere in the project area (P. Lloyd, Biodiversity Assessment and Management Pty Ltd, pers. comm.). This habitat may play a role in the buffering of inflows to Klin Wara and contribute to processes that interact with the lowland receiving areas to maintain clearwater conditions. . Therefore, this vegetation stand is considered a sensitive area at the scale of the project area.

4.8. Ecosystem Services in the Project Area

4.8.1. Provisioning Services

Watercourses that had flowing water were observed to be used by local people at all locations sampled. Uses included water collection, bathing, recreation, clothes washing, aggregate extraction and fishing. Water collected from rivers and streams in the project area may be used in cooking. Fishing was observed at Maralumi River (TribC-2) and Klin Wara (TribF-1). Here, the watercourses were relatively clear, slow-flowing and with a diversity of habitats and included deep pools. At these locations, nets and hook-and-line fishing practices were observed or equipment identified (Figure 4-15). At Maralumi River, and likely elsewhere in the project area, villagers reported the use of fish poisoning by *Derris* root (known locally as "poison rope"). In clearwater streams in PNG, freshwater prawns are usually collected by hand by diving. There was one anecdotal report that this activity takes place in Klin Wara.

At Maralumi River (TribC-2), where there was the most opportunity for observing fishing practices, even small rainbowfishes (sampled to maximum length of approximately 70 mm) were observed being caught and retained for food (Figure 4-16). Maralumi villagers reported the existence of larger fish species (reported to be exotic species such as carp and golden mahseer) in these streams. Prawns were also reported by Maralumi villagers to be collected and eaten. In the Markham River, fishing activities were observed and an encounter with one subsistence fisherman revealed a large catch of a single species, juvenile tilapia (*Oreochromis mossambica*), from one excursion (see Figure 4-16).

The levels of acceptance of exotic fish species in northern PNG among local communities remain largely unquantified, as do opinions of palatability and concerns regarding maintenance of native fish populations. Discussions held with fishers at Klin Wara (site Trib F-1) indicated that palatability of golden mahseer (*Tor putitora*) and "other new species" was considered good, but comment was made that the flesh is "loose and unformed" and that the head lacks the "grease" that local species have and that is considered good eating. Golden mahseer, copper mahseer (*Neolissochilus hexagonolepis*) and possibly juvenile carp (*Cyprinus carpio*) are not necessarily distinguished among local people, particularly for juvenile fishes that look similar. People in the PBMV project area refer to these species as "Michael fish", apparently named after some community knowledge that an individual by the name of Michael "developed" these species for introduction to the area. The term "besta fish" is used by some people. In other areas of PNG, this name is given to a different introduced species, the snow trout (*Schizothorax richardsoni*) probably owing to its superficial similarity to the mackerel pictured on the cans of "Besta" tinned fish common in stores. The snow trout is not expected to occur in the low altitude of the PBMV project area. Another name used by some local people to describe a number of small silvery fishes (e.g. juvenile golden and copper mahseer, juvenile mullet and juvenile tilapia) is "*Didiman fish*". *Didiman* is the name given to agricultural extension officers working in PNG prior to independence. This use of this name indicates some community understanding of the link between agricultural/aquacultural practice and the introduction of fish species under various programs. Local people appear to easily differentiate rainbowfishes from other small silvery fishes such as juvenile golden and copper mahseer.

The watercourses in and around the project area are not pristine. Some are ephemeral and most do not support species of large body size (although introduced species are reported to attain large size in some reaches). However, all aquatic species and aquatic habitats are considered to provide provisioning services to at least some portion of the local communities in and around the project area. Aquatic provisioning services are likely to be secondary to that provided by subsistence gardening and market produce in the project area.

Large aggregate stockpiles were observed in the Rumu River (site Rumu-2) that are presumed to be related to road base aggregate extraction works (Figure 4-17). Road works were underway at the time of the field survey. The large alluvial deposits in the project area and surrounds may provide a valuable source of aggregate for road maintenance that represents a provisioning service.

Figure 4-15 Hook-and-line fishing equipment at Maralumi River (TribC-2). At this location, hook-and-line fishing appeared to be the most prevalent fishing method.

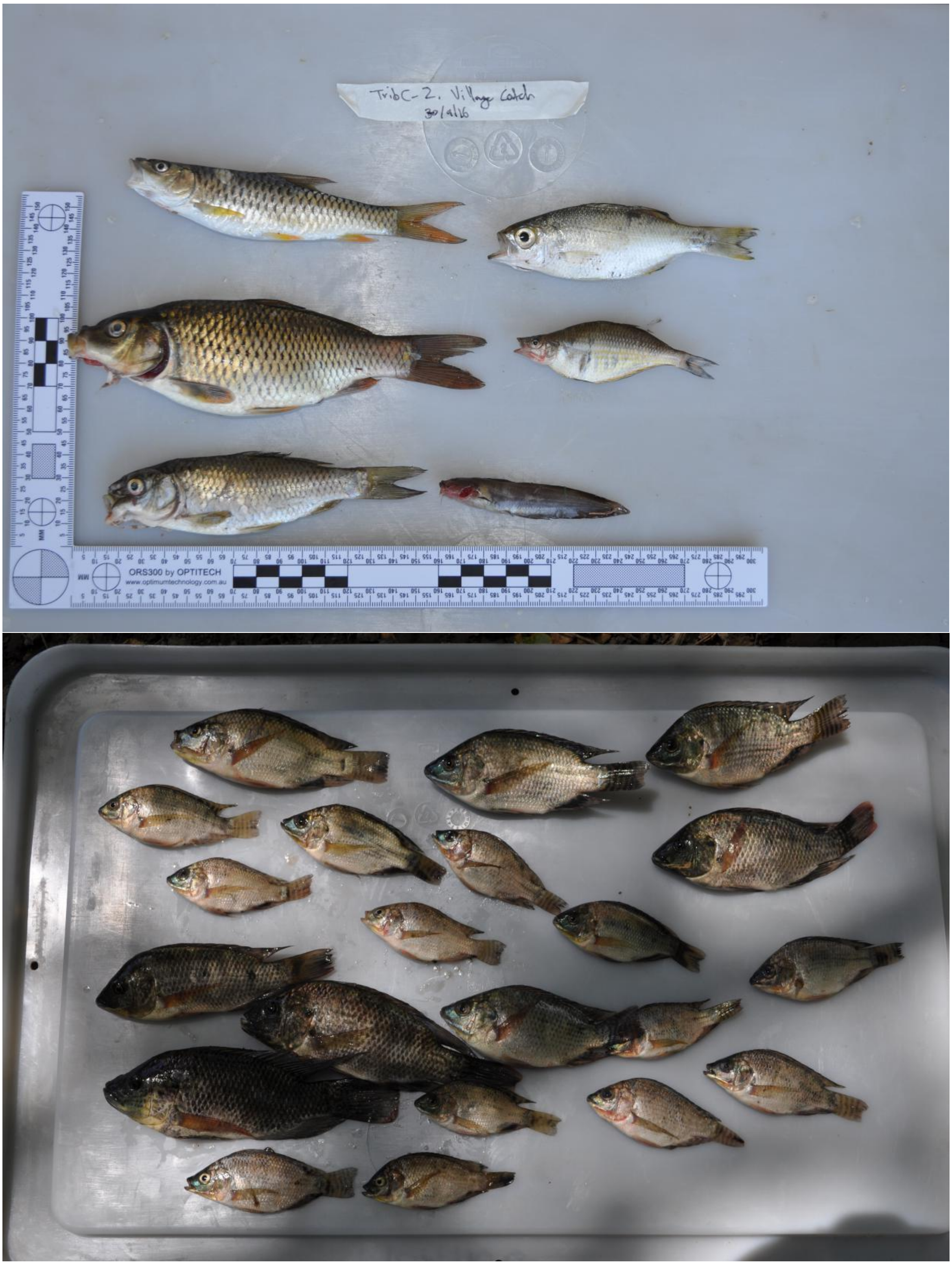


Figure 4-16 Observed villager catches at Maralumi River (Trib C-2) (top) and in the Markham River (Mark-1) (bottom). The catch from Maralumi River consists of (clockwise from top left) *Tor putitora, Kuhlia marginata, Melanotaenia affinis, Clarias battrachus, Cyrpinus carpio* (x 2). The catch from the Markham River consists entirely of *Oreochromis mossambica*. The photograph from the Markham River catch represents a small sub-sample of the monospecific catch observed. The catch was made by net, reportedly at the confluence of a tributary stream.

Figure 4-17 Aggregate stockpiling in the Rumu River (Rumu-2). View from the Highlands Highway looking upstream (top) and downstream (bottom).

4.8.2. Regulating Services

As discussed in Section 3, the geomorphology of catchments and watercourses in this area of the Markham Valley dictates regimes of generally high-energy flow and sediment transport. Lowland flat areas that receive inflows from streams draining the foothills of the Finisterre and Saruwaged ranges to the north of the project area and thus may serve to dissipate energy and trap sediments (see Section 4.1). This process, that may involve surface water, soil water and/or groundwater contributions to flow, is likely to maintain clearwater conditions in Maralumi River and Klin Wara and thus potentially represents a regulating service. This regulating system may also serve to buffer floods and landslips originating in headwaters in the Finisterre Ranges from downstream settlements and agricultural crops and infrastructure.

4.8.3. Cultural Services

Aquatic ecology field surveys did not report the existence of aquatic sites of specific cultural or spiritual significance. However, no formal specific questionnaires or interviews were conducted to identify detailed information on a village-by-village level. During field surveys, it was observed that clearwater streams are recognised as preferred areas for bathing and general recreation and these activities have a cultural connection.

The cultural identity of a subsistence lifestyle in Papua New Guinea is intrinsically linked to natural resources. Therefore, the activity of fishing, while possibly lower in importance than gardening or market produce as a food source, is likely to represent a significant cultural service provided by aquatic environments.

4.8.4. Supporting Services

Watercourses in the project area and surrounds may be used as water supply for existing agricultural practices. Alluvial soils deposited by rivers and streams in the project area and surrounds is likely to contribute to the fertility of the Markham Valley and thus its agricultural productivity.

5. Conclusions on Existing Environment

5.1. Aquatic Habitats

Aquatic habitats in the PBMV project area are influenced strongly by tectonic activity and geomorphologic processes at the scale of the entire Markham River valley and Finisterre/Saruwaged ranges. Shallow, high energy, first and second order streams that carry a high suspended sediment load are the dominant types in the project area and many of these are ephemeral or have ephemeral sections of braided channel. The Markham River is a highly dynamic river that is characterised by high energy, high sediment loads and braided channels and is subject to course alterations that can result from episodic flooding and landslips. This regime of alluvial soil supply to the Markham Valley may be one factor contributing to the fertility of soils in the valley that has supported commercial agriculture for several decades. Aquatic biological communities in these watercourses are limited by the availability and diversity of habitat types and tolerances to flow and sediment regimes. Riffle-run habitats with cobble-gravel-pebble substrates were the dominant aquatic habitat in the PBMV project area. Deep (>1 m) pool habitats were evident only in Maralumi River, Klin Wara and the Markham River. Vegetative debris, typified by log-branch-leaf piles occurred at most sites although the riparian zone is generally dominated by grasses. As will be discussed further below, the supply of allochthonous organic matter to streams in the form of vegetative material and regimes of decompositional and feeding-related breakdown of that material, is important to ecological functioning.

At the time of sampling, Maralumi River and Klin Wara, which had low turbidity, were recorded as having the highest diversity of aquatic habitats, fishes and macrocrustaceans, and macroinvertebrates, Clearwater streams in the project area also appear to be focus areas of aquatic resource utilisation. They are also likely to represent refugia for some species in the Markham River mainstream during episodic flow and sediment events that exceed tolerances. A number of other ephemeral clearwater streams appear to occur in the project area which may be important resources for local people when they are flowing.

There is some indication that Maralumi River and Klin Wara are fed by headwaters that drain flat receiving areas features in the landscape in flat or possibly low lying areas. These areas may act to receive high energy, sediment-laden inflows from first order streams draining the foothills of the Finisterre and Saruwaged ranges and subsequently contribute to surface water, soil water and/or groundwater flows (with buffered energy and lower sediment concentrations) that feed these two streams. If that process does indeed operate, the maintenance of these habitat and flow connections is expected to be important to the maintenance of biodiversity and ecological functioning in these watercourses and at the scale of the project area.

5.2. Biological Communities

Aquatic communities in the project area are typical of, and a subset of, those distributed throughout the Markham River catchment. In northern PNG, faunal affinities existing among the Ramu-Markham river systems, and even more broadly across the Sepik-Ramu-Markham systems. Fish and macrocrustacean species richness in the PNG Biomass Markham Valley project area was lower than that recorded from the lower Watut River. As expected, some species characteristic of higher altitudes in the Watut-Bulolo systems and upland streams draining the Huon Peninsula were not recorded in the PBMV project area. Macroinvertebrate richness was higher in the PBMV project area than that recorded in the lower Watut River. No species endemic to the PBMV project area were recorded or are considered likely to occur based on knowledge of the range of aquatic habitats in the area and biogeography of northern PNG.

Ephemeral flows, sediment loads and relatively low diversity aquatic habitats are likely to be among the main factors limiting aquatic faunal diversity in the PNG Biomass Markham Valley project area, as they are across the entire Markham River valley. Introduced exotic fish species dominate the diversity and biomass of most streams in the project area. Introduced exotic species are expanding their range and increasing in abundance across northern PNG. The impacts of exotic species remain largely undocumented, but data that are available indicate that there are likely to be significant and wide-ranging adverse impacts to native fauna, particularly in lower order streams (Hydrobiology 2005). Large-bodied introduced species in the carp family are known to be piscivorous as adults and thus are likely to place predatory pressure on small-bodied native species, fry and eggs. Other impacts may arise from detritivorous or herbivorous feeding behaviours and benthic habitat modification.

In the PBMV project area, three species of rainbowfishes, one species of goby and several species of freshwater prawn dominate the remaining native fauna. The Bulolo rainbowfish

(*Chilatherina bulolo*) is one such native species that remains in apparently healthy self-sustaining populations in the PBMV project area. The species was originally described from collections made in the Erap River and was once considered to have a potentially restricted distribution. The species is listed in the *Data Deficient* category of the IUCN Redlist. The species has since been recorded from multiple areas in the Ramu-Markham River system and is now known to be widespread. The potential for native species to maintain populations in the PBMV project area in light of existing or increasing abundance of exotic species is unknown. Notwithstanding, measures to manage aquatic systems that attempt to facilitate the maintenance of native fish populations in the project area streams, and monitor changes, are recommended below and reflect good environmental stewardship and requirements of FSC Principal 6[9] more broadly.

5.3. Ecological Processes and Key Sensitivities

Aquatic species inhabiting high energy, high sediment load, shallow watercourses in the PBMV project area are tolerant of, or adapted to, these conditions. For example, benthic species such as gobies, walking catfish and freshwater prawns use benthic microhabitats such as the lee side of cobbles and woody or vegetative matter to avoid excessively high current flow. Gobies have modified pelvic fins that are used to suction onto cobbles on which they graze algae and detritus. In these types of watercourses, other species such as rainbowfishes and introduced species in the carp family seek out channel margin microhabitat that offers some protection of the highest flows in the mid-channel. Riparian vegetation may encroach on this marginal habitat, providing additional refugia and foraging resources.

In clearwater streams of the project area, flows are generally slower and more stable, sediment loads lower and aquatic habitats more diverse. Here, a higher diversity of species can exploit a higher diversity of niches and deep pools can harbour larger-bodied species. The single record of jungle perch, *Kuhlia marginata*, in the present study was made from a villager catch in pool habitat in Maralumi River.

For all the stream and river types in the PBMV project area, allochthonous organic material is likely to dominate the production source. This may include fallen vegetation, soil matter and terrestrial insects washed into streams. Maintenance of native vegetation in riparian zones is therefore central to the maintenance of ecological processes. The macroinvertebrate and

[9] FSC International Standard (version 5-2), Principal 6.5, 6.6, 6.7.

macrocrustacean fauna of streams and rivers in the PBMV project area are indicative of an ecosystem with trophic pathways dominated by the processing of allochthonous organic matter. Freshwater prawns and some components of the macroinvertebrate fauna are shredders, breaking down vegetative material into smaller size fractions that are subsequently available to other functional groups. Other macroinvertebrates (macrophyte piercers and macrophyte collectors) feed directly on living vegetative material. Shredded vegetative material contributes to the pool of decomposing material at detritus that is fed upon by gatherer-collector macroinvertebrates and detritivorous fishes. Macroinvertebrates are fed upon by several fish species while other, larger bodied fish species are piscivorous.

Macroinvertebrates are generally considered to be more sensitive to environment perturbation than fishes and macrocrustaceans. Fine structural body forms (notably gills and feeding apparatus), narrow niche selection and specific feeding styles render macroinvertebrates particularly susceptible to adverse water quality and habitat alteration impacts. Sediment can adversely impact water quality (suspended sediment concentrations), physical habitats (sedimentation and scouring) and cause direct impacts to animals (abrasion, clogging of feeding apparatus). The fine feeding structures of filter-feeders and the delicate growths of periphyton are susceptible to abrasion and smothering and may be negatively impacted in conditions of high sediment input (Aldridge 1987). Smothering or scouring of bed substrates is also known to alter the distribution of macroinvertebrates. Typically, streams subjected to increased sediment loads have lower diversity of macroinvertebrate fauna (Water and Rivers Commission 2000). Maintenance of water quality, particularly with respect to turbidity and sedimentation but also with respect to nutrient loading and toxicants, is therefore central to the maintenance of macroinvertebrate populations and ecological processes.

Dominant macroinvertebrate taxa in the Markham River and other high sediment load watercourses (Baetidae and Caenidae) are considered to be more tolerant of turbid environments due to morphological adaptions such as plate-like gills and the ability to remove particulates from their gills with their limbs. Conversely, filter feeders/collectors (largely Hydropschidae and Chironominae), were either absent or in considerably lower abundance in high sediment load habitats. Hydropschidae obtain oxygen through paired ventral gills which are easily clogged in highly turbid water and the abundance of this taxa was considerably higher in clearwater streams than high sediment load watercourses. In clearwater streams, there was also a higher abundance of filter-feeding species that collect suspended particulate organic matter. In clearwater habitats, 'scraper' feeding guilds feed on biofilms of periphyton, algae and bacteria.

The fish species inhabiting streams in the project area can be broadly characterised as omnivorous predators feeding principally on aquatic and terrestrial invertebrates (e.g., rainbowfishes, adult mahseers and carp), benthic algae scrapers (gobies) and detritivores (e.g. walking catfish, juvenile mahseers and carp). The bright colouration of rainbowfishes suggests the importance of visual cues in the ecology of those species. High turbidity may have a negative impact on species that rely on visual cues for foraging. High turbidity and sedimentation may have negatively impacts on benthic algae, macroinvertebrates and organic content of the detrital matrix, thus potentially impacting fish species utilising those resources. High turbidity and sedimentation may also negativity impact benthic egg-laying/breeding surfaces through abrasion or scouring, thus potentially impacting fish species.

5.4. Ecosystem Services and Key Sensitivities

Aquatic environments in the PBMV project area provide provisioning, regulating, cultural and supporting services.

5.4.1. Provisioning Services

Provisioning services associated with collection of food resources from freshwater environments in the PBMV project area are likely to be secondary to those provided by terrestrial systems (i.e., gardening and market produce). Further, due to the ephemeral natural of some reaches, relatively low diversity of habitats and relatively low abundance of large-bodied species, the provisioning of aquatic food resources is expected to be of lower importance than that in other larger, more diverse aquatic environments such as the Watut River. However, fishing is conducted in the PBMV project area and is apparently most important in the permanent clearwater streams of Maralumi River and Klin Wara and in the Markham River. Any fishes and prawns caught are retained for eating. The provision of freshwater directly from watercourses, apparently for cooking and cleaning was observed at most sites visited. Drinking water is also sourced from watercourses and is supplemented with supplies from wells (White 2016). The provision of aggregate material from alluvial river beds may provide income and employment for people in the project area and supports road maintenance which has several other flow-on benefits to local communities.

5.4.2. Regulating Services

Aquatic systems in the project area may provide a regulating service by dissipating high-energy flows from headwaters draining the foothills of the Finisterre and Saruwaged ranges. Hydrological connectivity between these headwater streams and receiving areas in the landscape apparently maintain clearwater conditions in Maralumi River and Klin Wara via surface water, soil water and/or groundwater flows. This regulating system may also serve to buffer floods and landslips from downstream settlements and agricultural crops and infrastructure.

5.4.3. Cultural Services

The cultural identity of people with subsistence lifestyles in Papua New Guinea is intrinsically linked to natural environments and resources. On a practical level, aquatic environments in the PBMV project area are used for recreation, bathing, clothes washing and potentially other activities that are part of daily life for many people in the area.

5.4.4. Supporting Services

Aquatic systems in the project area provide a supporting service by contributing to soil fertility at the regional scale and by providing a source of water for existing agricultural practices.

5.4.5. Sensitivities

Ecosystem services in the project area are sensitive to alterations in water quality (and the secondary impact that this may have one people’s access to fisheries resources) and flow regimes. Experience from development projects in PNG and other high rainfall environments is that perceived or actual impacts to water quality, particularly suspended sediment concentrations in normally clearwater tributaries, are generally of most concern to cultural and provisioning services. Cultural and provisioning services are also sensitive to perceived or actual negative impacts associated with toxicants entering waterways. Provisioning services are sensitive to changes to abundance and catchability of fishes and prawns, the latter requiring clear water if harvested by hand. Regulating, cultural and provisioning services are sensitive to surface water, soil water and groundwater flow regimes that maintain freshwater habitats. It is unlikely that the landscape-scale supporting services provided by aquatic systems are sensitive to the types and scales of stressors that may be related to the development of the PBMV project.

6. Impact Assessment

6.1. Method

The method used for this impact assessment conforms to guidelines provided by ERIAS Group that takes a magnitude × sensitivity approach to the assessment with documentation of assumptions and the resulting impact significance in a matrix form. This approach is consistent with the approaches recommended by the PNG Environment Act (2000), the International Finance Corporation Performance Standards on Environmental and Social Sustainability (Guidance Note 1, IFC 2012) and the National Forest Management Standards for Papua New Guinea (FSC 2010 and 2016 drafted amendments).

The impact assessment followed these steps:

1. Existing stressors: the existing stressors of significance that exist in the current conditions were described, as this contextualises the potential project-derived impacts.
2. Screening of potential impacts: the potential (un-mitigated) impacts of the construction and operation of the PBMV project were profiled and screened for inclusion in the impact assessment based on magnitude of threat, sensitivity of receptor and severity of potential impact.
3. Mitigation measures: mitigation measures relevant to aquatic ecology that Markham Valley Biomass Limited has committed to and any additional recommended mitigation measures are described. These recommended mitigation measures are based on experience in assessment and monitoring of impacts associated with development projects in PNG, experience from a project relating to the use of eucalypt plantations for water treatment and review of regulations and literature.
4. Residual impact assessment: impacts were assessed assuming that the mitigation measures are adopted and are successful. Impacts were assessed for each of the habitat types present in the project area and followed the ERIAS Group guidelines for impact assessment.
5. Recommended management and monitoring. Based on the results of the impact assessment, recommendations have been proposed for management and monitoring.

Based on the analysis presented above and the conclusions regarding sensitivities and resilience, the *a-priori* aquatic habitats categories were rationalised down to three types for consideration in the impact assessment:

- The Markham River;
- High energy, high sediment load streams, recognising that this includes some ephemeral reaches; and
- Clearwater tributaries and apparently inflow dependent ecosystems.

6.2. Existing Stressors

The PBMV project is to be developed in a non-pristine area. The most significant existing anthropogenic stressors on aquatic systems in the project area are considered to be:

- Ecological impacts of introduced exotic fish species;
- In-stream, bank and riparian habitat stability impacts from natural vegetation removal and agricultural land use practices and associated indirect impacts concerning the supply of terrestrially sourced productivity to aquatic systems;
- Potential water and sediment quality impacts associated with current and historical agricultural practice although it is noted that ERIAS Group (2017) reported concentrations of glyphosate and residues in sediments were below detection limits in one round of sampling; and
- Stream bed and water quality impacts associated with aggregate extraction practices in river channels.

The non-anthropogenic stressors potentially limiting aquatic biodiversity and productivity in watercourses of the project area can be broadly characterised by the following inter-related factors:

- Catchment-scale geomorphology and sediment transport processes;
- Watercourse energy regimes and their relationship with in-stream habitat diversity and stability; and
- Watercourse or reach ephemerality.

De-coupling existing impacts from those potentially associated with the development of the PBMV project will form part of the objectives of future monitoring. However, quantifying the severity of the existing and potentially increasing effects of introduced exotic species presents particular challenges due to the lack of temporal data and the large scale of the problem across northern PNG. Therefore, while the maintenance of native fish populations, for example, is a desirable environmental performance objective for the project, and while water quality criteria may be met to achieve this, the ongoing impacts of exotic fish species that are beyond the control of the PBMV project are likely to threaten native populations.

Similarly, assessing potential existing water quality and chronic toxicological impacts associated with decades of agricultural practice (particularly glyphosate and its residues) in the area will be a challenge for future monitoring that will need careful selection of appropriate indicators.

6.3. Profiling and Screening of Potential Impacts

The potential impacts of the PBMV project on aquatic organisms, processes and habitats and aquatic ecosystem services are listed in Table 6- 1. The potential impacts screened into the impact assessment processes are described and ranked in sections 6.4 and 6.5. The potential impact that are profiled here for completeness but screened out of the assessment process (because they are of negligible scale or severity) are described in more detail below.

6.3.1. Potential Impacts Screened Out of the Assessment Process

6.3.1.1. Materials Transport Route

Potential impacts associated with the supply of materials to the PBMV project during the construction and operations phases will be via well-established air, sea and road transport routes. The primary route for materials supply to the project will be from the port of Lae (the largest cargo port in Papua New Guinea) to the project site via road transport on the Highlands Highway.

Materials handling along the supply chain, including the mitigation and management of accidents such as spills into the coastal marine environment or freshwater streams along the transport route, will be the responsibility of suppliers. The risk of these impacts associated with the construction and operation of the PBMV project represent a negligible incremental increase above existing materials handling operations at the Port of Lae and the Highlands Highway.

Within the PBMV project areas, materials transport will involve minor movements of machinery, fuels and oils, fertiliser, herbicide, seedlings and harvested wood product. This will be managed via the project's standard operating procedures for the operation of machinery and handling of chemicals. Spills or other accidents will be mitigated by adherence to the PNG Logging Code of Practice (1996) with regard to buffer zones (Part A of the PNG Logging Code with project-specific amendments as described below) the sighting and construction of forest roads and the transport of harvested product (Part B of the PNG Logging Code), and materials handling (Part D of the PNG Logging Code). Storage and handling of chemicals and other hazardous substances will comply with good industry practice as reflected in Australian and other international standards. Therefore, any impacts associated with materials handling for the PBMV project are expected to be insignificant and are not formally assessed here.

6.3.1.2. Potential Impacts of Increased Fishing Pressure

The risk of adverse impacts to fish populations due to increased in fishing pressure from PBMV project workforce is negligible and not formally assessed here. There will be no significant on-site accommodation associated with construction or operations phases of the project. Employees of the project will not be engaging in recreational or subsistence fishing in the project area and the number of individuals in question is small compared to that potentially engaged in fishing activities in surrounding villages and settlements.

6.3.1.3. Potential Impacts of Increased or Diminished Access to Watercourses by Gravel Extraction Industry and Other Users

Under the leasing arrangements of the plantation areas, the PBMV project will control access to, and activities in, some properties. Other industries in the area will be consulted as required if existing arrangements exist for users to access watercourses. Risk of adverse impacts to provisioning services related to gravel extraction or other existing uses is negligible. Further, the risk of the PBMV project to facilitate increased adverse impacts from other uses is negligible and is not assessed here.

6.3.1.4. Potential Impacts of Exacerbated Spread of Exotic Species

The presence and expected continued spread of exotic fish species in northern Papua New Guinea represents one of the most significant existing ecological impacts in the region. Exotic species dominate the diversity and biomass of most watercourses in the PBMV project area. Aquaculture of exotic species is practised in several locations in Morobe Province. The potential further spread and negative impacts of exotic fish species in watercourses of the project area are outside the control of the PBMV project. The risk of the PNG Biomass project exacerbating the spread of exotic fish species is negligible compared to natural range expansions and possible intentional or accidental releases from aquaculture impoundments and thus is not assessed here. However, the potential for project-related stressors (e.g. diminished water quality or environmental flows) to apply additional stress to native (and exotic) fish populations and therefore cause synergistic impacts is considered in this impact assessment.

6.3.1.5. Potential Impacts to Cultural Services

The cultural services provided by the aquatic ecosystems of the project area are described in general terms in Section 4.8.3. Aquatic ecosystems have inherent cultural value, some of which is related to fishing practices and other provisioning services. The potential for the PBMV project to adversely impact cultural services is negligible when put into context with existing and ongoing alterations to lifestyles and amenity resulting from the proximity to the city of Lae and established townships and markets along the Highlands Highway (e.g., Nadzab and 40 mile), the long history of agricultural practice in the region and additional future developments along this settlement corridor. The potential impacts to provisioning services resulting from the development of the PBMV project, that may have flow-on effects to cultural services (e.g. maintenance of fisheries resources) are assessed here. However, the potential impacts to cultural services *per se* are not addressed.

Table 6- 1 Profile of the potential impacts of the project components on aquatic fauna, habitats and ecosystem services before mitigation. Green cells = screened in to the assessment phase, grey cells = screened out of the assessment phases (with justification provided in text).

Potential Impact	**Project Component**						
	Plantation site preparation	**Plantation establishment and sequential harvesting**	**Power plant construction**	**Power plant operation**	**Nursery and ancillary infrastructure construction**	**Nursery and ancillary infrastructure operation**	**Materials transport**
Altered regimes of allochthonous production supply to watercourses	Clearing of existing vegetation removing supply	Plantation species with different leaf litter and woody debris regimes and altered foodweb breakdown, detrital properties and nutritional content					
Reduced availability of instream root and woody debris habitat and canopy shading.	Clearing of existing vegetation removing supply	Sequential eucalypt clearing removing supply					
Increased sediment delivery to watercourses in run-off or other sources	Clearing of existing vegetation, earthworks and road construction activity	Sequential eucalypt clearing and road use	Vegetation clearing, earthworks and road construction activity		Vegetation clearing, earthworks and road construction activity		
Altered environmental flows associated with *Eucalyptus* plantation		Groundwater and surface water usage by plantation affecting downstream flows					
Altered environmental flows associated with water abstraction				Groundwater and surface water usage by power plant affecting downstream flows		Groundwater and surface water usage by power plant affecting downstream flows	
Altered capacity of receiving areas to buffer high-energy flows and sediment loads	Clearing of existing vegetation in receiving areas altering the ability of these features to sustain and buffer flow to downstream watercourses	*Eucalyptus* plantations in receiving areas altering the ability of these features to sustain and buffer flow to downstream watercourses					
Altered nutrient regimes and water quality associated with fertiliser		Airborne or waterborne releases of nutrients from fertiliser					
Release of contaminants associated with herbicide treatments		Airborne or waterborne releases of herbicide					

Release of contaminants associated with wastewater and other discharges	Discharges and run-off from infrastructure, machinery and materials/chemicals storages	Discharges and run-off from infrastructure, machinery and materials/chemicals storages	Discharges and run-off from infrastructure, machinery and materials/chemicals storages	Discharges and run-off from infrastructure, machinery and materials/chemicals storages	Discharges and run-off from infrastructure, machinery and materials/chemicals storages	Discharges and run-off from infrastructure, machinery and materials/chemicals storages	Discharges and run-off from infrastructure, machinery and materials/chemicals storages
Release of contaminants associated with accidental spillages	Accidental spillages from machinery and materials/chemicals storages	Accidental spillages from machinery and materials/chemicals storages	Accidental spillages from machinery and materials/chemicals storages	Accidental spillages from machinery and materials/chemicals storages	Accidental spillages from machinery and materials/chemicals storages	Accidental spillages from machinery and materials/chemicals storages	Accidental spillages from machinery and materials/chemicals storages
Stream bank damage and instability associated with crossings	Physical impacts to bank habitat from watercourse crossing construction or upgrade		Physical impacts to bank habitat from watercourse crossing construction or upgrade				Physical impacts to bank habitat from watercourse crossing construction or upgrade
Ongoing stream bank erosion associated with crossings	Erosion and sediment release from unstable banks and crossings	Erosion and sediment release from unstable banks and crossings					Erosion and sediment release from unstable banks and crossings
Stream bed scour or barriers to upstream fish movements associated with crossings	Channel scour or creation of barriers to upstream-downstream movement	Channel scour or creation of barriers to upstream-downstream movement					Channel scour or creation of barriers to upstream-downstream movement
Increased fishing pressure	Increased fisheries resource pressure from workforce personnel or facilitating increased access to local people.	Increased fisheries resource pressure from workforce personnel or facilitating increased access to local people.	Increased fisheries resource pressure from workforce personnel or facilitating increased access to local people.	Increased fisheries resource pressure from workforce personnel or facilitating increased access to local people.	Increased fisheries resource pressure from workforce personnel or facilitating increased access to local people.	Increased fisheries resource pressure from workforce personnel or facilitating increased access to local people.	Increased fisheries resource pressure from workforce personnel or facilitating increased access to local people.
Increased access by people and other industries	Increased access to watercourse by aggregate extraction industry or other users	Increased access to watercourse by aggregate extraction industry or other users					Increased access to watercourse by aggregate extraction industry or other users
Spread of introduced exotic fish species	Additional introductions or inadvertent spread of exotic fish species	Additional introductions or inadvertent spread of exotic fish species	Additional introductions or inadvertent spread of exotic fish species	Additional introductions or inadvertent spread of exotic fish species	Additional introductions or inadvertent spread of exotic fish species	Additional introductions or inadvertent spread of exotic fish species	Additional introductions or inadvertent spread of exotic fish species
Cumulative impacts to native fish populations	Project-derived impact to stressed populations of native species	Project-derived impact to stressed populations of native species	Project-derived impact to stressed populations of native species	Project-derived impact to stressed populations of native species	Project-derived impact to stressed populations of native species	Project-derived impact to stressed populations of native species	Project-derived impact to stressed populations of native species
Cumulative impacts of project negatively affecting fisheries productivity and provisioning services	Impacts to aquatic species and habitats leading to diminished provisioning services	Impacts to aquatic species and habitats leading to diminished provisioning services	Impacts to aquatic species and habitats leading to diminished provisioning services	Impacts to aquatic species and habitats leading to diminished provisioning services	Impacts to aquatic species and habitats leading to diminished provisioning services	Impacts to aquatic species and habitats leading to diminished provisioning services	

Impacts to cultural services relating to the effects to aquatic ecosystems only	Impacts to provisioning services, visual amenity of existing vegetation and water quality leading to diminished cultural services	Impacts to provisioning services, visual amenity sequential plantation harvesting and water quality leading to diminished cultural services	Impacts to provisioning services, visual amenity and water quality leading to diminished cultural services	Impacts to provisioning services, visual amenity and water quality leading to diminished cultural services	Impacts to provisioning services, visual amenity and water quality leading to diminished cultural services	Impacts to provisioning services, visual amenity and water quality leading to diminished cultural services	
Impacts to regulating services associated with landscape features functioning to buffer potentially high energy flows and floods and high sediment loads from rivers draining foothills	Altered land use and surface water and groundwater capacity, retention and buffering impacting flow and flow regimes in downstream watercourses	Altered land use and surface water and groundwater capacity, retention and buffering impacting flow and flow regimes in downstream watercourses					
Decreased access of alluvial aggregate extraction industry negatively affecting provisioning services	Changed land use and accessibility leading to diminished provisioning services associated with alluvial aggregate resource	Changed land use and accessibility leading to diminished provisioning services associated with alluvial aggregate resource					
Impacts to coastal/marine environment from shipping operations							Cumulative impacts of project material supply chain from Lae port

6.4. Mitigation Measures

The mitigation measures that the PBMV project has committed to are reflected in, as a minimum, the PNG Logging Code of Practice (PNG/DEC 1996) and the National Forest Management Standards for Papua New Guinea (FSC 2010 and 2016 drafted amendments). Additional recommended mitigation measures made herein reflect good environmental management practice in response to the knowledge of the aquatic ecosystems of the project area, remaining uncertainty and experience from other projects.

6.4.1. Watercourse Buffer Zones

Buffer zones are a proven effective measure to mitigate impacts of vegetation clearing and altered land-use on aquatic systems (Campbell and Doeg 1989, Graça et al. 2002, Quinn et al. 2004). As they relate to the watercourses of the PBMV project, intact riparian zones[10] serve to:

- Maintain bank stability which maintains in-stream habitat integrity and limit erosional sediment supply;
- Maintain stream canopy cover therefore maintaining water temperature conditions that are tolerable to aquatic organisms;
- Maintain in-stream root and branch habitat and supply of woody debris that are important physical habitats of some aquatic organisms;
- Maintain supply of terrestrial derived vegetative organic matter (e.g. leaves, terrestrial insects, woody debris) that is the main source of production in these aquatic foodwebs;
- Trap sediment-laden runoff from disturbed areas and prevent it from entering watercourses;
- Provide a spatial buffer between watercourses and the contaminants that may derive from operational areas. This may include spatially buffering wind-blown herbicide sprays or spillages from chemical, fuel, oil storages and/or machinery.

The buffer zones that the PBMV project will commit to are outlined in Table 6- 2.

[10] As described herein, the majority of riparian habitat surveyed consisted of grassland.

Table 6-2 Riparian buffer zones adopted by the PBMV project in relation to the three watercourse types addressed in the impact assessment

Watercourse Type	**Buffer Type**	**Buffer Zone**
	BUFFER TYPE 1	
1	Markham River	100 m on all sides
2	Leron River	100 m on all sides
2	Rumu River	50 m on all sides
3	Lakes, Lagoons and Swamps	100 m on all sides
	BUFFER TYPE 2	
2 and 3	Permanent watercourses with bed widths > 5 m	50 m on all sides
	BUFFER TYPE 3	
2 and 3	Watercourses with an average width > 1 m	30 m on all sides
	BUFFER TYPE 4	
2 and 3	Watercourses with an average width < 1 m	15 m on all sides

The following activities will be excluded within the riparian buffer zones:

- Establishment of plantations;
- Felling of trees or clearing of vegetation except where required for designated stream crossings;
- Storing of logs, soil, machinery, fuels, oils, lubricant or herbicides. or placement of any other project related infrastructure;
- Construction of roads, except where required for designated stream crossings or bridges;
- Crossing of harvesting machinery, except at designated temporary crossings over dry watercourse beds. Where practicable, these should be located where low banks or natural fords facilitate crossing without significant earthworks to modify the bank, and located so as to minimise clearing of vegetation required to construct the crossing.
- Where harvesting machinery is required to cross watercourses, log crossings or culverts will be constructed. Where such construction occurs, crossings should be planned at locations of riparian grassland where practicable so as to minimise the clearing of vegetation through the buffer zone. Where culverts are used, the crossing construction will be subject to specific environmental and technical feasibility assessment and culvert designs will adopt the principals of the Papua New Guinea

Logging Code of Practice (PNGFA/DEC, 1996). Where culverts are used or bridges built, construction practices will be adopted to mitigate physical impacts to watercourse bank and stream bed, to stabilise banks from ongoing erosion, to control sediment release during construction and to mitigate potential impacts associated with stockpiling and spillages.

6.4.2. Fish Passage Through Watercourse Crossings

In addition to the optimisation of crossing location and bank stabilisation listed in Section 6.4.1, it is recommended that the design and construction of crossings adopt the principals of maintaining fish passage and cater for the range of expected flows. Several state agencies in Australia have recognised the potential impacts of fish passage barriers and useful guidelines for culvert designs are available (e.g. Kapitzke 2010, Fairfull and Witheridge 2003, NSW DPI, SA DPTL 2016, ODF 2002). The Queensland Department of Primary Industries and Fisheries Fish Habitat Guideline FHG 001 (Cotterell 1998) provides the most relevant guideline for adoption in PNG. The maintenance of upstream-downstream connectivity of aquatic habitats is central to the maintenance of aquatic ecological processes and provisioning services. This is particularly true for watercourses of the PBMV project area where several fish species have migratory life history phases and where villagers in upstream reaches or in reaches that are ephemeral may be more reliant on periodic availability of aquatic resources.

The key design consideration involves avoiding the creation of barriers to fish movement that can include hydraulic barriers (e.g. high flow velocity, reduced depth, steps between culvert and river bed) or physical barriers (e.g. trapping of sediment/logs). As such, design requires consideration of the flow characteristics of the watercourse being traversed and the characteristics of the resident fauna. Further, watercourse crossings should be constructed during dry periods and regularly inspected and maintained.

6.4.3. Power Plant and Nursery

Construction of the power plant and nursery will require vegetation clearing and earthworks. This has the potential to expose sediments to rainfall and cause sedimented runoff that may enter waterways. This risk is mitigated to a large extent by the lack of steep gradients in the construction areas that can exacerbate run-off. Vegetation clearing and earthworks will adopt the principals of the Papua New Guinea Logging Code of Practice (PNGFA/DEC, 1996).

The buffer zones outlined in Table 6-2 will apply to these construction areas. It is recommended that construction activities requiring major earthworks be planned for dry periods where feasible. Further, it is recommended that earth stockpiles (that shall not be placed within any buffer zones) be covered or surrounded by bunds and/or drainage lines that are directed to a suitable area. Silt socks or silt fences are recommended to manage localised areas of particular concern.

6.4.4. Sediment Delivery and Suspended Sediment in Run-off from Plantations

Hydrobiology (2017) predicated negligible changes in sediment supply associated with project construction and plantation establishment, and negligible decreases during harvesting and full establishment. As such, it was predicted that overall sediment yields from the Leron, Erap, Rumu, and Maralumi sub-catchments would not be affected. It was also predicted that there would be no impacts to Markham River sediment yields.

Buffer zones will be the principal measure mitigating potential impacts of sediment derived from plantation activities. No additional mitigation measures are recommended.

6.4.5. Herbicides and Fertiliser Application

There is no planned routine for pesticide treatment in the plantation. Insect pests will be assessed and remedied only if the need arises. Routine herbicide and fertiliser applications will be on-going throughout the cycle of planting, growth and harvesting. Material Safety Data Sheets for chemicals that will be used in plantations indicate:

- Generally low aquatic toxicity of Stockosorb gel;
- Apparently low toxicity of Grasskill 450 (active ingredient glyphosate) but with warnings against contamination of waterways (mitigated in this case by the watercourse buffers as listed in Section 6.4.1);
- Low to moderate aquatic toxicity of Propionic acid, the active ingredient of Apparent Buffer 700 Surfactant and no information on environmental fate;
- Low to moderate aquatic toxicity of metsulfuron methyl and no information on environmental fate.

Chemicals from sprayed herbicides have the potential to enter aquatic environments via groundwater, surface water run-off and/or wind. There will be no aerial spraying of herbicides with application being either manual from backpack units or potentially from a tractor spray rig. Further, following the PBMV standard operating procedure for herbicide spraying and the Tasmanian Forest Practices Code (2015) for herbicide application, spraying will avoid times of high wind conditions. Wind drift is therefore expected to be minimal and spatially constrained. Risks of fertiliser entering waterways is lower due to its manual burial into soil and its lower toxicity.

Buffer zones will be the primary measure mitigating the potential impacts of herbicide to aquatic ecosystems. It is recommended that herbicides and fertiliser are mixed, stored, secured and disposed of so that leaks and spillages are avoided as per the Tasmanian Forest Practices Code (2015) or other 'good practice' guidelines.

Glyphosate is strongly adsorbed to soil particles (Schuette 1998). The history of agricultural practice in the Markham River valley, the presence of apparently permeable sandy alluvial soils and the potential groundwater connectivity in project area watercourses, indicates the potential for glyphosate to enter surface run-off, subsurface or groundwater flows. Sediment quality investigations at the Markham River and showed that concentrations of glyphosate and aminomethylphosphonic acid (AMPA) (a principal degradation product of glyphosate) were <0.05 mg/kg (ERIAS Group 2017). No data for background concentrations of glyphosate concentrations in surface water or groundwater were available at the time of writing.

The following mitigation measures are recommended to limit risks associated with glyphosate entering aquatic ecosystems:

- Limit spraying adjacent to riparian buffers to drier months where feasible to minimise potential for interactions with surface water and groundwater;
- Implement an adaptive management plan that seeks to maximise efficiencies between weed control and volume application of glyphosate;
- Monitor concentrations of glyphosate in soils within buffer zones and in waters and bed sediments at strategic locations in watercourses. .

6.4.6. Chemicals and Materials Handling and Spillages

Applying the buffer zones listed in Section 6.4.1, adherence to the PNG Logging Code of Practice and good practice management of chemicals, machinery and sediment according to the project's standard operating procedures will be the key measures mitigating environmental risks associated with the use, transport and storage of chemicals and other materials. Measures will include:

- Designating chemicals, fuels and oils and machinery storage and wash-down/maintenance areas that are protected from the elements as it appropriate and consistent with good practice;
- Where such areas are exposed to rain, erosion, or run-off, protecting the area with hard-stand, bunds, drainage and diversion systems and sediment control devices such as silt socks or silt curtains as appropriate and consistent with good practice;
- Use of leak-proof storage containers and regular inspection;
- Regular maintenance of machinery and designated areas for storage and use of fuels, oils and lubricants;
- Development of a waste/refuse management plan that is consistent with good practice;
- Development of a spills emergency response plan including appropriate spills containment and training that is consistent with good practice;
- Good practice and corporate stewardship that will seek to continually improve in areas such as material handling training and waste management.

The performance of these measures will be quantified by comparison with PNG and Australian water quality guidelines in routine monitoring in receiving waters.

6.4.7. Unplanned Fire and Fire Fighting

No planned burning is proposed as part of the PBMV project. Unplanned fires and fire-fighting pose a threat to aquatic ecosystems. Heat stress, low water quality (particularly dissolved oxygen content), riparian habitat degradation, sediment releases from burnt areas (Dunham et al. 2003, Lyon and O'Connor 2008, Howard et al. 2009) and release of fire-fighting chemicals (Gaikowski et al. 1996, Buhl and Hamilton 1998) are the risks of most concern.

Applying the buffer zones listed in Section 6.4.1 between plantations, infrastructure and fuel/machinery/log/chemicals storage areas will be the key measures mitigating the risks associated with fires and fire fighting. Pursuant to the general principals of fire planning of the Tasmanian Forest Practices Code (2016), 6 to 8 m wide buffers around plantation compartments will be maintained for access and fire control. Tracks (approximately 5 m width) may also be established within some plantation compartments. Further, vegetation on roadside verges will be controlled and the workforce trained in fire safety.

6.4.8. Power Plant Water Abstraction

Water will be pumped from groundwater bores at a rate of 78,120 L/hour for each of two 15 MW power generators. By way of context, this volume represents approximately 0.001% of the surface water discharge of the Markham River mainstream recorded during a flood event at Markham Bridge (Tilley et al. 2006, Samanta et al. 2016). Recommended mitigation measures follow those of White (2016) as follows:

- Location of a suitable number of bores as close to the Markham River as practicable to ensure reliable groundwater supply and to mitigate potential impacts to groundwater dependent ecosystems associated with smaller watercourses.
- Location of bores downslope of plantations and the water supplies of villages and hamlets.

The following impact assessment assumes that bores will access groundwater close to the Markham River and that the groundwater accessed has no connectivity to other smaller watercourses and inflow dependent ecosystems upstream of the proposed water abstraction points. It is also assumed that there will be no measurable or significant impact to flows of the Markham River or any other watercourse in the project area as a result of groundwater extraction.

6.4.9. *Eucalyptus* Plantations in Lowland Flats Receiving Areas

The spatio-temporal pattern of planting and harvesting is yet to be determined. However, all areas currently falling under the Memoranda of Understanding with landowners are options for plantation. Klin Wara and Maralumi River are classified as inflow dependent ecosystems due to their potential reliance on surface water, soil water and/or groundwater sourced from the flat receiving areas. Within the lowland flats receiving areas described in this report, specific watercourse channels, and therefore riparian buffer zones, have not been delineated. In recommending mitigation measures, the following key results are from White (2016) hydrogeology assessment:

- Groundwater wells in the Klin Wara area have groundwater at relatively shallow depths ranging from approximately 0 to 2 m depth, which is shallower than groundwater from sites further north in the project area.
- Soil conditions in the project area are conducive to *Eucalyptus pellita* using groundwater. Groundwater extraction rates of 1-2 mm per day are possible when potential evaporation exceeds supply from the unsaturated zone.
- There may be a 15-20% increase in evapotranspiration in a plantation compared with 'short' grassland.
- Studies in Brazil showed that *Eucalytus* plantations affected local water balance in areas where there were already low rates of streamflow although other conflicting data exist for other studies in China.
- Modelling for the Markham valley indicates 10-20% decrease in overall predicted drainage (excess water that cannot be stored in the soil or used by vegetation) under plantation conditions compared with grassland.
- Modelling for Markham valley indicates a 20% decrease in the amount of annual groundwater recharge from land occupied by plantation compared with grassland.
- The effect of plantations will be decreased runoff and an increase in the number of months where no water is contributed to deep drainage (groundwater). The total effect is estimated to be reduction by 7000 to 30,000 ML reaching the Markham River. This impact to flow in the Markham River is negligible. However, potential impact to streams traversing the project area and inflow dependent ecosystems is potentially higher.
- Under the assumptions of modelling, the probability of a change in groundwater of more than 1 m is 0.4 to 0.7 when grassland (that in the baseline condition exists as short and tall grassland) is replaced by plantation. However, White (2016) also states that the proposed buffer zones will be sufficient to protect ecosystems using groundwater.
- Modelling requires validation.

Given these conclusions, the results of the aquatic ecology survey, and the unknowns regarding hydrogeology of the lowland flat receiving areas and their role in sustaining ground-water dependent ecosystems, the following mitigation measures are recommended:

- No plantation is recommended in lowland flat receiving areas until further information can be obtained on:
  - The relative dependence of aquatic ecosystems associated with Klin Wara and Maralumi River on surface water, soil water and groundwater.
  - The role of lowland flat receiving areas supplying flow to Klin Wara and Maralumi River..
  - The ecological functioning of the lowland flat receiving areas during wet periods.
  - The classification of soils in the lowland flat receiving areas to ascertain if peatlands are present as this soil type is relevant to FSC Standard 01 and Standard 60 Principal 5 (incl. Annex C) and Principal 6, the National Forest Management Standards for Papua New Guinea (2010) Principal 6.
  - A definitive classification of these areas so that a project-wide generalised approach to 'wetlands', 'seepages' and other potential waterlogged areas can be aligned with the Tasmania Forest Practices Code (2015).
- No plantation in the forest habitat patch located in the headwaters of Klin Wara until further information can be obtained. This patch of forest has been assessed as degraded and dominated by exotic species (BAAM 2016). However, the potential role of this vegetation in mediating groundwater or surface water flows and sediment delivery from foothill streams to Klin Wara indicates that further information is required to support future management planning.

This recommendation is also consistent with the Tasmanian Forest Practices Code (2015) recommendations for seepages and swamps and IFC Performance Standard 6, paragraphs 26 to 30. This recommendation potentially affects the MOU areas shown in Figure 6-1 and Figure 6-2.

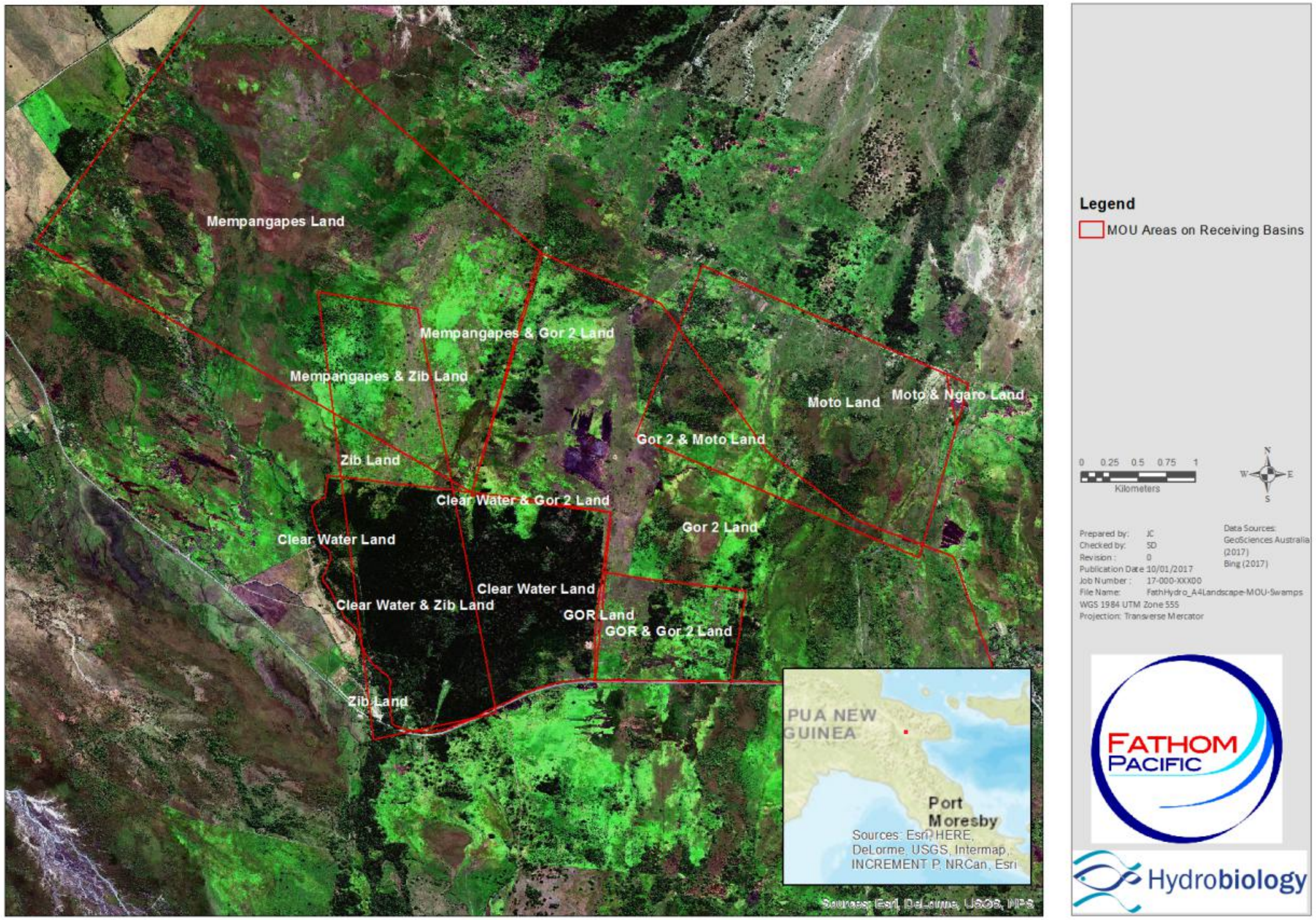


Figure 6-1 MOU areas (trimmed to area of interest) overlaying lowland flat receiving areas and intact forest at the headwaters of Klin Wara.

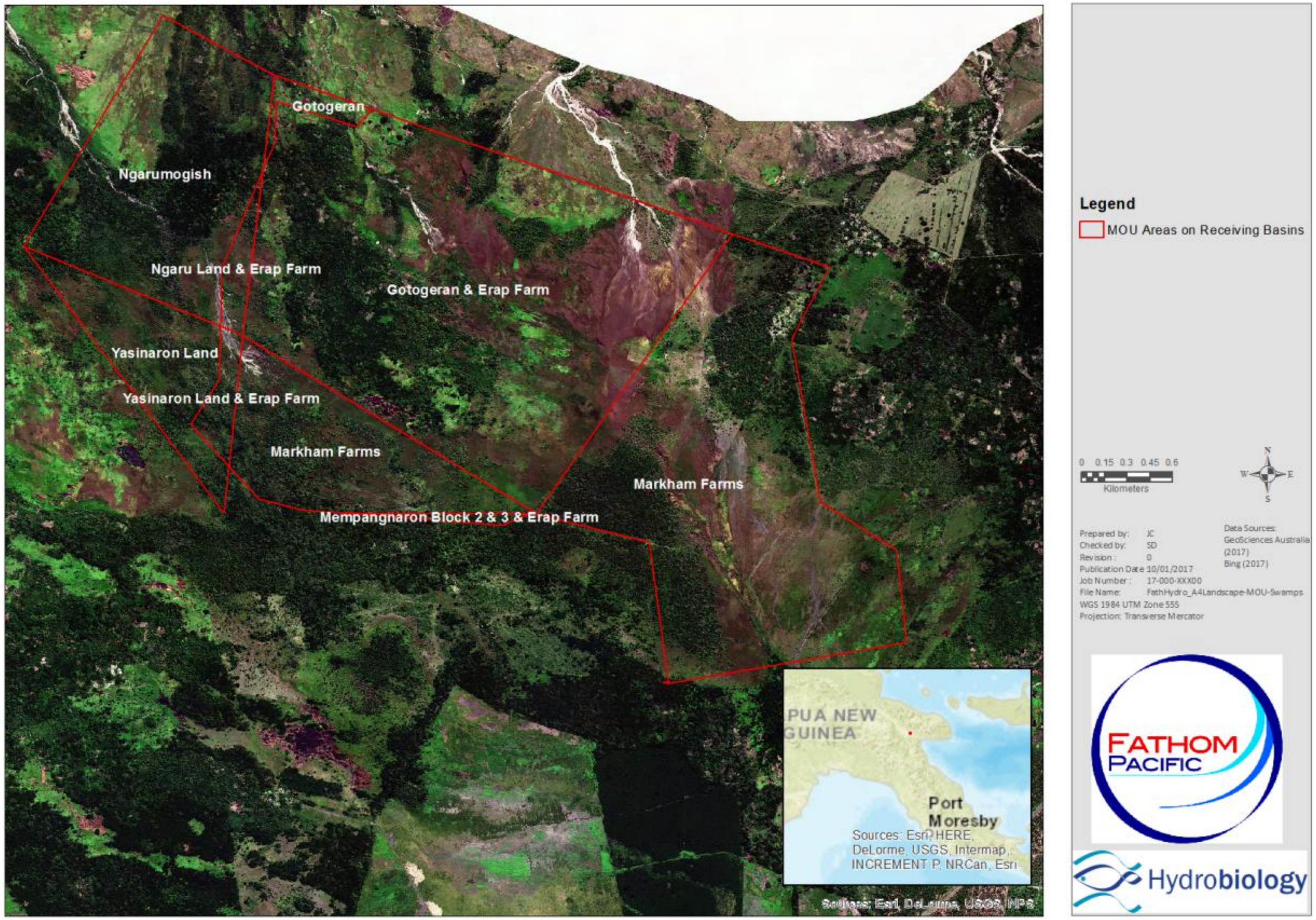


Figure 6-2 MOU areas (trimmed to area of interest) overlaying lowland flat receiving areas between the foothills of the Saruwaged Range and Maralumi River.

6.5. Residual Impact Assessment

The following impact assessment assumes successful implementation of all of the mitigation measures stated in Section 6.4 and their continued performance evaluation by routine monitoring. The criteria for classification of the magnitude of impact, sensitivity of the values in question and the matrix of impact significance are listed in Tables 6-4 to 6-6.

Table 6- 4 Criteria for classification of the magnitude of potential impacts

Magnitude	**Description**
High	An impact that is long lasting, widespread, and leads to substantial and possibly irreversible change to the value, resource or receptor
Moderate	An impact that is short term and is contained within the region where the project is being developed, but that extends beyond the area of disturbance to the surrounding area
Low	An impact that is temporary or short term and localised, and where the change is barely detectable with respect to natural variability
Negligible	An impact that is highly transient or very short term, highly localised, and easily remediated, and where the change is unlikely to be detectable with respect to natural variability
Positive	A beneficial impact on an environmental value

Table 6- 5 Criteria for classification of the sensitivity of the values being assessed

Sensitivity	Description
High	• The value is intact and retains its intrinsic attributes • The value is listed as being of conservation significance on a statutory or recognised international, national or state register • The value is unique to the environment in which it occurs. It is isolated to the affected area or system, and is poorly represented in the region, territory, country or the world • The value has not been exposed to threatening processes, or there has not been a noticeable impact on its integrity • Project activities would have an adverse effect on the value • Potentially affected communities are highly reliant on the value, e.g., it may be the primary or only source of food or income (i.e., the primary provisioning or regulating ecosystem service) for the community • The value highly important from a cultural heritage perspective
Moderate	• The value is recognised as being important at a regional level and may have been nominated for listing on recognised or statutory registers • The value is in a moderate to good condition and retains many of its key characteristics and structural elements • The value is relatively well represented in the areas/systems in which it occurs, but its distribution and abundance are limited by threatening processes • Threatening processes have reduced the environmental value's resilience to change. As such, changes resulting from project activities may lead to degradation • Due to the abundance and distribution of the value, replacement of unavoidable losses is possible • Potentially affected communities are somewhat reliant on the value, resource

	or receptor. The environmental value is one of a number of food sources or income streams and is not the primary or only provisioning or regulating ecosystem service available to the community • The value is moderately important from a cultural heritage perspective
Low	• The value is not listed on any recognised or statutory register, but may be recognised locally by relevant and suitably qualified experts or organisations • The value is in a poor to moderate condition • The value is not rare or unique, and numerous representative examples exist throughout the area/system • The value is widely distributed and abundant throughout the host area or system • Change is not expected to result in further degradation of the value, or there is no detectable response to change • Replacement of unavoidable losses is assured due to the abundance and wide distribution of the value • Potentially affected communities are not reliant on the value, resource or receptor. The value is not an important or regularly used source of food or income (it is an occasional ecosystem service) for the community • The value is not important from a cultural heritage perspective

Table 6- 6 Impact significance matrix

Magnitude	**Sensitivity**		
	High	**Moderate**	**Low**
High	Major	High	Moderate
Moderate	High	Moderate	Low
Low	Moderate	Low	Low
Negligible	Negligible	Negligible	Negligible
Positive	Positive	Positive	Positive

6.5.1. Markham River

The ranking of potential impacts to the Markham River are outlined in Table 6- 6 and described below. There are not expected to be any differences between construction phase and operations phase impacts or differences among the plantation cycles and this assessment reflects all phases of the project.

Table 6- 7 Impact ranking - Markham River

Component	**Ranking**		
	Magnitude	**Sensitivity**	**Significance**
Aquatic Habitats	Negligible	Low	Negligible
Benthic Macroinvertebrates	Negligible	Moderate	Negligible
Fishes and Prawns	Negligible	Moderate	Negligible
Provisioning Services	Negligible	Moderate	Negligible
Cultural Services	Negligible	Moderate	Negligible

6.5.1.1. Aquatic Habitats

Aquatic biological habitats of the Markham River are characterised by low diversity in structural types, elevated suspended sediment concentrations, high bed sediment loads, high-energy flows and reaches with disturbed riparian vegetation. The river is subject to episodic extremely high flow and suspended sediment conditions. Bed sediments are subject to mobilisation and reworking, with benthic surfaces and interstitial micro-habitats subject to smothering and scouring.

6.5.1.2. Benthic Macroinvertebrates

Benthic macroinvertebrate communities of the Markham River were characterised by low diversity and a dominance of forms that are tolerant of high sediment conditions. Any incremental increases in project-derived fugitive sediment reaching the Markham River will be negligible compared to the baseline conditions (Hydrobiology 2017). There will be no additional disturbance to riparian vegetation and only a small volume of project-related wastewater (from the power plant holding pond) entering the river. Therefore impacts to benthic macroinvertebrates are expected to be negligible.

6.5.1.3. Fishes and Macrocrustaceans

Fish and prawn assemblages in the Markham River are dominated by migratory species and those that can tolerate the high sediment and high flow conditions. Tolerating these conditions is likely to partly involve the selection of refugia such as backwaters, logs and vegetation piles, confluences with tributaries and micro-habitats such as lee sides of cobbles and close to banks. Exotic fish species have become established in the Markham River and are generally adapted to high flow and high sediment conditions. Detrital food webs based on terrestrial vegetation input are important to prawns and fishes but is likely to be limited in reaches with disturbed riparian habitats that are dominated by grasslands.

Any incremental increases in project-derived fugitive sediment reaching the Markham River will be negligible compared to the baseline conditions. There will be no additional disturbance to riparian vegetation and there will be only a small volume of project-related wastewater (from the power plant holding pond) entering the river. Further, there are expected to be negligible impacts at the confluence of tributaries and therefore negligible impacts to areas that are potentially important refugia for species inhabiting the Markham

River. There are expected to be negligible impacts to flow conditions resulting from water abstraction and therefore negligible impact to fish and prawn migration. Therefore impacts to fishes and prawns are expected to be negligible.

6.5.1.4. Provisioning Services

The Markham River is used for subsistence fishing, recreation and canoe transport. The project will have negligible impacts to biological communities and flow and thus is expected to have negligible impact on provisioning services.

6.5.1.5. Cultural Services

There will be no impact to visual amenity and negligible impact of power plant water abstraction during project construction and operation. Access to the river by people and travel on the river will not be affected by the project. Development of the project is not expected to significantly alter the lifestyle of local people at the scale of the Markham River catchment and within the context of surface watercourses. Therefore, the significance of impacts to cultural services of the Markham River are expected to be negligible.

6.5.2. High energy, high sediment load streams

The ranking of potential impacts to the high energy, high sediment load streams are outlined in Table 6- 7 and described below. There are not expected to be any differences between construction phase and operations phase impacts or differences among the plantation cycles and this assessment reflects all phases of the project.

Table 6- 8 Impact ranking - high energy, high sediment load streams

Component	Ranking		
	Magnitude	Sensitivity	Significance
Aquatic Habitats	Negligible	Low	Negligible
Benthic Macroinvertebrates	Negligible	Moderate	Negligible
Fishes and Prawns	Negligible	Moderate	Negligible
Provisioning Services	Negligible	Negligible	Negligible
Cultural Services	Negligible	Negligible	Negligible

6.5.2.1. Aquatic Habitats

Aquatic habitats in these watercourses are generally low diversity, dominated by cobble-pebble-gravel habitats with disturbed riparian zones. Some reaches are ephemeral and most reaches appear to be exposed to high energy, high sediment-load flows. Bed habitats are therefore expected to be exposed to sediment mobilisation and reworking, scouring and sedimentation. Gravel extraction activity represents a significant existing impact to aquatic habitats in some watercourses of this type in the project area.

There will be negligible incremental increases in riparian disturbance, sediment delivery and contamination sources as a result of the project. There are expected to be localised, negligible impacts to bank and bed habitats associated with the construction of watercourse crossings. Many of the alluvial banks of these watercourses are prone to failure and erosion under baseline conditions.

6.5.2.2. Benthic Macroinvertebrates

Benthic macroinvertebrate communities of these watercourses were characterised by a dominance of mayfly larvae and presence of taxa that are relatively tolerant of high sediment conditions. Ephemeral reaches are obviously not suitable habitat for aquatic macroinvertebrates during dry periods. Terrestrial vegetation is expected to represent the main production source for macroinvertebrates and detrital processes are expected to be important in foodwebs.

Any incremental increases in project-derived fugitive sediment reaching watercourses will be negligible compared to the baseline conditions. There will be no additional disturbance to riparian vegetation and buffer zones will mitigate potential impacts related to herbicide contamination from neighbouring plantation areas. Potential impacts associated with wastewater releases and/or spillages will be further mitigated by adherence to the PNG Logging Code of Practice and adherence to PBMV standard operating procedures that reflect good practice in materials handling and environmental management. There are expected to be localised impacts of low significance related to the construction of watercourse crossings. Therefore impacts to benthic macroinvertebrates are expected to be negligible.

6.5.2.3. Fishes and Macrocrustaceans

Fish communities of these watercourses are characterised by lower diversity and biomass compared to clearwater streams. Introduced exotic fish species have become established in these watercourses. High sediment loads, episodic high energy and ephemerality in some reaches, low habitat diversity and water quality and riparian impacts of settlements, roads and in-stream aggregate extraction works are the main factors limiting fish diversity and biomass in these streams. Prawn communities are similarly restricted. The introduced golden mahseer, *Tor putitora*, and the native rainbowfish, *Chilatherina bulolo*, and eels, *Anguila bicolor pacifica* appear to be the most abundant fish species inhabiting these watercourses. These species are likely to be eaten by local people if caught. Fish and prawn species are expected to migrate between the Markham River and these watercourses and expand their range into upstream reaches (that were dry at the time of this survey) during wet periods. Maintenance of fish and movement is therefore considered important to the maintenance of ecological functioning and ecosystem services in these watercourses.

Any incremental increases in project-derived fugitive sediment reaching watercourses will be negligible compared to the baseline conditions. There will be no additional disturbance to riparian vegetation and buffer zones will mitigate potential impacts related to herbicide contamination from neighbouring plantation areas. Potential impacts associated with wastewater releases and/or spillages will be further mitigated by adherence to the PNG Logging Code of Practice and adherence to PBMV standard operating procedures that reflect good practice in materials handling and environmental management. There are expected to be localised impacts of low significance related to the construction of watercourse crossings. Compliance with good practice in watercourse crossing designs where culverts are required will mitigate impacts to fish and prawn migrations. Therefore, potential impacts to fish and prawn communities in these watercourses are expected to be negligible.

6.5.2.4. Provisioning Services

No direct observations were made of fishing in this type of watercourse during surveys. However, it is expected that fishing does occur at some times and that fishes, eels or prawns caught are eaten. Bathing, recreation and clothes washing were observed in these watercourses. There are expected to be no impacts to flow, and negligible incremental impacts of the project to sediment loads, water quality related to herbicides and other chemicals, no wastewater releases and negligible impacts to aquatic biological resources. Therefore, there are expected to be negligible impacts to provisioning services.

6.5.2.5. Cultural Services

There will be no impact to visual amenity and there is expected to be no impacts to flow regimes of these watercourses. Riparian buffer zones will mitigate any impacts to the interactions and connectivity between settlements and watercourses. There will be negligible impacts to biological resources and provisioning services. Therefore, development of the project is not expected to significantly alter the lifestyle of local people at the scale of the region and within the context of surface watercourses, particularly when placed in the further context of other industries in the Markham Valley and developments along the Highlands Highway. Therefore, the significance of impacts to cultural services of these watercourses is expected to be negligible.

6.5.3. Clearwater Tributaries and Inflow Dependent Ecosystems

The ranking of potential impacts to clearwater tributaries and apparently inflow dependent ecosystems are outlined in Table 6- 8 and described below. There are not expected to be any differences between construction phase and operations phase impacts or differences among the plantation cycles and this assessment reflects all phases of the project. This assessment is made on the basis that the recommended mitigation measures described in Section 6.4.8 are implemented, that being there should be no plantation development in lowland flat receiving areas until further information can be obtained.

Table 6- 9 Impact ranking - clearwater tributaries and apparently inflow dependent ecosystems.

Component	Ranking		
	Magnitude	Sensitivity	Significance
Aquatic Habitats	Low	Moderate	Low
Benthic Macroinvertebrates	Low	Moderate	Low
Fishes and Prawns	Low	Moderate	Low
Provisioning Services	Low	Moderate	Low
Cultural Services	Low	Low	Low
Regulating Services	Low	Moderate	Low

6.5.3.1. Aquatic Habitats

Perennial clearwater tributaries are geographically restricted in the project area, represented by two streams: Klin Wara in the west and Maralumi River in the east. These streams have the highest diversity of aquatic habitats that are more stable than the high energy watercourses and have less disturbance in riparian zones. There is some indication that these habitats are dependent on inflows. There is also some indication that these habitats are maintained by buffering of surface water flows from watercourses draining the foothills of the Saruwaged Range. It is expected that if these surface water, soil water and/or groundwater connections exist, lowland flat receiving areas in the headwater regions of these streams have a role in buffering high energy, turbid surface water flows and supplying groundwater flows.

Aquatic habitats in clearwater streams and apparently inflow dependent ecosystems are more sensitive to perturbations in flow sediment loads. The maintenance of environmental flows and connectivity between riffles, runs, glides, and pools in a complex of habitats is important to maintenance of ecological function. At their downstream extents, these tributaries are expected to represent important clearwater refugia for mobile species in the Markham River. Buffer zones and the other measures listed in Section 6.4 will mitigate impacts to a large degree.

6.5.3.2. Benthic Macroinvertebrates

Clearwater tributaries recorded the highest diversity of benthic macroinvertebrates and included feeding guilds that were more adapted to low sediment conditions. Feeding guilds present indicated the dominance of foodwebs that relied on input of allochthonous vegetative material and the sequential breakdown and detrital processes. In clearwater streams, primary production by phytoplankton may contribute more highly to productivity. Benthic microalgae and biofilms available to scraper-collector feeding types and fine suspended organic matter available to filter feeders are expected to be more important in these streams compared to the high energy, high sediment load water courses. Therefore, clearwater tributaries are more sensitive to the potential impacts of bed and suspended sediment loads. Riffle zones are particularly productive habitats for benthic macroinvertebrates. Maintenance of riffle habitat is dependent upon the maintenance of environmental flows that submerge and aerate riffles and connectivity between this and other habitats such as runs, glides and pools within a reach.

Buffer zones and the recommended measure of not establishing plantations in the flat receiving areas and headwaters of these streams until further information can be obtained will mitigate impacts to benthic macroinvertebrates. Existing sources of diminished water quality potentially exist in the catchments of these clearwater tributaries including cattle ranching (including cattle slaughter practices), crossings and potential fish passage barriers (culverts and fords), settlements and riparian vegetation disturbance, and existing agricultural practices (e.g. oil palm plantations at Markham Farms). With adherence to mitigation measures listed herein and monitoring of the performance of those measures, the incremental increase in risks of diminished water quality and habitat disturbance to benthic macroinvertebrates is expected to be low.

6.5.3.3. Fishes and Macrocrustaceans

Clearwater tributaries recorded the highest diversity of fishes and prawns and relatively high biomass. Importantly, native fish species were recorded in these habitats that were not recorded elsewhere. Exotic fish species have become established in these streams. Detritivorous and omnivorous feeding styles dominate in these streams. Clearwater conditions favour visual predators and reproductive styles that involve delicate egg/nest structures that are prone to suspended or bed load sediment damage. The highest biomass of prawns in sampling was recorded from Klin Wara. In these systems, prawns are expected to play an important role in the processing of vegetative inputs and detritus. Fishes and prawns occupy, and move through, the variety of habitats available in these streams. Deep pools (>1 m depth) probably provide habitat for the larger-bodied species. Maintenance of environmental flows is important to the maintenance of water quality (e.g. temperature and dissolved oxygen regimes in deep pools) and connectivity between habitats (e.g. suitable depth over riffles, runs and glides).

Buffer zones and the recommended measure of not establishing plantations in the flat receiving areas and headwaters of these streams until further information can be obtained will mitigate impacts to fishes and prawns in these streams. Existing sources of diminished water quality potentially exist in the catchments of these clearwater tributaries including cattle ranching (including cattle slaughter practices), crossings and potential fish passage barriers (culverts and fords), settlements and riparian vegetation disturbance, and existing agricultural practices (e.g. oil palm plantations at Markham Farms). With adherence to mitigation measures listed herein and monitoring of the performance of those measures, the incremental increase in risks of diminished water quality and habitat disturbance to fishes and prawns is expected to be low.

6.5.3.4. Provisioning Services

Subsistence fishing, recreation, bathing and washing were observed in clearwater tributaries. The introduced golden mahseer and common carp and native rainbowfishes were among the most common species observed in local catches. All fishes and prawns that are caught in these streams are likely to be eaten. Anecdotal observations in the field suggest that these clearwater streams are particularly appreciated by local people for bathing, washing and recreation. Given the mitigation measures in place, and the predicted low impacts to aquatic biological resources, impacts to provisioning services are expected to be low.

6.5.3.5. Cultural Services

There will be no impact to visual amenity and there is expected to be low impact to flow regimes of these watercourses. Riparian buffer zones will mitigate any impacts to the interactions and connectivity between settlements and watercourses. There will be low impacts to biological resources and provisioning services. Therefore, development of the project is not expected to significantly alter the lifestyle of local people at the scale of the region and in the context of surface watercourses, particularly when placed in further context of the other industries in the Markham Valley and developments along the Highlands Highway. Therefore, the significance of impacts to cultural services of these watercourses are expected to be negligible.

6.5.3.6. Regulating Services

Current information suggests that a key regulating service may exist relation to clearwater tributaries, and this forms a key assumption underlying this impact assessment. It is possible that clearwater tributaries are:

- Supplied by surface waters that are buffered via lowland flat receiving areas in their headwaters that act to dissipate surface water energy and sediment from further upslope.
- Supplied by surface water, soil water and/or groundwater flows originating in or flowing through these receiving areas.

It is also possible that:

- Groundwater flows either supplement surface water flows during wet periods when surface waters feeder streams are flowing from the foothills of the Saruwaged Range or make up the majority of flow to clearwater streams during dry periods.
- The clearwater streams are therefore defined here as being inflow dependent ecosystems (see Section 7).

Until further information can be obtained on the hydrology of these systems, it is unknown whether lowland flat receiving areas should be considered as swamps, swampy meadows, marches, bogs, fens or seeps. Further, the nature of soils and the potential for the existence of peatlands associated with these areas is unknown. Such classification and understanding of hydrological connectivity is important as it has direct relevance to the requirements of FSC guidelines and effective management of clearwater tributaries.

The avoidance of planting in these areas will mitigate potential impacts that are ranked as minor.

7. Recommended Management and Monitoring

The impact assessment process has identified some unknowns that require further investigation. Two key unknowns are:

- Surface water, soil water and groundwater regimes associated with lowland flat receiving areas in the catchments of Maralumi and Klin Wara that have the most significant biodiversity values, provisioning services and regulating services of the project area.
- Existing impacts of historical and ongoing herbicide use.

These unknowns have contributed to the recommendation for the precautionary approach to be applied, with no plantation activities within MOU areas overlaying lowland flat receiving areas until further information can be obtained. Recommendations are made below to address these unknowns and thus assist in decision-making processes to move beyond the precautions applied.

7.1.1. Pre-Construction Monitoring

7.1.1.1. Flow Regimes in Clearwater Tributaries

In-situ physicochemical properties of Maralumi River and Klin Wara reported herein, and the inspection of aerial imagery and landscape geomorphology, indicated the potential for inflow dependent ecosystems in these catchments. By extension, provisioning services in these watercourses may have inflow dependencies that may include groundwater. Further still, the regulating services provided by the lowland flat receiving areas may be defined specifically with respect to the aquatic ecological functioning and flows and flood mitigation in these two clearwater tributaries.

We recommend study to quantify surface water, soil water and groundwater contributions to flows in Maralumi River and Klin Wara that will provide information about which areas can be used for plantations while minimising adverse impacts on these watercourses. This may involve physicochemical water quality markers, groundwater measurements and modelling.

7.1.1.2. Aquatic Ecological Functioning of Lowland Flat Receiving Areas

Parallel to the study described above, we recommend further assessment of the biological environment of the upstream reaches of Maralumi River and Klin Wara during a time of maximum wetting/flow. It is recognised that, even during high rainfall/flow periods, there may be very little standing water to sample in these areas. Therefore, it is strongly recommended that this study involve a vegetation specialist, as the definition of wetland types will be based as much on the presence of wetland vegetation types as the presence of water or aquatic habitats. It is also recommended that this study include characterisation of soils to further enable the ecological characterisation of these areas.

This study would have the additional benefit of defining wetland and channel habitats within the flat receiving areas that buffer zones associated with high value vegetation stands or watercourse sub-channels/swamps/fens can be identified to assist in finer scale planning if planting within sub-areas of the MOUs in this area is to proceed.

We recommend that this study also include an additional round of aquatic ecology sampling at key locations of interest sampled in the baseline program to capitalise on the mobilisation effort. Additional baseline information needed to more fully assess the biodiversity and ecosystem services at key sites in the project area, and link with the recommended pre-construction monitoring is:

- Deep pool habitat in Klin Wara and Maralumi River with increased priority of net-based sampling, including water column physicochemical profiles.
- Additional sampling effort in Markham River, with particular focus on tributary confluence refugia.
- Leron River and upland reaches that were dry at the time of this baseline study, as the survey would target a period of high flow.
- Meetings to obtain additional information on aquaculture operations in the Lae area and additional aquatic resource-use surveys focussing on exotic fish populations and impacts to native species.

7.1.1.3. Water Quality Indicators of Existing Herbicide Impacts

It is recommended that pre-construction water quality monitoring targets quantification of existing herbicide impacts, with a focus on glyphosate and residues, thereby expanding the data obtained from sampling to date. Literature values are available for the toxicity of glyphosate to aquatic species and information is available on sub-lethal effects. Results of this recommended study would provide a more robust and defensible baseline with respect to documenting the baseline condition for a contaminant of key significance.

Pending the results of this water quality program, the use of biomarkers in fish tissue to quantify baseline exposure can be investigated.

7.1.1.4. Buffer Zone Optimisation

Given the potential sensitivity differential among the different types of watercourses in the project area, there is scope for optimising the buffer zones on the basis of exposure sensitivity in addition to the size-only considerations. At the conclusion of the aforementioned additional studies prior to construction, we recommend a process of mapping high value and high sensitivity riparian zones to ascertain where size-only criteria may not provide the best level of protection, and where wide buffers associated with large watercourses may be optimised for planting (e.g. see Bavins et al. 2000). A possible mechanism is a workshop attended by vegetation, water quality, terrestrial fauna and aquatic fauna specialists.

7.1.2. Construction Monitoring

We envisage that water quality and macroinvertebrates will provide the most useful and cost-effective monitoring indicators for the nature of impacts predicted in the construction phase. Rationalised monitoring of macroinvertebrate community composition and abundance is a standard tool implemented to detect ecologically significant change and link this change to water quality. It is recommended that monitoring the success of mitigation measures is reflected in Environmental Management Plans related to waste and spills management, buffer zones and watercourse crossings, with monitoring results reported through the permitting authority. Construction phase monitoring should be focussed on confirming the success of mitigation measures, linked to effective adaptive management where targets are not met or where improvements can be identified.

Activities of most relevance are vegetation clearing associated with plantation establishment, nursery construction and power plant construction, and road crossing construction. These have the greatest potential to cause adverse effects to water quality and impacts to aquatic fauna and ecosystem services. We recommend macroinvertebrate sampling at times corresponding to construction of the power plant (sampling to target downstream reaches) and establishment of plantation areas (targeting upstream and downstream regions). Results would be compared with the baseline to identify environmental change that can be interpreted with respect to the success of mitigation measures. We recommend that construction phase fish sampling only be considered if water quality triggers are exceeded or other monitoring activities indicate a specific need for further assessment.

7.1.3. Operations Monitoring

We envisage that water quality monitoring will provide the most useful and cost-effective routine monitoring that is relevant to the protection of aquatic life and ecosystem services during operations. It is recommended that monitoring the success of mitigation measures is reflected in Environmental Management Plans related to waste and spills management, buffer zones and watercourse crossings, with routine monitoring results reported through the permitting authority.

It is recommended that ongoing monitoring include a community liaison component as a lens into the status of populations of exotic and native fish species. While we do not recommend that Markham Valley Biomass Limited has a direct obligation to monitor or remediate the exotic species incursion, it is recommended that liaison with the National Fisheries Authority (NFA), the Conservation and Environment Protection Authority (CEPA), other operators in the Markham River valley, aquaculture operators and the community will provide useful information and potentially identify fisheries-related projects of interest to multiple stakeholders in the catchment. Given the state of exotic fish invasion in Morobe Province and the potential for further aquaculture business development there is potential for Markham Valley Biomass Limited to become involved in community-based projects in this area. However, this should not come at the expense of the maintenance of native fish populations and requires careful consideration.

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ATTACHMENT 1

Habitats photo compilation

Wawin River - TribE -1 - Type 1 Habitat

Leron River - Leron-4 - Type 1 Habitat

TribC-1 - Type 1 Habitat

TribA-1 - Type 1 Habitat

Ngaromanki River - TribB-1 - Type 1 Habitat

Rumu River US - Rumu-1 - Type 2 Habitat

Rumu River DS - Rumu-2 - Type 2 Habitat

Klin Wara US - TribF-1 - Type 3 Habitat

Klin Wara Mid- TribG-1-WQ - Type 3 Habitat

Klin Wara DS - TribF-2 - Type 3 Habitat

Maralumi River - TribC-2 - Type 3 Habitat




Markham River DS - Mark-2 - Type 4 Habitat




Markham River US - Mark-1 - Type 4 Habitat

ATTACHMENT 2

Fish and macrocrustacean electrofishing data

site_code	site_name	replicate	start_sec	end_sec	species	length	LT	weight
TribE-2	Wawim River US	1	6309	6406	Clarius batrachus	154		30.6
TribE-2	Wawim River US				Clarius batrachus	175		43.4
TribE-2	Wawim River US				Anguilla bicolor	375		131.6
TribE-2	Wawim River US	2	6406	6465	Chilatherina bulolo	94		13.3
TribE-2	Wawim River US				Chilatherina bulolo	63		4
TribE-2	Wawim River US				Chilatherina bulolo	55		3
TribE-2	Wawim River US				Chilatherina bulolo	66		4.6
TribE-2	Wawim River US				Chilatherina bulolo	64		4.5
TribE-2	Wawim River US				Chilatherina bulolo	60		3.4
TribE-2	Wawim River US				Xiphophorus helleri	40		1.1
TribE-2	Wawim River US				Xiphophorus helleri	40		1
TribE-2	Wawim River US	3	6465	6500	Clarius batrachus	156		31.3
TribE-2	Wawim River US				Clarius batrachus	150		28.8
TribE-2	Wawim River US				Clarius batrachus	143		23.4
TribE-2	Wawim River US				Chilatherina bulolo	64		4.4
TribE-2	Wawim River US				Chilatherina bulolo	55		3
TribE-2	Wawim River US				Chilatherina bulolo	50		2.2
TribE-2	Wawim River US				Chilatherina bulolo	57		3
TribE-2	Wawim River US	4	6500	6565	Clarius batrachus	125		17.2
TribE-2	Wawim River US				Chilatherina bulolo	52		2
TribE-2	Wawim River US				Chilatherina bulolo	57		3.9
TribE-2	Wawim River US	5	6565	6628	Chilatherina bulolo	58		4.2
TribE-2	Wawim River US				Chilatherina bulolo	57		2.7
TribE-2	Wawim River US				Chilatherina bulolo	59		2.7
TribE-2	Wawim River US				Chilatherina bulolo	60		3.2
TribE-2	Wawim River US				Chilatherina bulolo	50		2.1
TribE-2	Wawim River US				Chilatherina bulolo	44		1
TribE-2	Wawim River US				Chilatherina bulolo	42		1
TribE-2	Wawim River US				Xiphophorus helleri	37		0.8
Rumu-1	Rumu River US	1	6628	6743	No catch			
Rumu-1	Rumu River US	2	6734	6870	Tor putitora	63		2.8
Rumu-1	Rumu River US				Chilatherina bulolo	46		1.1
Rumu-1	Rumu River US				Chilatherina bulolo	35		0.5
Rumu-1	Rumu River US	3	6870	6970	Awaous melanocephalus	56		1.5
Rumu-1	Rumu River US	4	6970	7105	Tor putitora	180		83.5
Rumu-1	Rumu River US	5	7105	7243	Tor putitora	139		59.6
Rumu-1	Rumu River US				Tor putitora	65		3.6
Rumu-1	Rumu River US				Tor putitora	67		2.9
TribF-1	Klin Wara US	1	7243	7358	Glossamia gjellerupi	76		5.5
TribF-1	Klin Wara US				Glossamia gjellerupi	65		3
TribF-1	Klin Wara US				Oreochromis mossambica	116		25.3
TribF-1	Klin Wara US				Awaous melanocephalus	96		9.6
TribF-1	Klin Wara US				Awaous melanocephalus	103		10.7
TribF-1	Klin Wara US				Awaous melanocephalus	54		1.2
TribF-1	Klin Wara US				Awaous melanocephalus	44		0.9
TribF-1	Klin Wara US				Gambusia affinis	34		0.3
TribF-1	Klin Wara US				Gambusia affinis	30		0.2
TribF-1	Klin Wara US				Melanotaenia affinis	80		6.8
TribF-1	Klin Wara US				Melanotaenia affinis	70		3.9
TribF-1	Klin Wara US				Melanotaenia affinis	53		1.7
TribF-1	Klin Wara US	2	7358	7469	Tor putitora	220		210.6
TribF-1	Klin Wara US				Chilatherina bulolo	54		1.4
TribF-1	Klin Wara US				Chilatheria crassispinosa	70		3.8
TribF-1	Klin Wara US				Awaous melanocephalus	35	<	0.1
TribF-1	Klin Wara US				Awaous melanocephalus	28	<	0.1
TribF-1	Klin Wara US	3	7469	7575	Hephaestus transmontanus	77		9.7
TribF-1	Klin Wara US				Hephaestus transmontanus	90		11.8
TribF-1	Klin Wara US				Hephaestus transmontanus	73		7.6
TribF-1	Klin Wara US				Hephaestus transmontanus	81		11.7
TribF-1	Klin Wara US				Chilatherina bulolo	60		2.3
TribF-1	Klin Wara US				Chilatherina bulolo	55		1.5
TribF-1	Klin Wara US				Chilatherina bulolo	55		1.3
TribF-1	Klin Wara US				Chilatherina bulolo	45		0.9
TribF-1	Klin Wara US				Chilatheria crassispinosa	53		1.2
TribF-1	Klin Wara US				Valamugil buchanani	98		14.2

TribF-1	Klin Wara US				Valamugil buchanani	110		25.5
TribF-1	Klin Wara US				Awaous melanocephalus	45		0.2
TribF-1	Klin Wara US	4	7575	7740	Valamugil buchanani	138		43.5
TribF-1	Klin Wara US				Awaous melanocephalus	70		3.4
TribF-1	Klin Wara US				Awaous melanocephalus	39		0.4
TribF-1	Klin Wara US	5	7740	7799	No catch			
TribF-2	Klin Wara DS	1	7799	7909	Macrobrachium australe	45.7		19.3
TribF-2	Klin Wara DS				Macrobrachium australe	43.4		17.6
TribF-2	Klin Wara DS				Macrobrachium australe	39.5		13.5
TribF-2	Klin Wara DS				Macrobrachium australe	37		9.9
TribF-2	Klin Wara DS				Macrobrachium australe	37.1		8.5
TribF-2	Klin Wara DS				Macrobrachium australe	28.9		4.3
TribF-2	Klin Wara DS				Macrobrachium australe	25.7		2.9
TribF-2	Klin Wara DS				Macrobrachium australe	24.7		2.1
TribF-2	Klin Wara DS				Macrobrachium australe	27.2		3.2
TribF-2	Klin Wara DS				Macrobrachium australe	31.7		4
TribF-2	Klin Wara DS				Macrobrachium australe	21		0.5
TribF-2	Klin Wara DS				Macrobrachium australe	19		0.7
TribF-2	Klin Wara DS				Macrobrachium australe	17.7		0.4
TribF-2	Klin Wara DS				Macrobrachium australe	17.5		0.5
TribF-2	Klin Wara DS				Anguilla bicolor	147		3.6
TribF-2	Klin Wara DS	2	7909	7970	Valamugil buchanani	109		16.1
TribF-2	Klin Wara DS				Valamugil buchanani	100		13.6
TribF-2	Klin Wara DS				Macrobrachium australe	45.7		17.9
TribF-2	Klin Wara DS				Macrobrachium australe	29.5		4.4
TribF-2	Klin Wara DS				Macrobrachium australe	25.9		2.5
TribF-2	Klin Wara DS				Macrobrachium australe	30.1		5.7
TribF-2	Klin Wara DS				Macrobrachium australe	23.2		2.9
TribF-2	Klin Wara DS				Macrobrachium australe	34.9		6.6
TribF-2	Klin Wara DS				Macrobrachium australe	28.9		3.6
TribF-2	Klin Wara DS				Macrobrachium australe	23.9		3.9
TribF-2	Klin Wara DS				Macrobrachium australe	24.4		1.9
TribF-2	Klin Wara DS				Macrobrachium australe	23.9		1.9
TribF-2	Klin Wara DS				Macrobrachium australe	27.4		1.7
TribF-2	Klin Wara DS				Macrobrachium australe	22.3		4.1
TribF-2	Klin Wara DS				Macrobrachium australe	17.9		1.1
TribF-2	Klin Wara DS	3	7970	8129	Macrobrachium australe	44.4		14.9
TribF-2	Klin Wara DS				Macrobrachium australe	30.5		5.8
TribF-2	Klin Wara DS				Macrobrachium australe	29.8		4.6
TribF-2	Klin Wara DS				Macrobrachium australe	36.7		6.6
TribF-2	Klin Wara DS				Macrobrachium australe	35		6.2
TribF-2	Klin Wara DS				Macrobrachium australe	32.7		5.2
TribF-2	Klin Wara DS				Macrobrachium australe	30.8		3.9
TribF-2	Klin Wara DS				Macrobrachium australe	26.7		3.6
TribF-2	Klin Wara DS				Macrobrachium australe	27		4
TribF-2	Klin Wara DS				Macrobrachium australe	26.3		2
TribF-2	Klin Wara DS				Macrobrachium australe	23.4		1.1
TribF-2	Klin Wara DS				Macrobrachium australe	21.7		1.4
TribF-2	Klin Wara DS				Macrobrachium australe	24		1.8
TribF-2	Klin Wara DS				Macrobrachium australe	20.2		0.7
TribF-2	Klin Wara DS				Macrobrachium australe	19.2		0.4
TribF-2	Klin Wara DS				Macrobrachium australe	20		1.5
TribF-2	Klin Wara DS				Awaous melanocephalus	47.3		1
TribF-2	Klin Wara DS				Anguilla bicolor	142		4.2
TribF-2	Klin Wara DS				Anguilla bicolor	122		2.4
TribF-2	Klin Wara DS	4	8129	8186	Valamugil buchanani	150		53.8
TribF-2	Klin Wara DS				Valamugil buchanani	135		37.8
TribF-2	Klin Wara DS				Hephaestus transmontanus	59		3.3
TribF-2	Klin Wara DS	5	Not done					
TribC-2	Maralumi River DS	1	8186	8366	Valamugil buchanani	110		19.6
TribC-2	Maralumi River DS				Valamugil buchanani	101		14.9
TribC-2	Maralumi River DS				Awaous melanocephalus	95		11.6
TribC-2	Maralumi River DS				Awaous melanocephalus	42		0.7
TribC-2	Maralumi River DS				Awaous melanocephalus	31		0.3
TribC-2	Maralumi River DS				Xiphophorus helleri	67		3.7
TribC-2	Maralumi River DS				Xiphophorus helleri	55		2.3

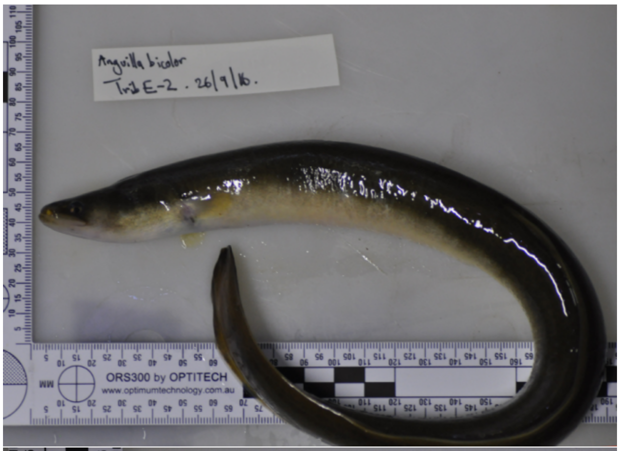
TribC-2	Maralumi River DS				Xiphophorus helleri	36		0.5
TribC-2	Maralumi River DS				Xiphophorus helleri	60		3.3
TribC-2	Maralumi River DS				Melanotaenia affinis	59		1.9
TribC-2	Maralumi River DS				Melanotaenia affinis	70		4.1
TribC-2	Maralumi River DS				Melanotaenia affinis	68		3.4
TribC-2	Maralumi River DS				Melanotaenia affinis	55		2.1
TribC-2	Maralumi River DS				Melanotaenia affinis	65		4
TribC-2	Maralumi River DS				Melanotaenia affinis	49		1.7
TribC-2	Maralumi River DS				Melanotaenia affinis	40		1
TribC-2	Maralumi River DS				Chilatheria crassispinosa	67		3.3
TribC-2	Maralumi River DS				Chilatheria crassispinosa	84		9.6
TribC-2	Maralumi River DS				Chilatherina bulolo	64		2.9
TribC-2	Maralumi River DS				Chilatherina bulolo	60		2.4
TribC-2	Maralumi River DS				Chilatherina bulolo	43		0.8
TribC-2	Maralumi River DS				Chilatherina bulolo	42		0.9
TribC-2	Maralumi River DS				Chilatherina bulolo	42		0.5
TribC-2	Maralumi River DS				Chilatherina bulolo	44		0.9
TribC-2	Maralumi River DS				Chilatherina bulolo	32		0.4
TribC-2	Maralumi River DS				Chilatherina bulolo	21		0.2
TribC-2	Maralumi River DS				Chilatherina bulolo	26		0.2
TribC-2	Maralumi River DS				Tor putitora	66		3.4
TribC-2	Maralumi River DS	2	8366	8472	Oreochromis mossambica	80		11.3
TribC-2	Maralumi River DS				Hephaestus transmontanus	102		16.9
TribC-2	Maralumi River DS				Xiphophorus helleri	50		1.4
TribC-2	Maralumi River DS				Xiphophorus helleri	50		1.4
TribC-2	Maralumi River DS				Xiphophorus helleri	52		1.6
TribC-2	Maralumi River DS				Xiphophorus helleri	59		2.2
TribC-2	Maralumi River DS				Xiphophorus helleri	55		2.6
TribC-2	Maralumi River DS				Xiphophorus helleri	51		1.7
TribC-2	Maralumi River DS				Xiphophorus helleri	58		3
TribC-2	Maralumi River DS				Chilatheria crassispinosa	70		4.2
TribC-2	Maralumi River DS				Chilatheria crassispinosa	61		2.3
TribC-2	Maralumi River DS				Chilatheria crassispinosa	61		2.7
TribC-2	Maralumi River DS				Melanotaenia affinis	47		1.2
TribC-2	Maralumi River DS				Melanotaenia affinis	46		1.4
TribC-2	Maralumi River DS				Melanotaenia affinis	54		1.9
TribC-2	Maralumi River DS				Melanotaenia affinis	49		1.4
TribC-2	Maralumi River DS				Melanotaenia affinis	37		0.6
TribC-2	Maralumi River DS				Melanotaenia affinis	57		2.4
TribC-2	Maralumi River DS				Melanotaenia affinis	46		1.4
TribC-2	Maralumi River DS				Chilatherina bulolo	35		0.5
TribC-2	Maralumi River DS				Chilatherina bulolo	26		0.2
TribC-2	Maralumi River DS				Chilatherina bulolo	28		0.2
TribC-2	Maralumi River DS				Chilatherina bulolo	24		0.3
TribC-2	Maralumi River DS				Awaous melanocephalus	51		1.5
TribC-2	Maralumi River DS				Anguilla bicolor	150		4
TribC-2	Maralumi River DS	3	8472	8552	Anguilla bicolor	178		7.2
TribC-2	Maralumi River DS				Melanotaenia affinis	43		0.8
TribC-2	Maralumi River DS				Awaous melanocephalus	50		1.3
TribC-2	Maralumi River DS				Awaous melanocephalus	31		0.4
TribC-2	Maralumi River DS				Awaous melanocephalus	36		0.6
TribC-2	Maralumi River DS				Awaous melanocephalus	31		0.3
TribC-2	Maralumi River DS	4	8552	8631	Melanotaenia affinis	68		2.9
TribC-2	Maralumi River DS				Melanotaenia affinis	42		0.9
TribC-2	Maralumi River DS				Melanotaenia affinis	44		0.7
TribC-2	Maralumi River DS				Xiphophorus helleri	55		2.5
TribC-2	Maralumi River DS				Awaous melanocephalus	45		0.9
TribC-2	Maralumi River DS	5	Not done					
TribA-1	TribA-1	1	8631	8743	Chilatherina bulolo	70		4.1
TribA-1	TribA-1				Chilatherina bulolo	61		2.6
TribA-1	TribA-1				Chilatherina bulolo	52		1.8
TribA-1	TribA-1				Chilatherina bulolo	45		1.4
TribA-1	TribA-1				Chilatherina bulolo	50		2.1
TribA-1	TribA-1				Chilatherina bulolo	36		1.1
TribA-1	TribA-1				Chilatherina bulolo	47		1.5
TribA-1	TribA-1				Chilatherina bulolo	42		1.8

TribA-1	TribA-1				Chilatherina bulolo	42		1.7
TribA-1	TribA-1				Chilatherina bulolo	46		1.4
TribA-1	TribA-1				Chilatherina bulolo	37		0.9
TribA-1	TribA-1				Chilatherina bulolo	45		1.3
TribA-1	TribA-1				Chilatherina bulolo	38		0.9
TribA-1	TribA-1				Chilatherina bulolo	36		1
TribA-1	TribA-1				Chilatherina bulolo	33		1.1
TribA-1	TribA-1				Awaous melanocephalus	77		5.4
TribA-1	TribA-1				Awaous melanocephalus	80		5.3
TribA-1	TribA-1				Awaous melanocephalus	70		3.7
TribA-1	TribA-1				Clarius batrachus	50		1
TribA-1	TribA-1	2	8743	8844	Chilatherina bulolo	65		2.7
TribA-1	TribA-1				Chilatherina bulolo	70		4.7
TribA-1	TribA-1				Chilatherina bulolo	56		2.2
TribA-1	TribA-1				Chilatherina bulolo	42		0.9
TribA-1	TribA-1				Chilatherina bulolo	45		1.3
TribA-1	TribA-1				Chilatherina bulolo	42		1.1
TribA-1	TribA-1				Chilatherina bulolo	38		0.7
TribA-1	TribA-1				Chilatherina bulolo	40		0.9
TribA-1	TribA-1				Chilatherina bulolo	40		0.8
TribA-1	TribA-1				Chilatherina bulolo	41		0.9
TribA-1	TribA-1				Chilatherina bulolo	38		0.5
TribA-1	TribA-1				Chilatherina bulolo	36		0.6
TribA-1	TribA-1				Chilatherina bulolo	35		0.5
TribA-1	TribA-1				Chilatherina bulolo	32		0.3
TribA-1	TribA-1				Chilatherina bulolo	25		0.2
TribA-1	TribA-1				Awaous melanocephalus	26		0.3
TribA-1	TribA-1				Awaous melanocephalus	21		0.1
TribA-1	TribA-1	3	8844	8926	Chilatherina bulolo	75		5.2
TribA-1	TribA-1				Chilatherina bulolo	68		4.8
TribA-1	TribA-1				Chilatherina bulolo	70		5.4
TribA-1	TribA-1				Chilatherina bulolo	56		2.3
TribA-1	TribA-1				Chilatherina bulolo	62		3.1
TribA-1	TribA-1				Chilatherina bulolo	70		3.3
TribA-1	TribA-1				Chilatherina bulolo	60		2
TribA-1	TribA-1				Chilatherina bulolo	53		2.1
TribA-1	TribA-1				Chilatherina bulolo	51		1.6
TribA-1	TribA-1				Chilatherina bulolo	45		0.9
TribA-1	TribA-1				Chilatherina bulolo	43		1.2
TribA-1	TribA-1				Chilatherina bulolo	50		1.4
TribA-1	TribA-1				Chilatherina bulolo	31		0.6
TribA-1	TribA-1				Chilatherina bulolo	44		0.9
TribA-1	TribA-1				Chilatherina bulolo	40		1
TribA-1	TribA-1				Chilatherina bulolo	40		0.8
TribA-1	TribA-1				Chilatherina bulolo	38		0.8
TribA-1	TribA-1				Chilatherina bulolo	35		0.5
TribA-1	TribA-1				Chilatherina bulolo	34		0.6
TribA-1	TribA-1				Awaous melanocephalus	91		9.2
TribA-1	TribA-1				Awaous melanocephalus	61		3
TribA-1	TribA-1				Awaous melanocephalus	50		1.8
TribA-1	TribA-1	4	8926	9049	Chilatherina bulolo	56		2.5
TribA-1	TribA-1				Chilatherina bulolo	52		2.1
TribA-1	TribA-1				Chilatherina bulolo	45		1.3
TribA-1	TribA-1				Chilatherina bulolo	56		2.5
TribA-1	TribA-1				Chilatherina bulolo	50		1.6
TribA-1	TribA-1				Chilatherina bulolo	48		1.4
TribA-1	TribA-1				Chilatherina bulolo	45		1.4
TribA-1	TribA-1				Chilatherina bulolo	50		1.3
TribA-1	TribA-1				Chilatherina bulolo	45		1.1
TribA-1	TribA-1				Chilatherina bulolo	42		1.5
TribA-1	TribA-1				Chilatherina bulolo	46		1.2
TribA-1	TribA-1				Chilatherina bulolo	40		0.9
TribA-1	TribA-1				Chilatherina bulolo	44		1.1
TribA-1	TribA-1				Chilatherina bulolo	40		0.8
TribA-1	TribA-1				Chilatherina bulolo	42		0.9
TribA-1	TribA-1				Chilatherina bulolo	37		0.6

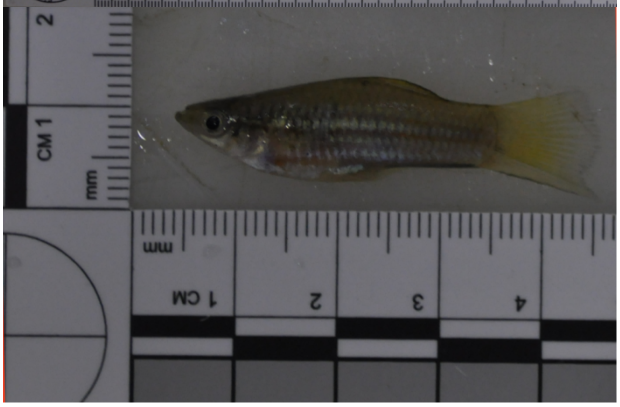
TribA-1	TribA-1				Chilatherina bulolo	41		0.8
TribA-1	TribA-1				Chilatherina bulolo	40		0.7
TribA-1	TribA-1				Chilatherina bulolo	30		0.4
TribA-1	TribA-1				Chilatherina bulolo	35		0.4
TribA-1	TribA-1				Awaous melanocephalus	83		5.1
TribA-1	TribA-1				Awaous melanocephalus	50		1.4
TribA-1	TribA-1				Awaous melanocephalus	35		0.5
Mark-2-actual	Markham River US	1	9049	9227	Awaous melanocephalus	30		0.1
Mark-2-actual	Markham River US				Macrobrachium australe	34		7.7
Mark-2-actual	Markham River US				Macrobrachium australe	24		2.7
Mark-2-actual	Markham River US				Macrobrachium australe	28		2.8
Mark-2-actual	Markham River US				Macrobrachium australe	13	<	0.1
Mark-2-actual	Markham River US				Macrobrachium australe	8.9	<	0.1
Mark-2-actual	Markham River US	2	9227	9424	Chilatherina bulolo	32		0.4
Mark-2-actual	Markham River US				Chilatherina bulolo	29		0.1
Mark-2-actual	Markham River US				Chilatherina bulolo	24	<	0.1
Mark-2-actual	Markham River US				Macrobrachium australe	30		4
Mark-2-actual	Markham River US				Macrobrachium australe	18		0.6
Mark-2-actual	Markham River US				Macrobrachium australe	23.1		1.8
Mark-2-actual	Markham River US				Macrobrachium australe	21		1.3
Mark-2-actual	Markham River US				Macrobrachium australe	17		1.3
Mark-2-actual	Markham River US				Macrobrachium australe	16		0.6
Mark-2-actual	Markham River US				Macrobrachium australe	16.8		0.9
Mark-2-actual	Markham River US				Macrobrachium australe	15.3		0.4
Mark-2-actual	Markham River US				Macrobrachium australe	17.9		0.7
Mark-2-actual	Markham River US				Macrobrachium australe	15.7		0.3
Mark-2-actual	Markham River US				Macrobrachium australe	14.6		0.3
Mark-2-actual	Markham River US				Macrobrachium australe	13.2		0.4
Mark-2-actual	Markham River US				Macrobrachium australe	8	<	0.1
Mark-2-actual	Markham River US				Macrobrachium australe	10		0.3
Mark-2-actual	Markham River US	3	9424	9531	Chilatherina bulolo	34		0.5
Mark-2-actual	Markham River US				Chilatherina bulolo	31.6		4.2
Mark-2-actual	Markham River US				Chilatherina bulolo	35.4		5.7
Mark-2-actual	Markham River US				Chilatherina bulolo	29		2.4
Mark-2-actual	Markham River US				Chilatherina bulolo	28.9		1.9
Mark-2-actual	Markham River US				Chilatherina bulolo	26		1.6
Mark-2-actual	Markham River US				Chilatherina bulolo	23.1		1.3
Mark-2-actual	Markham River US				Chilatherina bulolo	11.5		0.2
Mark-2-actual	Markham River US				Chilatherina bulolo	14.4		0.4
Mark-2-actual	Markham River US	4	Not done					
Mark-2-actual	Markham River US	5	Not done					
Rumu-2	Rumu River DS	1	9531	9679	Tor putitora	141		60.8
Rumu-2	Rumu River DS				Tor putitora	60		3.6
Rumu-2	Rumu River DS				Tor putitora	55		2.5
Rumu-2	Rumu River DS				Tor putitora	54		1.8
Rumu-2	Rumu River DS				Xiphophorus helleri	51		2
Rumu-2	Rumu River DS				Chilatherina bulolo	62		3.4
Rumu-2	Rumu River DS				Chilatherina bulolo	67		3.6
Rumu-2	Rumu River DS				Chilatherina bulolo	54		1.8
Rumu-2	Rumu River DS				Chilatherina bulolo	49		1.3
Rumu-2	Rumu River DS				Awaous melanocephalus	68		4
Rumu-2	Rumu River DS				Awaous melanocephalus	75		4.1
Rumu-2	Rumu River DS				Awaous melanocephalus	50		1.6
Rumu-2	Rumu River DS				Awaous melanocephalus	53		1.5
Rumu-2	Rumu River DS	2	9679	9793	Chilatherina bulolo	46		1.2
Rumu-2	Rumu River DS				Chilatherina bulolo	63		3.1
Rumu-2	Rumu River DS				Awaous melanocephalus	74		3.9
Rumu-2	Rumu River DS				Awaous melanocephalus	74		3.9
Rumu-2	Rumu River DS				Tor putitora	50		1.6
Rumu-2	Rumu River DS				Tor putitora	44		1.2
Rumu-2	Rumu River DS	3	9793	9897	Awaous melanocephalus	51		1.3
Rumu-2	Rumu River DS				Awaous melanocephalus	54		1.6
Rumu-2	Rumu River DS				Awaous melanocephalus	45		1.1
Rumu-2	Rumu River DS				Chilatherina bulolo	63		3.4
Rumu-2	Rumu River DS	4	Not done					
Rumu-2	Rumu River DS	5	Not done					

ATTACHMENT 3

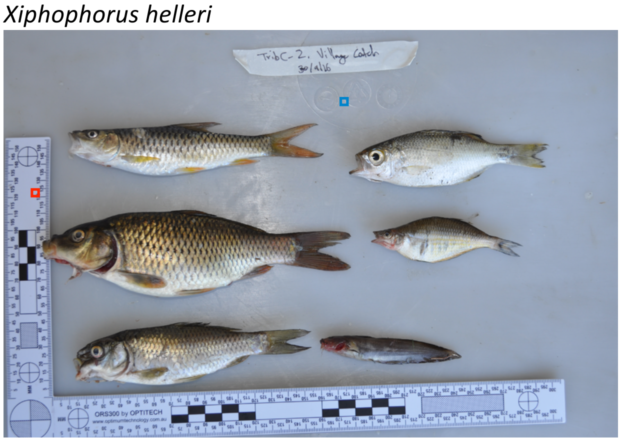
Fish and macrocrustacean specimen photo collection



Macrobrachium australe



Xiphophorus helleri



Cyprinus carpio (red), *Kuhlia marginata* (blue)

ATTACHMENT 4

Macroinvertebrate raw data

Electronic file can be supplied on request

Reference	Phylum	Subphylum	Class	Subclass	Order	Suborder	Family	Subfamily	*Genus*	Species	Life stage	TribE-2 Wawim River US 603-5-001	603-5-002	603-5-003	603-5-004	603-5-005	Rumu-1 Rumu River US 603-5-006
77	Formanifera								Formanifera	sp. 1		0	0	1	0	0	0
	Nematoda								Nematoda	sp. 1		0	0	0	0	0	0
20	Nemertea								Nemertea	sp. 1		0	0	0	0	0	0
40	Mollusca		Gastropoda		Hygrophila		Lymnaeidae		Lymnaeidae	sp. 1		0	0	0	0	0	0
71	Mollusca		Gastropoda		Hygrophila		Lymnaeidae		Lymnaeidae	sp. 2		1	0	0	0	0	0
124	Mollusca		Gastropoda		Hygrophila		Planorbidae		Planorbidae	sp. 1		1	0	0	0	0	0
167	Mollusca		Gastropoda		Hygrophila		Planorbidae		*Ferrisa*	sp.1		0	0	0	0	0	0
190	Mollusca		Gastropoda		Hygrophila		Planorbidae		Planorbidae	sp. 2		0	0	0	0	0	0
152	Mollusca		Gastropoda		Hygrophila		Thiaridae		*Thiara*	sp.1		0	0	0	0	0	0
207	Mollusca		Gastropoda		Hygrophila		Thiaridae		*Thiara*	sp. 2		0	0	0	0	0	0
145	Annelida		Clitellata		Oligochaeta		Lumbriculidae		*cf. Lumbriculus*	sp.		0	0	0	0	0	0
27	Annelida		Clitellata		Oligochaeta				*Oligochaeta*	sp. 1		0	0	0	0	0	1
62	Annelida		Clitellata		Oligochaeta		Naididae		*Pristina*	sp. 1		0	0	0	0	0	0
180	Annelida		Clitellata		Oligochaeta		Naididae		*Pristina*	sp.2		0	0	0	0	0	0
21	Arthropoda		Arachnida	Acarina	Orbatida				Orbatida	sp. 1		0	0	0	0	0	0
99	Arthropoda		Arachnida	Acari	Orbatida				Orbatida	sp. 2		2	0	0	1	1	0
123	Arthropoda		Arachnida	Acari	Orbatida				Orbatida	sp.2a		0	0	0	0	0	0
	Arthropoda		Arachnida	Acari	Orbatida				Orbatida	sp, (immature)		0	0	0	0	0	0
69	Arthropoda		Arachnida	Acari	Mesostigmata				Mesostigmata	sp. 1	immature	0	0	0	1	0	0
121	Arthropoda		Arachnida	Acari	Hydracarina					spp.	immature	0	0	0	0	0	0
136	Arthropoda		Arachnida	Acari	Trombidiformes		Trombidiidae		Trombidiidae	sp. 1		0	0	0	0	0	0
92	Arthropoda		Arachnida	Acari					unid.	sp. 1		0	0	0	0	0	1
93	Arthropoda		Arachnida	Acari					unid.	sp. 2		0	0	0	0	0	1
94	Arthropoda		Arachnida	Acari					unid.	sp. 3	immature	0	0	0	0	1	1
70	Arthropoda		Arachnida	Aranae					Arachnid (juvenile)	sp. 1	juvenile	0	0	0	0	0	0
87	Arthropoda		Arachnida	Aranae					Arachnid (juvenile)	sp. 2	juvenile	0	0	0	0	0	0
118	Arthropoda		Arachnida	Aranae			Pisauridae		*Dolomedes*	sp.	adult	0	0	0	0	0	0
174	Arthropoda		Arachnida	Aranae			Lycosidae		Lycosidae	sp. 1	adult	0	0	0	0	0	0
	Arthropoda		Ostracoda						Ostracoda	sp.		0	0	0	0	0	0
	Arthropoda		Crustacea		Decapoda		Palaemonidae		*Macrobrachium*	australe		0	0	0	0	0	0
24	Arthropoda		Crustacea		Decapoda		Palaemonidae		Palaemonidae	sp. (first stage larvae)	first stage	0	0	0	0	0	0
61	Arthropoda		Crustacea		Decapoda		Palaemonidae		Palaemonidae	sp. 1		0	0	0	0	0	0
64	Arthropoda		Crustacea		Decapoda		Atyidae		*cf. Caridina*	sp. 1		0	0	0	0	0	0
65	Arthropoda		Crustacea		Decapoda		Palaemonidae		*Palaemon*	sp. (juvenile)		0	0	0	0	0	0
66	Arthropoda		Crustacea		Decapoda		Palaemonidae		Palaemonidae	sp.2		0	0	0	0	0	0
68	Collembola		Entognatha		Entomobryomorpha		Isotomidae		Isotomidae	sp.1		0	0	0	0	0	0
81	Collembola		Entognatha		Entomobryomorpha		Isotomidae		Isotomidae	sp. 2		0	0	0	0	0	0
100	Collembola		Entognatha		Entomobryomorpha		Isotomidae		Isotomidae	sp. 3		0	0	0	0	0	0
135	Collembola		Entognatha		Entomobryomorpha		Isotomidae		Isotomidae	sp. 4		0	0	0	0	0	0
	Collembola		Entognatha		Entomobryomorpha		Isotomidae		Isotomidae	spp. (juv)		0	0	0	0	1	0
139	Collembola		Entognatha		Symphypleona		Sminthurididae		Sminthurididae	sp. 1		0	0	0	0	0	0
140	Collembola		Entognatha		Symphypleona		Sminthurididae		Sminthurididae	sp. 2		0	0	0	0	0	0
80	Arthropoda		Insecta		Ephemeroptera		Caenidae		*Tasmanocoenis*	spp. (immature nymph)	immature	0	0	0	0	2	0
98	Arthropoda		Insecta		Ephemeroptera		Caenidae		*Tasmanocoenis*	spp.	mature ny	0	0	0	0	0	0
208	Arthropoda		Insecta		Ephemeroptera		Caenidae		*Wundacaenis*	sp.	mature ny	0	0	0	0	0	0
	Arthropoda		Insecta		Ephemeroptera		Caenidae		Caenidae	spp. (immature nymph)	immature	11	81	0	8	22	0
5	Arthropoda		Insecta		Ephemeroptera		Baetidae		*(Offadens?)*	sp. 1	mature ny	0	0	0	0	0	0
6	Arthropoda		Insecta		Ephemeroptera		Baetidae		*(Offadens?)*	sp. 2	mature ny	0	0	0	0	0	0
22	Arthropoda		Insecta		Ephemeroptera		Baetidae		*Offadens*	sp. 3	mature ny	0	0	0	0	2	0
63	Arthropoda		Insecta		Ephemeroptera		Baetidae		*Offadens*	sp. 4	mature ny	5	0	0	0	0	0
168	Arthropoda		Insecta		Ephemeroptera		Baetidae		*Offadens*	sp. 5	mature ny	0	0	0	0	0	0
	Arthropoda		Insecta		Ephemeroptera		Baetidae		*Offadens*	spp.	mature ny	0	1	0	3	2	0
111	Arthropoda		Insecta		Ephemeroptera		Baetidae		*Platybaetis*	sp. 1	mature ny	0	0	0	0	0	0
31	Arthropoda		Insecta		Ephemeroptera		Baetidae		*Playtybaetis sp. (immature nymph)*		immature	6	5	0	1	4	1
7	Arthropoda		Insecta		Ephemeroptera		Baetidae			sp. 3	mature ny	0	0	0	0	0	0
101	Arthropoda		Insecta		Ephemeroptera		Baetidae			sp. 4	mature ny	0	1	0	0	0	0
183	Arthropoda		Insecta		Ephemeroptera		Baetidae			sp. 5	mature ny	0	0	0	0	0	0
205	Arthropoda		Insecta		Ephemeroptera		Baetidae			sp. 6	mature ny	0	0	0	0	0	0
206	Arthropoda		Insecta		Ephemeroptera		Baetidae			sp. 7	mature ny	0	0	0	0	0	0
	Arthropoda		Insecta		Ephemeroptera		Baetidae			spp. (immature nymph/part specimen)		152	638	36	71	205	1
2	Arthropoda		Insecta		Ephemeroptera		Leptophlebiidae		*Thraulus*	sp. 1 (immature nymph)	immature	0	0	0	0	0	0
4	Arthropoda		Insecta		Ephemeroptera		Leptophlebiidae		*Thraulus*	sp. 2 (mature nymph -prev sp.2)		0	0	0	0	0	0
3	Arthropoda		Insecta		Ephemeroptera		Leptophlebiidae		Leptophlebiidae	spp. (immature nymph)		2	0	1	0	1	0
115	Arthropoda		Insecta		Odonata	Zygoptera	Calopterygidae		*Neurobasis*	cf. chinensis		0	0	0	0	0	0
95	Arthropoda		Insecta		Odonata	Epiprocta	Libellulidae		Libellulidae	sp.1	immature	0	0	0	0	0	0
96	Arthropoda		Insecta		Odonata	Epiprocta	Libellulidae		Libellulidae	sp.2	immature	0	1	0	0	0	0
131	Arthropoda		Insecta		Odonata	Epiprocta	Libellulidae		Libellulidae	sp. 3	mature ny	0	4	0	0	1	0
153	Arthropoda		Insecta		Odonata	Epiprocta	Libellulidae		*Nannophlebia*	sp. 1	mature ny	0	0	0	0	0	0
49	Arthropoda		Insecta		Odonata	Epiprocta				sp.	(immatur	0	4	0	0	3	0
48	Arthropoda		Insecta		Hemiptera				*unid.*	sp. 1	immature	0	0	0	3	2	0
50	Arthropoda		Insecta		Hemiptera				*unid.*	sp. 2	immature	0	0	0	0	0	0
56	Arthropoda		Insecta		Hemiptera		Naucoridae		Naucoridae	sp. 1	adult	0	0	0	0	0	0
57	Arthropoda		Insecta		Hemiptera		Naucoridae		Naucoridae	sp. 2	adult	0	1	0	0	0	0
58	Arthropoda		Insecta		Hemiptera		Naucoridae		Naucoridae	sp. 3	adult	0	1	0	0	0	0
103	Arthropoda		Insecta		Hemiptera		Naucoridae		Naucoridae	sp. 4	adult	0	1	0	0	0	0
154	Arthropoda		Insecta		Hemiptera		Naucoridae		Naucoridae	sp. 5	adult	0	0	0	0	1	0
59	Arthropoda		Insecta		Hemiptera		Naucoridae		*Naucoris*	sp. 1	adult	0	1	0	0	0	0
129	Arthropoda		Insecta		Hemiptera		Naucoridae		*Naucoris*	sp. 2	adult	0	0	0	0	0	0
132	Arthropoda		Insecta		Hemiptera		Naucoridae		*Naucoris*	sp.3	adult	0	1	0	0	0	0
155	Arthropoda		Insecta		Hemiptera		Naucoridae		Naucoridae	sp. A	juvenile	0	0	0	0	0	0
184	Arthropoda		Insecta		Hemiptera		Naucoridae		Naucoridae	sp. B	juvenile	0	0	0	0	0	0
112	Arthropoda		Insecta		Hemiptera		Aphididae		Aphididae	sp.	juvenile	0	0	0	0	0	0
141	Arthropoda		Insecta		Hemiptera		Aphididae		Aphididae	sp. 1	adult	0	0	0	0	0	0
120	Arthropoda		Insecta		Hemiptera		Mesovelidae		*Mesovelia*	sp. (juv)	juvenile	0	0	0	0	0	0
142	Arthropoda		Insecta		Hemipera		Velidae		Velidae	sp. 1	juvenile	0	0	0	0	0	0
147	Arthropoda		Insecta		Hemiptera		Velidae		*Rhagovelia*	sp. 1	adult	0	0	0	0	0	0
189	Arthropoda		Insecta		Hemiptera		Gerridae		Gerridae	sp. 1	mature ny	0	0	0	0	0	0
34	Arthropoda		Insecta		Coleoptera		Elmidae		*Notriolus*	sp.1	adult	0	0	0	0	0	0
212	Arthropoda		Insecta		Coleoptera		Elmidae		Elmidae	sp. 1	adult	0	0	0	0	0	0
35	Arthropoda		Insecta		Coleoptera		Elmidae		Elmidae	sp. A	larvae	0	0	0	0	0	0
55	Arthropoda		Insecta		Coleoptera		Elmidae		Elmidae	sp. B	larvae	0	0	0	0	0	0
173	Arthropoda		Insecta		Coleoptera		Elmidae		Elmidae	sp. C	larvae	0	0	0	0	0	0
39	Arthropoda		Insecta		Coleoptera		Elmidae		Elmidae	sp. D	larvae	0	0	0	0	1	0
36	Arthropoda		Insecta		Coleoptera		Psephenidae		Psephenidae	sp. 1	larvae	0	0	0	0	0	0
97	Arthropoda		Insecta		Coleoptera		Hydrophilidae		Hydrophilidae	sp. A	larvae	0	0	0	0	0	0
110	Arthropoda		Insecta		Coleoptera		Hydrophilidae		Hydrophilidae	sp. B	larvae	0	0	0	0	0	0
119	Arthropoda		Insecta		Coleoptera		Hydrophilidae		Hydrophilidae	sp. 1	adult	0	0	0	0	0	0
199	Arthropoda		Insecta		Coleoptera		Hydrophilidae		*Berosus*	sp. 1	pupa	0	0	0	0	0	0
172	Arthropoda		Insecta		Coleoptera		Hydraenidae		Hydraenidae	sp.1	adult	0	0	0	0	0	0
52	Arthropoda		Insecta		Coleoptera		Hydraenidae		*Hydraena*	sp. 1	adult	0	0	0	0	0	0
104	Arthropoda		Insecta		Coleoptera		Hydraenidae		*Hydraena*	sp. 2	adult	0	0	0	0	0	0
179	Arthropoda		Insecta		Coleoptera		Hydraenidae		*Hydraena*	sp. 3	adult	0	0	0	0	0	0
181	Arthropoda		Insecta		Coleoptera		Hydraenidae		*Hydraena*	sp. 4	adult	0	0	0	0	0	0
13	Arthropoda		Insecta		Coleoptera		Chrysomelidae		Chrysomelidae	sp. 1	larvae	0	0	0	0	0	0
200	Arthropoda		Insecta		Coleoptera		Haplidae		Haplidae	sp. 1	adult	0	0	0	0	0	0
177	Arthropoda		Insecta		Coleoptera		Hydrochidae		*Hydrochus*	sp. 1	adult	0	0	0	0	0	0
105	Arthropoda		Insecta		Coleoptera					sp. 1	adult	0	0	0	0	0	0
194	Arthropoda		Insecta		Coleoptera					sp. 2	adult	0	1	0	0	0	0
15	Arthropoda		Insecta		Coleoptera					sp. 3	adult	0	0	0	0	0	0
137	Arthropoda		Insecta		Coleoptera					sp. A	larvae	0	0	0	0	0	0
	Arthropoda		Insecta		Diptera		Simulidae		*Simulium*	sp.	larvae	3	0	0	4	3	0
116	Arthropoda		Insecta		Diptera		Simulidae		*Simulium*	sp.	pupa	1	0	0	0	0	0
1	Arthropoda		Insecta		Diptera		Tipulidae		Tipulidae	sp. 1	larvae	0	0	0	0	0	0
122	Arthropoda		Insecta		Diptera		Tipulidae		Tipulidae	sp.	immature	0	0	0	0	0	0
134	Arthropoda		Insecta		Diptera		Culicidae		*Culex*	sp.	larvae	0	0	0	0	0	0
9	Arthropoda		Insecta		Diptera		Stratiomyidae		*Odontymia*	sp. 1	larvae	0	0	0	0	0	0
14	Arthropoda		Insecta		Diptera (adult)		Chironomidae		Chironomidae	sp.	adult	0	0	1	2	1	0
89	Arthropoda		Insecta		Diptera		Chironomidae			sp. 1	larvae	0	0	0	0	0	1
148	Arthropoda		Insecta		Diptera		Chironomidae			sp. 2	larvae	0	1	0	0	3	0
41	Arthropoda		Insecta		Diptera		Chironomidae			sp. 3	larvae	0	0	0	0	0	0
	Arthropoda		Insecta		Diptera		Chironomidae			spp.	larvae	0	2	0	0	5	0
	Arthropoda		Insecta		Diptera		Chironomidae			sp.	pupa	1	3	0	3	6	0
18	Arthropoda		Insecta		Diptera		Chironom	Chironominae		sp. 1	larvae	0	1	0	0	0	0
19	Arthropoda		Insecta		Diptera		Chironom	Chironominae		sp. 2	larvae	0	0	0	0	0	2
75	Arthropoda		Insecta		Diptera		Chironom	Chironominae		sp. 3	larvae	0	0	2	0	0	0
88	Arthropoda		Insecta		Diptera		Chironom	Chironominae		sp. 4	larvae	0	0	0	0	0	1
144	Arthropoda		Insecta		Diptera		Chironom	Chironominae		sp. 5	larvae	0	0	0	0	0	0
159	Arthropoda		Insecta		Diptera		Chironom	Chironominae		sp. 6	larvae	0	0	0	0	0	0
162	Arthropoda		Insecta		Diptera		Chironom	Chironominae		sp. 7	larvae	0	0	0	0	0	0
163	Arthropoda		Insecta		Diptera		Chironom	Chironominae		sp. 8	larvae	0	0	0	0	0	0
164	Arthropoda		Insecta		Diptera		Chironom	Chironominae		sp. 9	larvae	0	0	0	0	0	0
165	Arthropoda		Insecta		Diptera		Chironom	Chironominae		sp. 10	larvae	0	0	0	0	0	0
175	Arthropoda		Insecta		Diptera		Chironom	Chironominae		sp. 11	larvae	0	0	0	0	0	0
187	Arthropoda		Insecta		Diptera		Chironom	Chironominae		sp. 12	larvae	0	0	0	0	0	0
213	Arthropoda		Insecta		Diptera		Chironom	Chironominae		sp.14	larvae	0	0	0	0	0	0
60	Arthropoda		Insecta		Diptera		Chironom	Chironominae		sp. 15	larvae	0	0	0	0	0	0
29	Arthropoda		Insecta		Diptera		Chironom	Chironominae		sp. 16	larvae	0	0	0	0	0	0
30	Arthropoda		Insecta		Diptera		Chironom	Chironominae		sp. 17	larvae	3	26	0	3	10	0
72	Arthropoda		Insecta		Diptera		Chironom	Chironominae		sp. 18	larvae	0	0	0	0	0	0
84	Arthropoda		Insecta		Diptera		Chironom	Chironominae		sp. 19	larvae	0	0	0	0	0	0
108	Arthropoda		Insecta		Diptera		Chironom	Chironominae		sp. 20	larvae	1	0	0	1	2	0
126	Arthropoda		Insecta		Diptera		Chironom	Chironominae		sp. 21	larvae	2	0	0	0	0	0
128	Arthropoda		Insecta		Diptera		Chironom	Chironominae		sp. 22	larvae	0	2	0	1	0	0
150	Arthropoda		Insecta		Diptera		Chironom	Chironominae		sp. 23	larvae	0	0	0	0	0	0
193	Arthropoda		Insecta		Diptera		Chironom	Chironominae		sp. 24	larvae	0	0	0	0	0	0
178	Arthropoda		Insecta		Diptera		Chironom	Chironom	*Tanytarsus*	spp.	larvae	0	0	0	0	0	0
202	Arthropoda		Insecta		Diptera		Chironom	Chironom	*Stenochironomus*	sp. 1	larvae	0	0	0	0	0	0
203	Arthropoda		Insecta		Diptera		Chironom	Chironom	*Dicrotendipes*	sp. 1	larvae	0	0	0	0	0	0
204 & 99	Arthropoda		Insecta		Diptera		Chironom	Chironom	*Chironomus*	sp.	larvae	0	0	0	0	0	0
	Arthropoda		Insecta		Diptera		Chironom	Chironominae		spp.	larvae	2	0	0	1	0	0
17	Arthropoda		Insecta		Diptera		Chironom	Tanypodi	*(cf. Thiemannimia sp.)*	sp. 1	larvae	0	23	0	0	4	0
76	Arthropoda		Insecta		Diptera		Chironom	Tanypodinae		sp. 2	larvae	0	0	1	0	0	0
186	Arthropoda		Insecta		Diptera		Chironom	Tanypodinae		sp. 3	larvae	0	0	0	0	0	0
191	Arthropoda		Insecta		Diptera		Chironom	Tanypodi	*Pentaneurini Genus C*	sp.	larvae	0	0	0	0	0	0
192	Arthropoda		Insecta		Diptera		Chironom	Tanypodi	*Nilotanypus (cf)*	sp.	larvae	0	0	0	0	0	0
	Arthropoda		Insecta		Diptera		Chironom	Tanypodinae		spp.	larvae	1	0	0	1	0	0
28	Arthropoda		Insecta		Diptera		Chironom	Orthocladinae		sp. 1	larvae	0	1	0	0	0	0
143	Arthropoda		Insecta		Diptera		Chironom	Orthoclad	*Corynoneura*	sp. 1	larvae	0	0	0	0	0	0
185	Arthropoda		Insecta		Diptera		Chironom	Orthoclad	*Thienemanniella*	sp.	larvae	0	0	0	0	0	0
	Arthropoda		Insecta		Diptera		Chironom	Orthocladinae		spp.	larvae	0	0	0	0	0	0
12	Arthropoda		Insecta		Diptera		Certopog	Ceratopo	*Bezzia*	sp. 1	larvae	0	0	0	0	0	0
109	Arthropoda		Insecta		Diptera		Certopog	Forcipomyi	*Atrichopogon*	sp. 1	larvae	0	0	0	0	0	0
138	Arthropoda		Insecta		Diptera		Ceratopogonidae			sp.	pupa	0	0	0	0	0	0
47	Arthropoda		Insecta		Diptera		Psychodidae			sp. 1	larvae	0	0	0	0	0	0
133	Arthropoda		Insecta		Diptera		Dolichopodidae			sp. 1	larvae	0	1	0	0	0	0
215	Arthropoda		Insecta		Diptera		Ephydridae (cf.)		Ephydridae (cf.)	sp. 1	larvae	0	0	0	0	0	0
45	Arthropoda		Insecta		Diptera (adult)				unid.	sp. 1	adult	0	1	0	0	2	2
46	Arthropoda		Insecta		Diptera (adult)				unid.	sp. 2	adult	0	0	0	0	0	0
53	Arthropoda		Insecta		Diptera (adult)				unid.	sp. 3	adult	0	0	1	2	0	0
82	Arthropoda		Insecta		Diptera (adult)				unid.	sp. 4	adult	0	0	0	0	0	1
188	Arthropoda		Insecta		Diptera (adult)				unid.	sp. 5	adult	0	0	0	0	0	0
79	Arthropoda		Insecta		Diptera (adult)				unid.	sp. 6	adult	0	0	0	0	0	0
91	Arthropoda		Insecta		Diptera (adult)				unid.	sp. 7	adult	0	0	0	0	0	0
214	Arthropoda		Insecta		Diptera		Muscidae			sp. 1	larvae	0	0	0	0	0	0
216	Arthropoda		Insecta		Diptera				unid.	larvae01	larvae	0	0	0	0	0	0
217	Arthropoda		Insecta		Diptera				unid.	larvae02	larvae	0	0	0	0	0	0
125	Arthropoda		Insecta		Hymenoptera				unid.	sp. 1	adult	1	0	0	0	0	0
85	Arthropoda		Insecta		Hymenoptera				unid.	sp. 2	adult	0	0	0	0	0	0
	Arthropoda		Insecta		Hymenoptera		Formicidae			sp.	ant -terre	1	2	5	4	2	0
74	Arthropoda		Insecta		Trichoptera		Calamoceratidae		*Anisocentropus*	sp. 1	larvae	0	0	1	0	0	0
117	Arthropoda		Insecta		Trichoptera		Ecnomidae		*Ecnomus*	sp. 1	larvae	0	0	0	0	0	0
10	Arthropoda		Insecta		Trichoptera		Hydropsychidae		*Cheumatopsyche*	sp. 1	larvae	1	13	1	0	0	0
11	Arthropoda		Insecta		Trichoptera		Hydropsychidae		*Cheumatopsyche*	sp. 2	larvae	0	0	0	0	1	0
38	Arthropoda		Insecta		Trichoptera		Hydropsychidae		*Cheumatopsyche*	sp. 3	larvae	0	12	0	0	2	0
127	Arthropoda		Insecta		Trichoptera		Hydropsychidae		*Cheumatopsyche*	sp. 4	larvae	0	0	0	1	0	0
157	Arthropoda		Insecta		Trichoptera		Hydropsychidae		*Cheumatopsyche*	sp. 5	larvae	0	0	0	0	0	0

158	Arthropoda	Insecta	Trichoptera	Hydropsychidae	*Cheumatopsyche*	sp.6	larvae	0	0	0	0	0	0	0	0	0	0	12	13	3	128	8	13	14	23	308	52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Arthropoda	Insecta	Trichoptera	Hydropsychidae	*Cheumatopsyche*	spp. (immature larvae)	immature	2	9	0	0	0	0	0	0	0	0	0	101	0	144	0	0	0	0	0	0	0	48	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	7	0	0	0	0	0	0	0	0
169	Arthropoda	Insecta	Tricoptera	Hydropsychidae	Hydropschidae	sp. 1	larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
170	Arthropoda	Insecta	Tricoptera	Hydropsychidae	Hydropschidae	sp. 2	larvae	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Arthropoda	Insecta	Tricoptera	Hydropsychidae	Hydropschidae	spp. (immature larvae)	immature	0	42	0	0	0	0	5	0	0	1	184	72	122	224	83	34	58	45	108	53	40	4	24	0	0	0	0	0	0	0	0	0	0	0	1	1	0	2	0	0	0	0	0	0	0	0	0	0	0
32	Arthropoda	Insecta	Trichoptera	Leptoceridae	*Triplectides*	sp. 1	larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0
33	Arthropoda	Insecta	Trichoptera	Leptoceridae	*Oecetis*	sp. 1 (box case)	larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
171	Arthropoda	Insecta	Tricoptera	Leptoceridae	Leptoceridae	sp. 1	larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Arthropoda	Insecta	Tricoptera	Leptoceridae	Leptoceridae	sp. (immature larvae)	immature	0	0	0	0	0	0	0	0	0	0	0	1	1	4	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	Arthropoda	Insecta	Trichoptera	Hydroptilidae	*Orthotrichia*	sp. 1	larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	4	0	6	5	0	0	0	0	0	0	0	0	0	0
8	Arthropoda	Insecta	Trichoptera	Hydroptilidae	Hydroptilidae	sp. 1	larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
83	Arthropoda	Insecta	Trichoptera	Hydroptilidae	Hydroptilidae	sp.2	larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
198	Arthropoda	Insecta	Tricoptera	Glossosomatidae	*Agapetus*	sp. 1	larvae	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Arthropoda	Insecta	Tricoptera			spp. (immature)	immature	1	0	0	3	4	1	0	3	0	0	40	75	0	32	0	4	14	78	232	36	0	0	0	3	1	0	1	0	2	1	8	6	2	8	4	3	0	0	2	0	0	0	0	3	0	1	0	0	0
67	Arthropoda	Insecta	Trichoptera (pupa/emerging adult)			sp. 1	pupa/eme	0	7	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
73	Arthropoda	Insecta	Trichoptera (adult/pupa)			sp.1a	newly em	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
209	Arthropoda	Insecta	Trichoptera (pupa)			sp. 2	pupa	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42	Arthropoda	Insecta	Lepidoptera	Crambidae	Crambidae	sp. 1	larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	Arthropoda	Insecta	Lepidoptera	Crambidae	Crambidae	sp. 2	larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	Arthropoda	Insecta	Lepidoptera	Crambidae	Crambidae	sp. 3	larvae	0	0	0	0	1	0	0	0	0	0	2	5	0	28	1	9	4	12	60	52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90	Arthropoda	Insecta	Lepidoptera	Crambidae	Crambidae	sp. 4	larvae	0	0	0	0	0	1	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
156	Arthropoda	Insecta	Lepidoptera	Crambidae	Crambidae	sp. 5	larvae	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
210	Arthropoda	Insecta	Lepidoptera	Crambidae	Crambidae	sp. 6	larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
211	Arthropoda	Insecta	Lepidoptera	Crambidae	Crambidae	sp. 7	larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
182	Arthropoda	Insecta	Lepidoptera	Crambidae	Crambidae	sp. 8	larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
102	Arthropoda	Insecta	Lepidoptera	Crambidae	Crambidae	sp. 9	larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Arthropoda	Insecta	Lepidoptera	Crambidae	Crambidae	spp. (immature larvae)	(immatur	1	2	0	1	1	0	0	0	0	0	0	6	0	0	2	0	1	3	0	0	0	0	0	0	0	1	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
197	Arthropoda	Insecta	Thysanoptera	Thripidae	Thripidae	sp. 1	adult	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
114	Arthropoda	Insecta	Thysanoptera	Thripidae	Thripidae	sp. 2	adult	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
201	Arthropoda	Insecta	Thysanoptera	Thripidae	Thripidae	sp. 3	adult	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
195	Arthropoda	Insecta	Orthoptera			sp. 1	adult	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
86	Arthropoda	Insecta			unid. Pupa	sp. 1	pupa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
113	Arthropoda	Insecta			*Pentaneurini Genus C*	sp. 1	larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
146	Arthropoda	Insecta			unid. Larvae/pupa	sp. 2	larvae/pu	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
149	Arthropoda	Insecta			unid. Larvae	sp. 3	larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
160	Arthropoda	Insecta			unid. Larvae	sp. 4	larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
161	Arthropoda	Insecta			unid. Larvae	sp.5	larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
166	Chordata	Amphibia	Anura	Bufonidae	*Rhinella*	*marina*	tadpoles	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	3	1	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
130	Chordata	Actinopterygii	Perciformes		unid.	sp. (eggs)	eggs	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
151	Chordata	Actinopterygii	Perciformes	Gobiidae	*Stenogobius*	sp. 1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
176	Chordata	Actinopterygii	Perciformes	Anabantidae	*Anabas*	*testudinous*		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0

Appendix 8
Plume Rise Assessment

PNG Biomass Markham Valley

Plume Rise Assessment

Report Number 640.10761-R02

1 March 2017

ERIAS Group
13-25 Church Street
Hawthorn Vic 3122

Version: v1.0

PNG Biomass Markham Valley

Plume Rise Assessment

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Executive Summary

SLR has performed a plume rise assessment for the proposed PNG Biomass Markham Valley project (the Project) located in the Markham Valley in Papua New Guinea, near the confluence of the Watut and Markham Rivers, 50 km northwest of the provincial capital Lae. The Project, which involves both a power plant and *Eucalyptus* plantations to provide biomass as fuel, has a proposed maximum total production capacity of 30 MW (net) from the power plant based on two 15 MW boilers.

Lae Nadzab Airport is located approximately 10 km east of the proposed power plant site. This plume rise assessment was therefore commissioned to inform an aviation hazard analysis to assess whether the thermal plumes from the Project have the potential to pose any risk to aircraft using Lae Nadzab Airport.

The plume rise assessment has been conducted using the CALPUFF dispersion model. Three-dimensional meteorological data representative of the site and surrounding area was generated for input to the CALPUFF dispersion model using a combination of the Weather Research and Forecast (WRF) and CALMET models. Observational meteorological data from the Lae Nadzab Airport monitoring site was also input into the CALMET model to refine the predicted meteorological data.

The results of the CALPUFF modelling indicate that the vertical velocities of the exhaust plumes from the boiler stacks are unlikely to exceed the threshold limit of 4.3 m/s at the relevant Obstacle Limitation Surface (OLS) of 150 m above ground level. The maximum plume height with a vertical velocity of 4.3 m/s or higher was predicted by the modelling to be 103 m above ground level

Based on the modelling results, the proposed Project is unlikely to pose any significant risks to the flight path for aircraft landing or taking off from the Lae Nadzab Airport. However, appropriate mitigation measures (e.g. insertion of a symbol and a height on aviation charts) should be taken to enhance awareness of the plume rise zone, particularly for slow flying or hovering helicopters that may fly within 100 m above ground level at the Project site or in the surrounding area.

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1 INTRODUCTION

ERIAS Group commissioned SLR on behalf of Markham Valley Biomass Limited (MVB) to perform a detailed plume rise assessment study for the boiler stacks at the proposed PNG Biomass Markham Valley project (‘the Project’), located approximately 50 kilometres (km) northwest of Lae in Papua New Guinea (PNG).

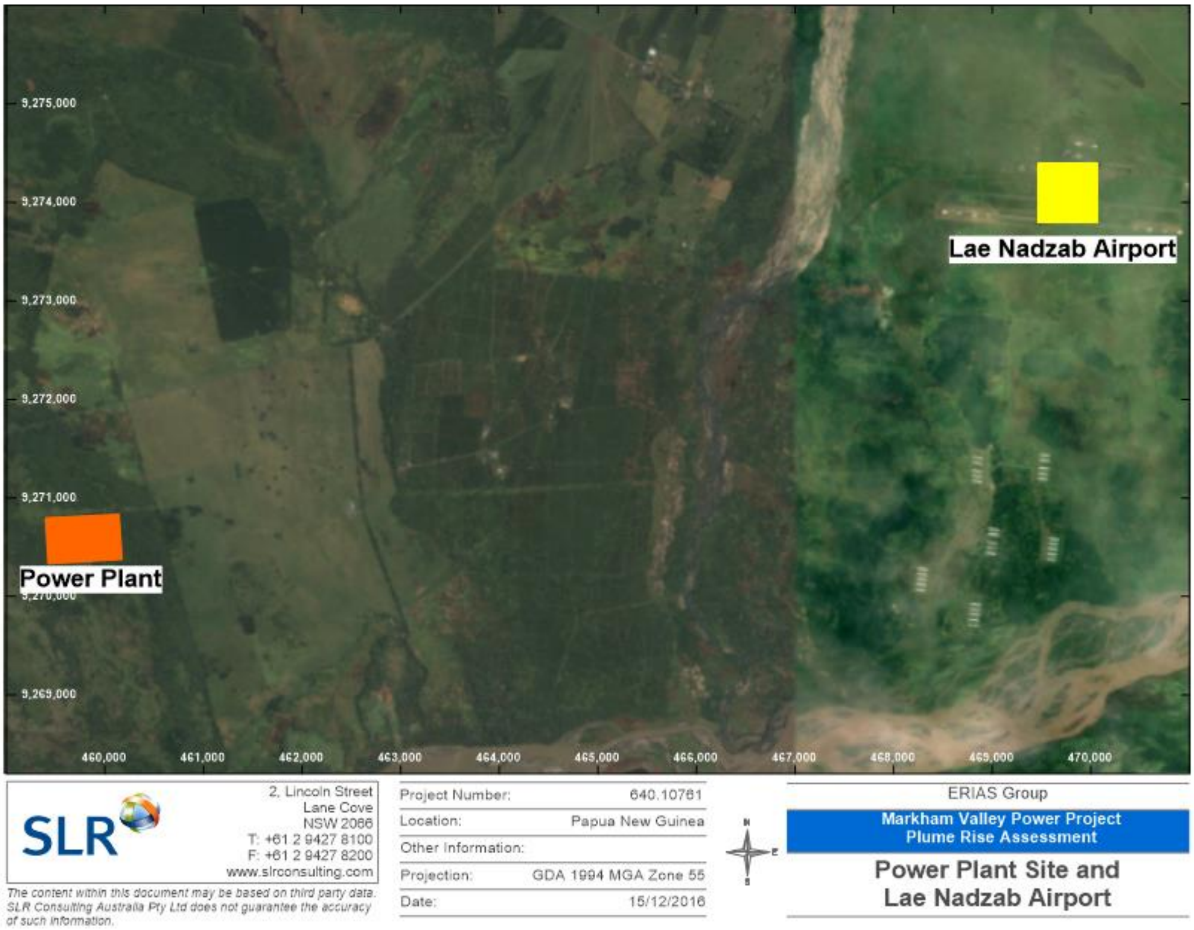
The purpose of this report is to allow an aviation hazard analysis to assess whether the thermal plumes from the power plant (which is one of the two main Project components, the other being *Eucalyptus* plantations to provide biomass as fuel) have the potential to pose any risk to aircraft using Lae Nadzab Airport. In the absence of relevant regulatory guidelines in PNG, this assessment has been performed based on the methodology and assessment criteria set out by the Australian Civil Aviation Safety Authority (CASA) in their Advisory Circular AC 139-5(1) published in November 2012. Australia plays a significant role in the development of aviation safety infrastructure and systems in PNG through the PNG-Australia Transport Sector Support Program, hence the methodology outlined in AC 139-5(1) is anticipated to be acceptable for use in PNG in the absence of any local requirements.

2 PROJECT DESCRIPTION

The power plant site is located in the Markham Valley near the confluence of the Watut and Markham rivers, 50 km northwest of the provincial capital Lae. The site will be accessed from the Highlands Highway and is located approximately 10 km west of Lae Nadzab Airport which is served by both private and regional aircraft with domestic flights.

The relative locations of the power plant site and Lae Nadzab Airport are shown in **Figure 1**.

Figure 1 Power Plant Location



2.1 Source Characteristics

The power plant site covers a total area of 17 hectares (ha), including laydown areas for wood stockpiles. Harvested biomass will be stockpiled then chipped, dried and stored at the power station. The plant includes two 15 MW power plant modules each of which consist of one biomass boiler and one steam turbine generator, fired with woodchips supplied from the dedicated plantations.

The maximum peak load for the power plant will occur when it is operating at full capacity, generating 30 MW (net) of electricity. The hot flue gas in the furnace will be cooled before entering the superheaters at the outlet of the furnace and then the steam generating banks. The flue gas will then exit the boiler before passing through the fan and Electrostatic Precipitator (ESP) to the stack. Operational parameters of the stack for each boiler are outlined in **Table 1** (conservatively based on 50% moisture content fuel)

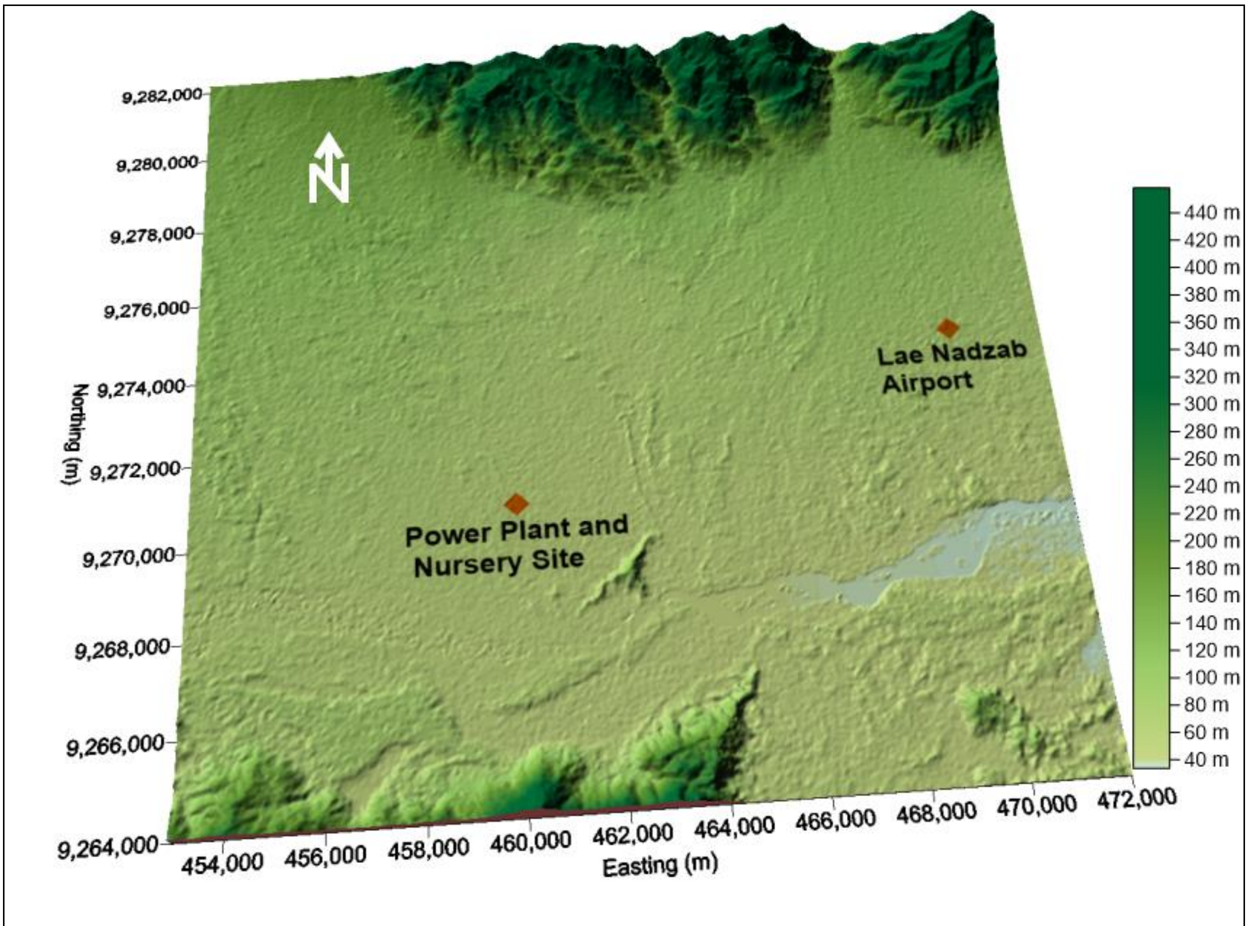
Table 1 Stack Parameters

Parameter	Unit	Value
Height	m	40
Exit velocity	m/s	29.1
Exit diameter	m	1.83
Exit temperature	ºC	166

2.2 Local Topography and Land Use

The topography of the study area is illustrated in **Figure 2** based on topographical data sourced from the United States Geological Service's Shuttle Radar Topography Mission (SRTM) database that has recorded topography with a 3 arc second (~90 m) spacing.

Figure 2 Topography Surrounding the Power Plant Site



As shown in **Figure 2**, the topography surrounding the Project site is predominantly flat with low rolling hills. There are no significant topographical features close to the site that could significantly influence wind patterns, such as mountainous regions/peaks or coastlines. The nearest elevated terrain is located beyond the Markham River, approximately 5 km to the south.

The land use in the surrounding area is primarily subsistence agriculture and some cash cropping. The power plant site is largely a modified environment, consisting of anthropogenic grassland or a mosaic with introduced rain trees. Grasslands are regularly burnt by local communities.

3 REGULATORY REQUIREMENTS

Exhaust plumes emanating from power plant stacks or other industrial facilities can have adverse impacts on aircraft during periods of calm winds. Adverse impacts can be exacerbated if the temperature is low or the atmosphere is unstable. While low oxygen concentrations and elevated temperatures inside the plume can be detrimental to slow flying or hovering helicopters, the turbulence generated from the upward motion of the plume is the main potential hazard to light, fixed-wing aircraft at low altitude.

As outlined in **Section 1**, in the absence of relevant regulatory guidelines in PNG, this assessment was performed following the guidelines outlined in CASA Advisory Circular (AC) 139-5(1) (CASA 2012).

The purpose of AC 139-5(1) is to provide:

- A standard method of determining the critical velocity of a vertical exhaust plume so that the impact of a plume near aerodromes and away from aerodromes can be assessed in a consistent and reliable way;
- Guidance to persons involved in the design, construction and operation of facilities with vertical exhaust plumes about the information required to assess the potential hazard from a plume to aircraft operations; and
- Guidance to proponents and stakeholders on the plume rise assessment process.

CASA has identified, in AC 139-5(1), the need to assess the potential hazard to aircraft posed by any exhaust plume with an exit velocity greater than 4.3 m/s.

3.1 Obstacles in Airspace

Based on the information provided in AC 139-5(1), the following parameters may be considered for identifying obstacles in airspaces.

3.1.1 Obstacle Restriction Area

The obstacle restriction area of an aerodrome comprises the following:

- Runway strips
- Runway end safety areas
- Clearways
- Taxiway strips

3.1.2 Obstacle Limitation Surfaces

Obstacle Limitation Surfaces (OLS) are a series of surfaces that set the height limits of objects around an aerodrome. The OLS may comprise the following individual surfaces:

- Inner and outer horizontal surface
- Conical surface
- Approach surface
- Inner approach surface
- Transitional surface
- Inner transitional surface
- Baulked landing surface and

- Take-off climb surface

The standards for, and description of, each OLS are presented in **Appendix A**.

As outlined in **Section 2**, the power plant site is located approximately 10 km from Lae Nadzab Airport. Based on the standard outlined in **Appendix A**, the plumes from the plant only have potential to impact on the outer horizontal surface due to the large distance between the site and the airport.

As per the standard, the exhaust plumes will have no significant effect on aircraft operations associated with Lae Nadzab Airport if the critical plume height (i.e., the height at which the vertical velocity drops below 4.3 m/s) is less than 150 m in the outer horizontal surface.

4 MODELLING METHODOLOGY

The plume rise assessment was conducted using a combination of the Weather Research and Forecast (WRF) model, and the CALMET and CALPUFF modelling suite. Regional meteorological data was generated using the WRF model and then refined using CALMET with the inclusion of finer scale land use and topographical information to generate meteorological data representative of the site and the surrounding area. The output from CALMET was then used as an input to CALPUFF in combination with the operational parameters of the boiler stacks to predict the critical plume height up to which the vertical velocity of plume is equal or greater than 4.3 m/s.

It is noted that AC 139-5(1) refers to the use of the TAPM model to perform the meteorological modelling and to characterise the plume rise. However the TAPM model was developed in Australia for Australian conditions and is not able to resolve the complex topography and climatic conditions found in PNG. In SLR's experience, TAPM either does not successfully complete a simulation or generates outputs that do not satisfactorily represent actual conditions. The meteorological data used in this study was therefore generated using WRF and CALMET, with the outputs validated against observational data from Lae Nadzab Airport. These models have also successfully been used for other projects in other locations within PNG (e.g. Port Moresby). CALPUFF is widely used throughout the world for plume modelling studies and has recently been updated to provide the output data specifically required for plume rise assessments.

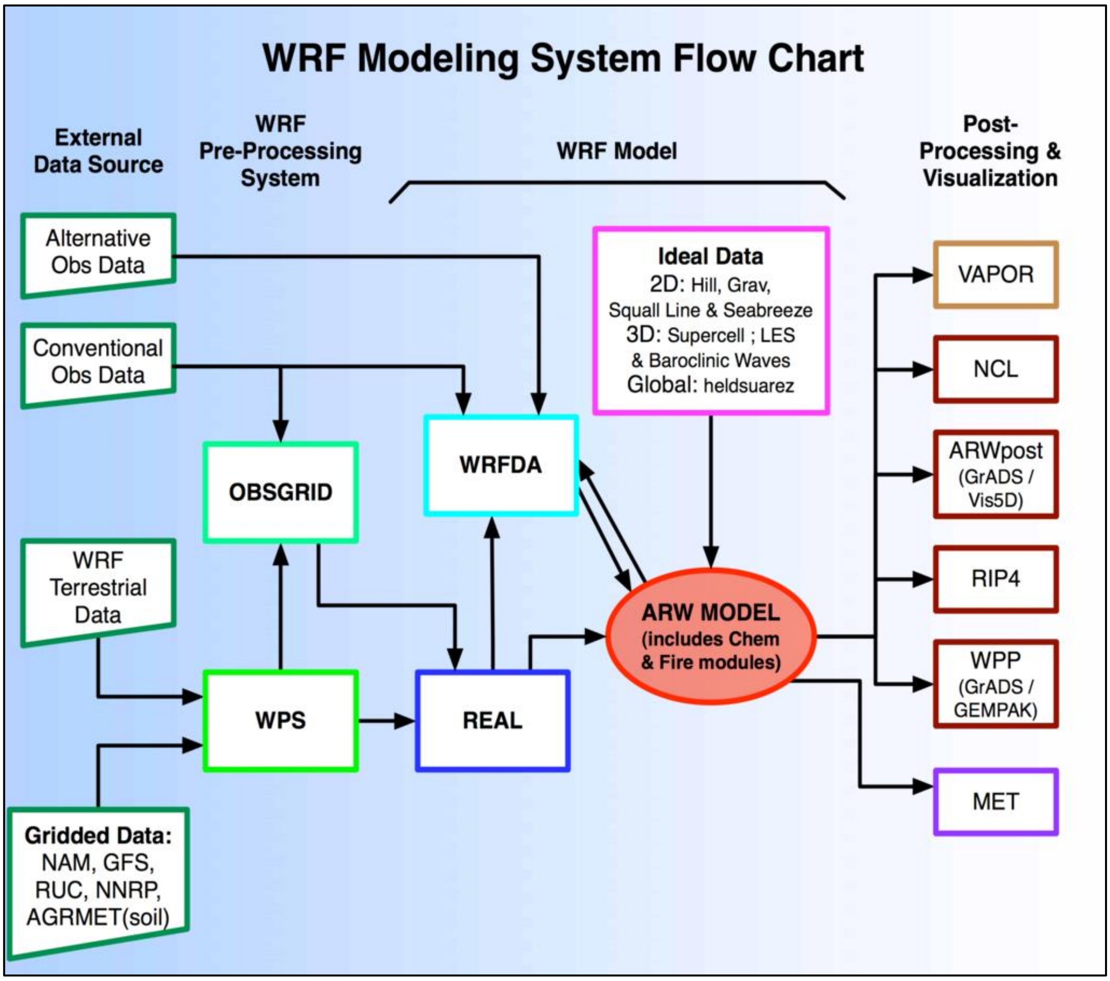
4.1 Weather Research and Forecast Model (WRF)

The WRF model is a mesoscale numerical weather prediction system designed for both atmospheric research and operational forecasting needs. The model serves a wide range of meteorological applications, across scales from tens of metres to thousands of kilometres. A brief overview of the WRF modelling system is presented in **Figure 3**.

The WRF model uses data derived from the GFS (Global Forecast System) model. This is a global spectral atmosphere model, operated by the National Centers for Environmental Prediction, USA (NCEP). GFS is a global spectral model (GSM), composed of four separate models (an atmosphere model, an ocean model, a land/soil model, and a sea ice model), that work together to provide an accurate picture of weather conditions. The GFS data provides initial and/or boundary conditions for NCEP's other models for regional, ocean and wave prediction systems. The Global Data Assimilation System (GDAS) uses maximum amounts of satellite and conventional observations from global sources and generates initial conditions for the global forecasts. The GFS model has a spatial resolution of 0.5° x 0.5° and produces 10-day forecasts, four times per day. The final analysis (FNL) data - a historical collection of all "best estimate" analysis results from the GFS - is used in WRF, which has a time resolution of 6 hours and a spatial resolution of 1° x 1°.

For this assessment, the WRF modelling system was used to produce the meteorological field required as an input to the CALMET meteorological model over the domains shown in **Figure 4**. Parameters used in the WRF model for this assessment are presented in **Table 2**. An analysis of meteorological data recorded at Lae Nadzab airport from 2012 – 2015 showed very little variation between years in the key meteorological parameters relevant to plume dispersion. Based on this, the latest year (2015) was selected for meteorological modelling for the power plant site.

Figure 3 WRF Modelling System Flowchart



Source: UCAR, 2016

Figure 4 WRF Modelling Domains

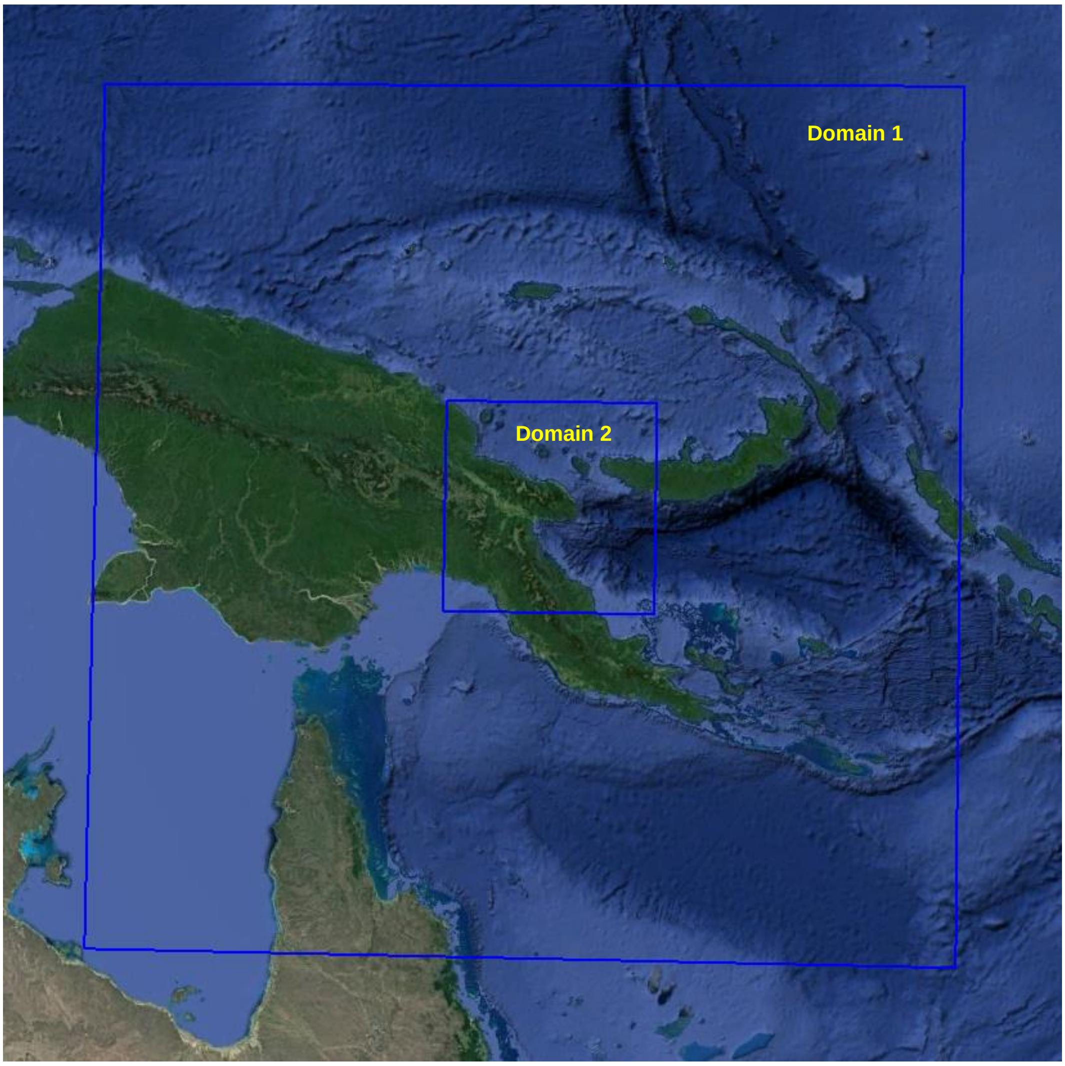


Table 2 Meteorological Parameters used for this Study (WRF)

Parameter	Domain 1	Domain 2
Modelling domain	2,100 km × 2,100 km	490 km × 490 km
Grid resolution	30 km	10 km
Number of vertical levels	30	30
Microphysics	WSM6	WSM6
Cumulus parameterisation	Kain-Fritsch	Kain-Fritsch
Shortwave radiation physics	Dudhia	Dudhia
Longwave radiation physics	RRTM	RRTM
Planetary boundary layer	YSU	YSU

4.2 CALMET

In the simplest terms, CALMET is a meteorological model that develops hourly wind and other meteorological fields on a three-dimensional gridded modelling domain that are required as inputs to the CALPUFF dispersion model. Associated two-dimensional fields such as mixing height, surface characteristics and dispersion properties are also included in the file produced by CALMET. The interpolated wind field is then modified within the model to account for the influences of topography, sea breeze (where relevant), as well as differential heating and surface roughness associated with different land uses across the modelling domain. These modifications are applied to the winds at each grid point to develop a final wind field. The final hourly varying wind field thus reflects the influences of local topography and land uses.

CALMET modelling was conducted using the nested CALMET approach, where the final results from a coarse-grid run were used as the initial guess of a fine-grid run. This has the advantage that off-domain terrain features including slope flows and blocking effects can be allowed to take effect and the larger-scale wind flow provides a better start in the fine-grid run.

The outer domain was modelled with a resolution of 3 km. WRF-generated three-dimensional meteorological data were used as the initial-guess wind field and local topographical and land use information were used to refine the wind field predetermined by the WRF output. Available meteorological data recorded at the nearest meteorological station (Lae Nadzab Airport) were entered into the CALMET model as an observed dataset to refine the model prediction.

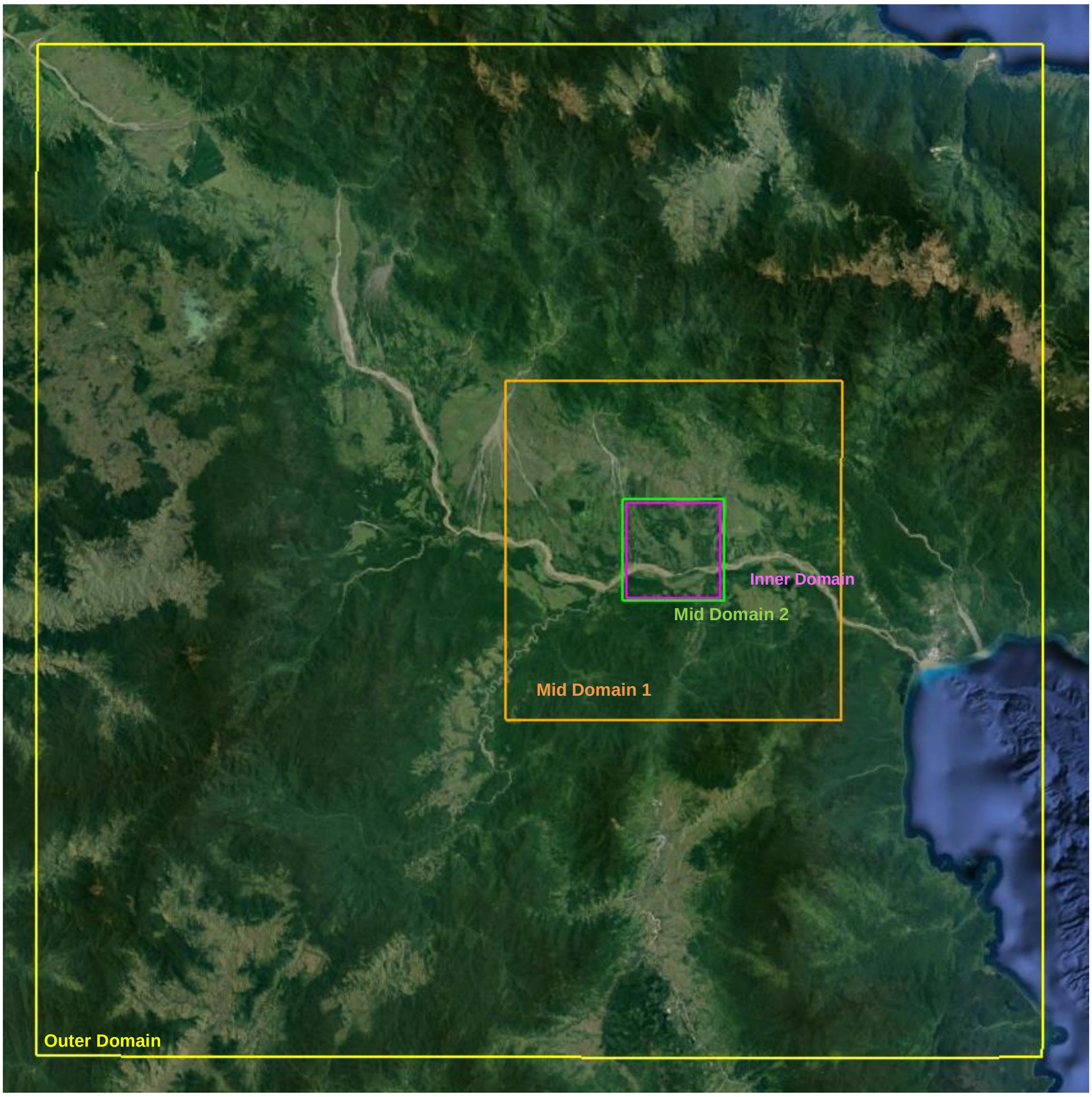
The output from the outer domain CALMET modelling was then used as the initial-guess field for the mid and inner domain CALMET modelling. A horizontal grid spacing of 1 km, 0.3 km and 0.1 km were used in the two mid and inner domains to adequately represent the important local terrain features and land use. Fine-scale local topographical and land use information were used in the inner domain run to refine the wind field parameters predetermined by the coarse CALMET runs.

Table 3 details the parameters used in the meteorological modelling to drive the CALMET model, while the extents of the model domains are illustrated in **Figure 5**.

Table 3 Meteorological Parameters used for this Study

Meteorological Modelling Parameters	Project Site
Outer Domain	
Meteorological grid	150 km × 150 km
Meteorological grid resolution	3 km
Initial guess filed	3D output from WRF model
Mid Domain 1	
Meteorological grid	50 km × 50 km
Meteorological grid resolution	1 km
Initial guess field	3D output from outer domain modelling
Mid Domain 2	
Meteorological grid	15 km × 15 km
Meteorological grid resolution	0.3 km
Initial guess field	3D output from mid domain 1 modelling
Inner Domain	
Meteorological grid	14 km × 14 km
Meteorological grid resolution	0.1 km
Initial guess field	3D output from mid domain 2 modelling

Figure 5 CALMET Modelling Domains



4.3 Meteorological Data Used in this Assessment

A summary of the site representative meteorological dataset derived for the power plant site using the methodology described in **Section 4.1** and **Section 4.2** and used in CALPUFF for the plume rise assessment is provided in the following sections.

4.3.1 Wind Speed and Direction

A summary of the predicted site-representative annual wind behaviour for 2015 is presented as a frequency distribution plot in **Figure 6** and as a wind rose plot in **Figure 7**. The annual wind rose indicates that the prevailing wind directions are from the east and west-southwest. Calm conditions occur 12% of the time. Wind speeds are light to moderate in nature, ranging between 0.5 m/s and 8 m/s.

Figure 6 Frequency of Wind Speed as Predicted by CALMET (2015) – Power Plant Site

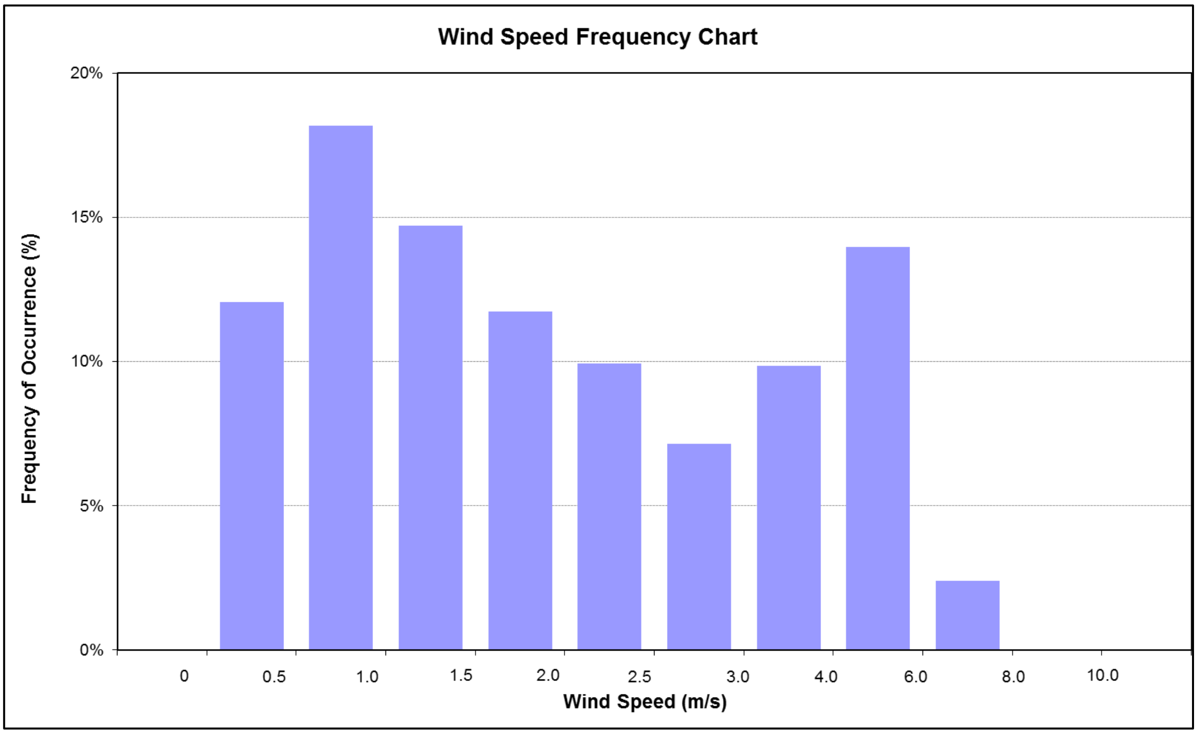
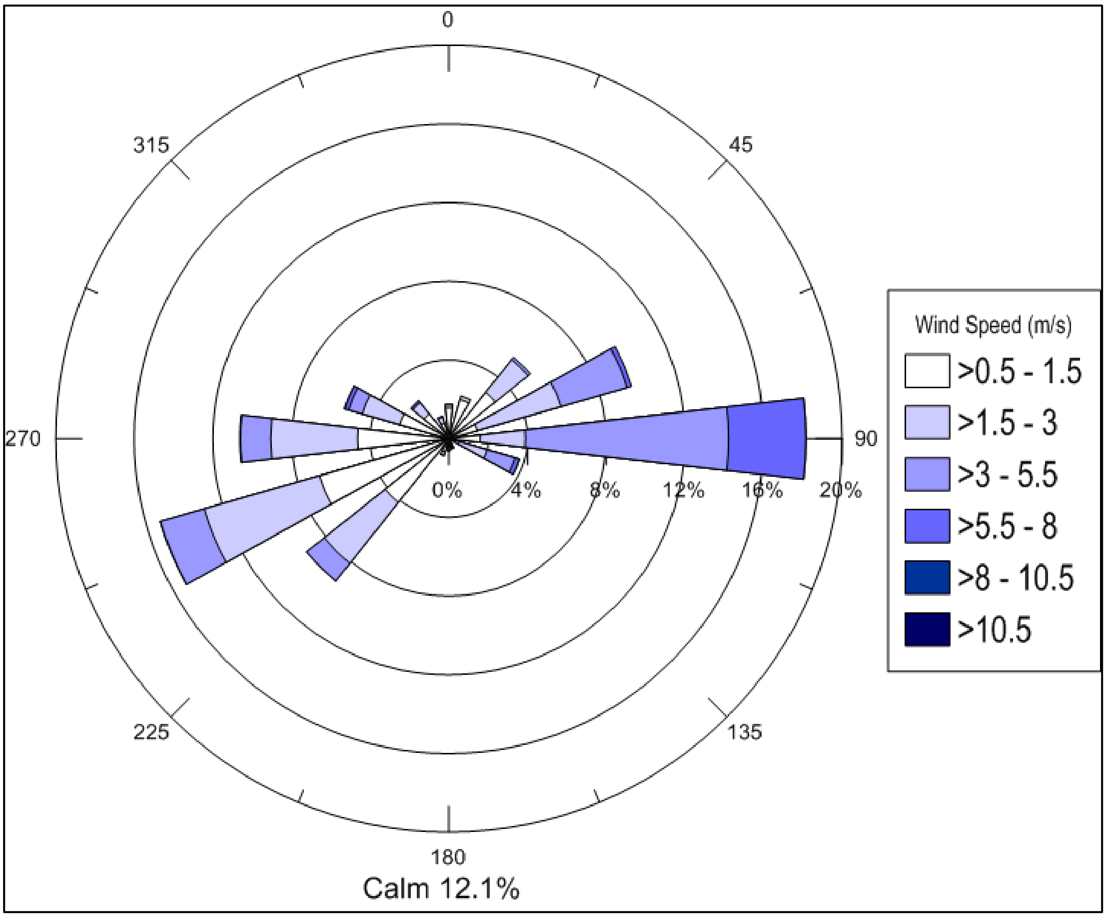


Figure 7 Annual Wind Rose as Predicted by CALMET (2015) – Power Plant Site

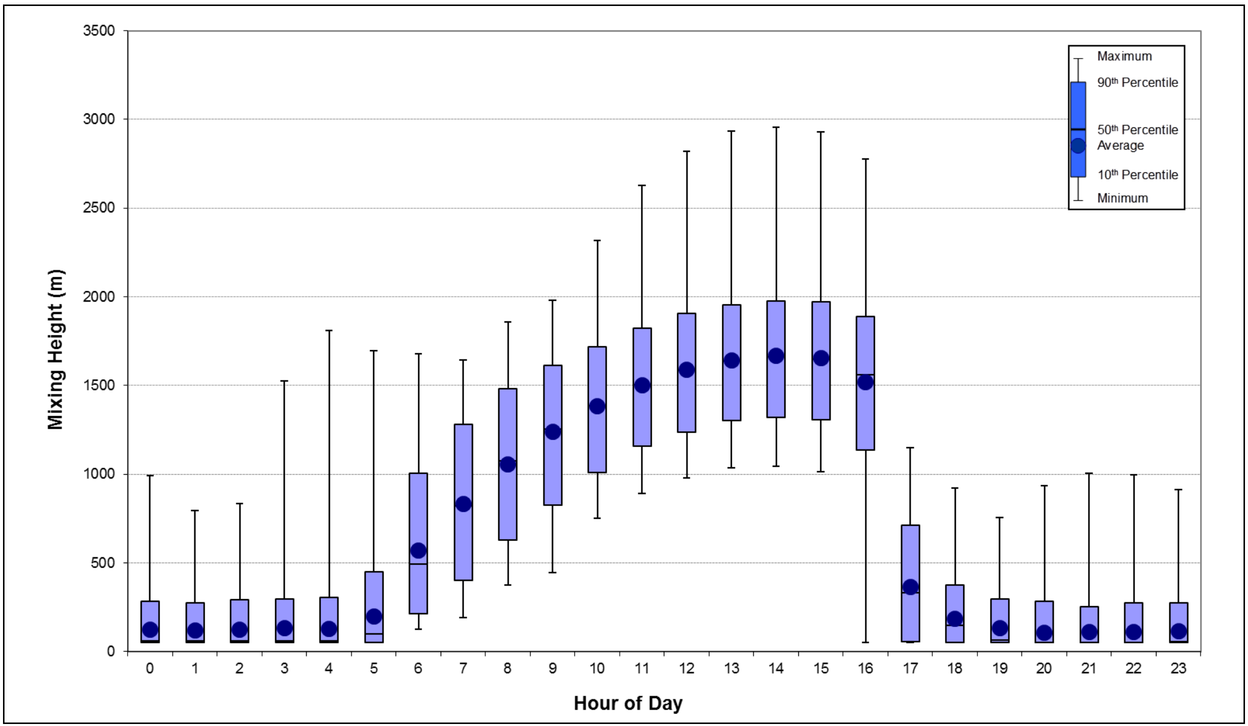


4.3.2 Mixing Height

A summary of the mixing height profiles predicted at the Project site for 2015 is shown in **Figure 8**.

As would be expected, an increase in the mixing height during the morning is apparent, arising due to the onset of vertical mixing following sunrise. Maximum mixing heights occur in the mid to late afternoon, due to the dissipation of ground-based temperature inversions and the growth of the convective mixing layer.

Figure 8 Mixing Height Profiles as Predicted by CALMET (2015) – Power Plant Site



4.3.3 Atmospheric Stability

Atmospheric stability refers to the tendency of the atmosphere to resist or enhance vertical motion. The Pasquill-Turner assignment scheme (Pasquill, 1961) identifies six Stability Classes, A to F, to categorize the degree of atmospheric stability as follows:

- A = Extremely unstable conditions
- B = Moderately unstable conditions
- C = Slightly unstable conditions
- D = Neutral conditions
- E = Slightly stable conditions
- F = Moderately stable conditions

The meteorological conditions defining each Pasquill Stability Class are shown in **Table 4**.

Table 4 Meteorological Conditions Defining Pasquill Stability Classes

Surface wind speed (m/s)	Daytime insolation			Night-time conditions	
	Strong	Moderate	Slight	Thin overcast or > 4/8 low cloud	<= 4/8 cloudiness
< 2	A	A - B	B	E	F
2 – 3	A - B	B	C	E	F
3 – 5	B	B - C	C	D	E
5 – 6	C	C - D	D	D	D
> 6	C	D	D	D	D

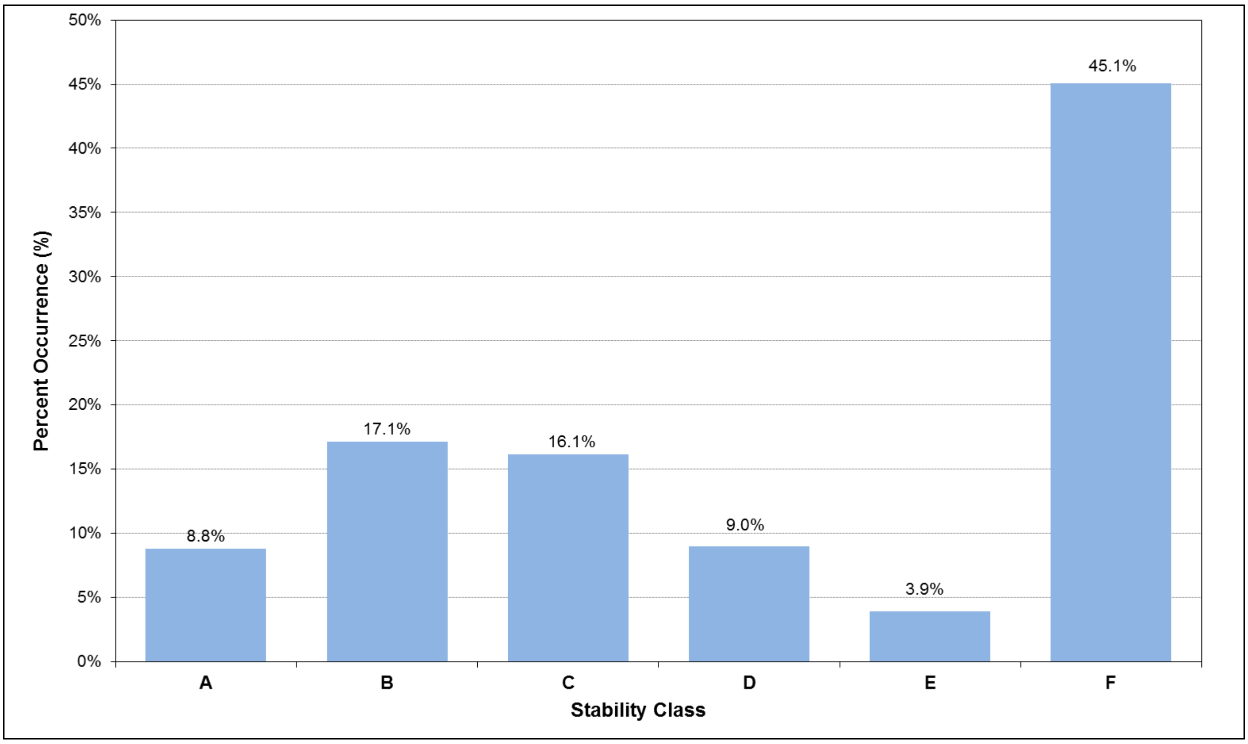
(Source: Pasquill, 1961)

Notes:

1. Strong insolation corresponds to sunny midday in midsummer in England; slight insolation to similar conditions in midwinter.
2. Night refers to the period from 1 hour before sunset to 1 hour after sunrise.
3. The neutral category D should also be used, regardless of wind speed, for overcast conditions during day or night and for any sky conditions during the hour preceding or following night as defined above.

The frequency of each stability class predicted by CALMET during the modelling period, extracted at the power plant site, is presented in **Figure 9**. The results indicate a high frequency of conditions typical to Stability Class F. These conditions represent a moderately stable atmosphere and occur during night-time, when wind speeds are low.

Figure 9 Stability Class Distributions as Predicted by CALMET (2015) – Power Plant Site



4.4 CALPUFF

The CALPUFF dispersion model was used to predict the critical plume height for the boiler stacks. Version 6.42 of CALPUFF allows the details of its numerical plume rise module to be written to a file for subsequent post-processing, specifically for use in plume rise assessments. The post processor RISEPOST is used to extract statistics on the plume vertical velocity at various user-specified heights.

It is noted that the CALPUFF dispersion model can only write the details of its numerical plume rise module for model runs with a single stack. As outlined in **Section 2.1**, two boilers will operate concurrently at the proposed site, each with a separate 40 m tall stack to be located approximately 25 m apart. There is therefore potential for plume merging to occur, which will enhance the strength of the plume, potentially resulting in a higher critical plume height. Since the model is not designed for multiple stacks with potential merging of the plumes, as a conservative approach, the concurrent operation of both stacks was modelled as a single combined stack, essentially assuming that merging of the plumes is occurring within the stack. The equivalent diameter of the combined stack was calculated based on the total cross-sectional area of both stacks. This is a conservative, worst-case approach that accounts for the higher vertical momentum that would occur if the two plumes completely merged. The stack parameters entered into CALPUFF therefore included the same stack height, exit velocity and temperature shown in **Table 1** for each individual stack, but used a larger equivalent diameter representative of the total combined cross-sectional area of the two stacks. The parameters of the combined stack used in the CALPUFF model are presented in **Table 5**.

Table 5 Modelled Stack Parameters

Parameter	Unit	Value
Height	m	40
Exit velocity	m/s	29
Exit diameter [1]	m	2.6
Exit temperature	ºC	166

[1] Based on the total cross-sectional area of 5.26 m^2 of the two separate 1.83 m diameter stacks.

5 PREDICTED RESULTS

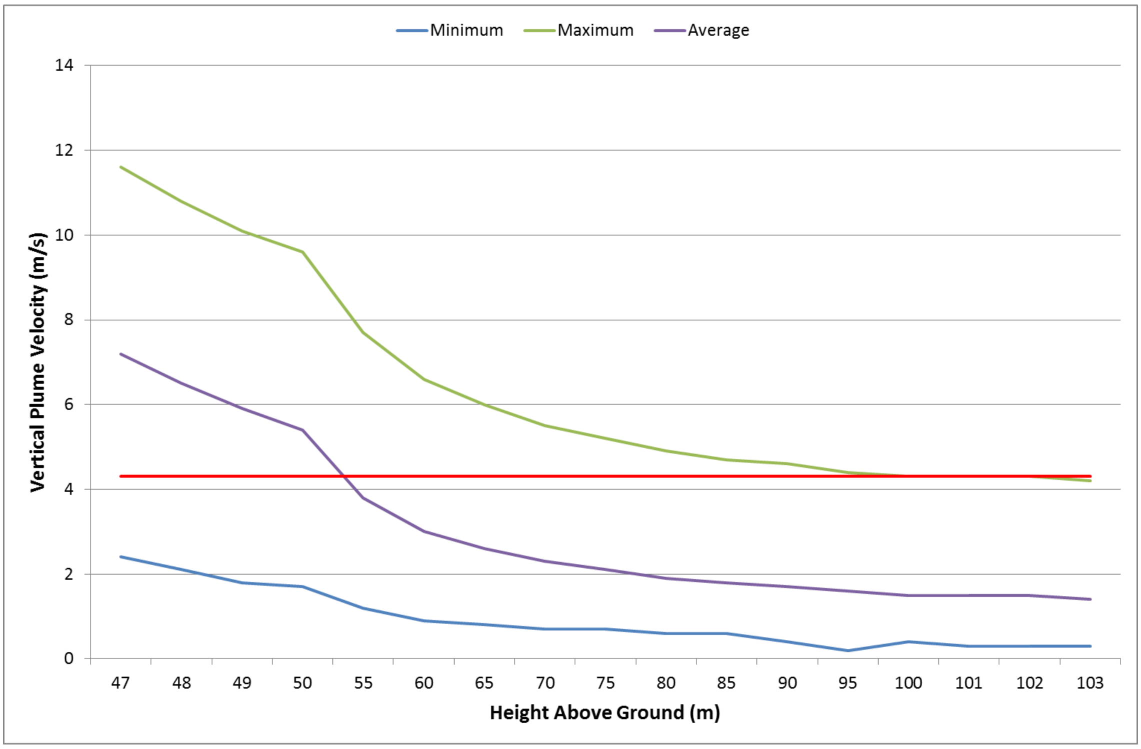
An analysis of the maximum predicted plume heights is presented in **Table 6** for a vertical plume velocity exceeding 4.3 m/s. This table shows the predicted frequency of the vertical plume velocity exceeding 4.3 m/s at different heights above ground based on the site-representative meteorological data file (refer **Section 4.3**). The maximum predicted plume height exceeding the critical vertical velocity of 4.3 m/s defined by CASA is approximately 103 m above ground level.

The relationship between the minimum and maximum predicted vertical plume velocities and height above ground is presented in **Figure 10**. This figure shows the influence of the various meteorological conditions experienced at the site on the predicted vertical velocities at each elevation.

Table 6 Frequency of Vertical Plume Velocity > 4.3 m/s

Height Above Ground (m)	Hours per year exceeding 4.3 m/s	Percentage
101	0	0%
100	1	<0.1%
95	4	<0.1%
90	27	0.3%
85	80	0.9%
80	189	2.2%
75	361	4.1%
70	614	7.0%
65	1089	12.4%
60	1911	21.8%

Figure 10 Variation of Vertical Plume Velocity with Height above Ground



Red line indicates CASA assessment criterion for critical vertical plume velocity of 4.3 m/s

6 CONCLUSIONS

A detailed plume rise assessment has been conducted in accordance with CASA requirements for the proposed PNG Biomass Markham Valley power plant. The modelling was conducted using the design stack parameters and a calculated equivalent diameter representing the flow from both boiler stacks to predict the maximum critical plume heights under the full range of meteorological conditions likely to be experienced at the site (using a one year dataset of site-representative hourly meteorological data).

Based on the modelling results it is concluded that the plumes from the Project are unlikely to exceed the vertical plume velocity threshold of 4.3 m/s at the OLS of 150 m above ground level, even under worst case meteorological conditions and assuming complete merging of the two plumes. The maximum predicted plume height with a vertical velocity of 4.3 m/s or higher was approximately 103 m above ground level, which is well below the OLS of 150 m.

Given the above, the proposed Project is considered unlikely to pose any significant hazard on the flight path for aircraft landing or taking off from Lae Nadzab Airport.

It is recommended however that appropriate mitigation measures be implemented to minimise risks to slow flying, hovering helicopters that may fly within 150 m above ground level at the project site or the surrounding area. This includes insertion of a symbol and a height on aviation charts to enhance awareness of the potential plume rise risks in this area.

7 REFERENCES

CASA, 1999 *Rules and Practices for Aerodromes, Chapter 10 – Obstacles in Airspace*.

CASA, 2012 *Advisory Circular AC 139-5(1), Plume Rise Assessments, November 2012.*

UCAR 2016 http://www2.mmm.ucar.edu/wrf/users/model.html, visited on 21st February 2017

Pasquill, 1961 *The estimation of the dispersion of windborne material*, The Meteorological Magazine, Vol 90, No. 1063, pp 33-49.

PHYSICAL DIMENSIONS OF OLS

Table 10-1 — Approach Runways										
OLS & Dimensions (in metres and percentages)	Runway Classification									
	VFR and Circling Non-instrument				Instrument					
					Non-precision			Precision		
								I		II & III
	Code No				Code No			Code No		Code No
	1*	2	3	4	1, 2	3	4	1, 2	3, 4	3, 4
OUTER HORIZONTAL Height (m)									150	150
Radius (m)									15000	15000
CONICAL Slope	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
Height (m)	35	55	75	100	60	75	100	60	100	100
INNER HORIZONTAL Height (m)	45	45	45	45	45	45	45	45	45	45
Radius (m)	2000	2500	4000	4000	3500	4000	4000	3500	4000	4000
APPROACH Length of inner edge (m)	60	80	150[a]	150	90	150	300[b]	150	300	300
Distance from threshold (m)	30	60	60	60	60	60	60	60	60	60
Divergence each side	10%	10%	10%	10%	15%	15%	15%	15%	15%	15%
First section length (m)	1600	2500	3000	3000	2500	3000	3000	3000	3000	3000
Slope	5%	4%	3.33%	2.5%	3.33%	3.33%	2%	2.5%	2%	2%
Second section length (m)	-	-	-	-	-	3600[e]	3600	12000	3600	3600
Slope	-	-	-	-	-	2.5%[e]	2.5%	3%	2.5%	2.5%
Horizontal section length (m)	-	-	-	-	-	8400[e]	8400	-	8400	8400
Total length (m)	1600	2500	3000	3000	2500	15000[f]	15000	15000	15000	15000
INNER APPROACH Width (m)								90	120	120
Distance from threshold (m)								60	60	60
Length (m)								900	900	900
Slope								2.5%	2%	2%
TRANSITIONAL Slope	20%	20%	14.3%	14.3%	20%	14.3%	14.3%	14.3%	14.3%	14.3%

PHYSICAL DIMENSIONS OF OLS

Table 10-1 — Approach runways (continued)

INNER TRANSITIONAL Slope								40%	33.3%	33.3%
BAULKED LANDING Length of inner edge (m)								90	120	120
Distance from threshold (m)								[c]	1800[d]	1800
Divergence each side								10%	10%	10%
Slope								4%	3.3%	3.3%

All distances are measured horizontally unless otherwise specified.

* Runways used for RPT operations at night by aircraft with maximum take-off weight not exceeding 5,700 kg are required to meet code 2 standards.

[a] 90 m where width of runway is 30 m.

[b] 150 m if only used by aeroplanes requiring 30 m wide runway

[c] distance to end of strip.

[d] or to the end of strip, which ever is less.

[e] no actual ground survey required unless specifically required by procedure designer. Procedure designer will use topographical maps and tall structure data bank to determine minimum altitudes.

[f] approach area up to this distance needs to be monitored for new obstacles. Refer to procedure designer's advice on significant high ground or tall structure that needs monitoring.

PHYSICAL DIMENSIONS OF OLS

Table 10-2 – Take-off runways			
Take-off climb surface – Dimensions	Take-off runways Code number		
(in metres and percentages)	1*	2[a]	3 or 4
Length of inner edge	60	80	180[b]
Minimum distance of inner edge from runway end[c]	30	60	60
Rate of divergence (each side)	10%	10%	12.5%
Final width	380	580	1800[d]
Overall length	1600	2500	15000
Slope	5%	4%	2%[e]

All dimensions are measured horizontally unless otherwise specified.

* Runways used for RPT operations at night by aircraft with maximum take-off weight not exceeding 5,700 kg are required to meet code 2 standards.

[a] For aircraft above 5700 kg the survey area does not cover full extent of obstacle clearance required as specified in CAO 20.7.1B.

[b] The length of the inner edge may be reduced to 90m if the runway is intended to be used by aeroplanes having an MTOW less than 22700kg and operating in VMC by day. In this case the final width may be 600m, unless the flight path may involve a change of heading in excess of 15°.

[c] The take-off climb starts from the end of clearway if a clearway is provided.

[d] the final width may be reduced to 1200m if the runway is used only by aircraft with take-off procedure which does not include changes of heading greater than 15° for operations conducted in IMC or at night.

[e] The operational characteristics of aircraft for which the runway is intended should be examined to see if it is desirable to reduce the slope to cater for critical operating conditions as specified in CAO 20.7.1B. If the specified slope is reduced, corresponding adjustment in length for take-off climb is to be made so as to provide protection to a height of 300m. If no object reaches the 2% take-off climb surface, new objects should be limited to preserve the existing obstacle free surface or a surface down to a slope of 1.6%.

Appendix 9
Environmental Management Plan

ENVIRONMENTAL MANAGEMENT PLAN

PNG BIOMASS
MARKHAM VALLEY

MARCH 2017
Report No. 01183B_3_v3

Oil Search

PNG BIOMASS

ERIAS GROUP

ERIAS Group Pty Ltd
ACN 155 087 362

Markham Valley Biomass Limited

PNG Biomass Markham Valley

Environmental Management Plan

March 2017
(Report No. 01183B_3_v3)

Prepared by ERIAS Group Pty Ltd
(ACN: 155 087 362)

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01183B_3_v3	10/03/2017	M Clark	L David	L David

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1. Introduction

1.1 Context

Oil Search Limited (Oil Search/OSL), through its wholly-owned subsidiary Markham Valley Biomass Limited (MVB)[1], proposes to develop the PNG Biomass Markham Valley project (hereafter referred to as 'the Project') in Morobe Province, Papua New Guinea (PNG). The Project area (also referred to as Area A) is located in the Markham Valley, about 50 km west-northwest of the provincial capital Lae (Figure 1.1).

The Project involves the development of up to 16,000 ha of eucalypt plantations and a 30 MW biomass power plant (two 15 MW units). The power plant will generate electricity for supply to the Ramu grid using existing transmission lines. The preferred site for the power plant is located in the southeast part of the Project area.

1.2 Scope and Purpose

This Environmental Management Plan (EMP) applies to the power plant construction and plantation development activities as summarised in Chapter 2. The EMP serves to guide the MVB workforce in identifying, managing and mitigating potential environmental impacts that may result from these activities. In so doing, this document describes the environmental management framework that is required to identify and assess risks, implement appropriate mitigation measures, and monitor and evaluate their success to facilitate continual improvement.

It is a requirement for all MVB personnel and contractors to comply with the EMP.

The EMP will sit within the framework of the Integrated Management System (IMS) that is currently being developed as described in Chapter 5. The IMS will ultimately encompass all activities undertaken for the Project, from office-based work through to plantation establishment and harvesting, and operation of the power plant. From an environmental perspective, the IMS will also be consistent with Oil Search's policies, statutory obligations, and commitments made as part of the environmental assessment (EA) process in accordance with the requirements of the *Environment Act 2000*.

The IMS will be developed in line with the principles of relevant international standards such as ISO 9000 (quality and loss control), ISO 14000 (environment) and OHSAS 18000 (occupational health and safety), and will incorporate all aspects of MVB's documentation including policies, planning procedures, standard operating procedures (SOPs) and management prescriptions. The environmental aspects will be consistent with ISO 14001:2015, as reflected in the Australian and New Zealand equivalent AS/NZS ISO 14001:2016 (see Chapter 5).

[1] The entity name of Markham Valley Biomass Limited (MVB) will be changed to PNG Biomass Limited. However, for the purposes of this report, the former will be used. This EMP applies to the activities of both MVB and its subsidiary Markham Valley Power Limited (MVP).

PROJECT AREA LOCATION

PNG Biomass Markham Valley I Environmental Management Plan

FIGURE 1.1

Image Source: Google Earth.

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2. Project Description

2.1 Eucalypt Plantations

The plantations will be developed and operated to comply with Forest Stewardship Council (FSC) sustainability criteria, and will use a fast-growing *Eucalyptus* tree species (*E. pellita*, which is indigenous to Papua New Guinea) or a hybrid species. Establishment of up to 16,000 ha of plantations within the Project area will occur over a seven-year period between 2017 and 2023, with the plantation area to be maintained indefinitely. During this initial phase, plantation establishment will be around 2,000 ha/year on average, with a maximum of 4,500 ha/year in 2019. The plantation area (which excludes non-planted areas such as roads, watercourses, villages, gardens and buffer zones) will be sufficient to supply biomass fuel to the 30 MW power plant. Plantations will be developed in a manner that is consistent with the development timeline of the power plant. Road upgrades and establishment of a large plant nursery will be associated with the plantations.

Plantation establishment will involve the following stages:

- Site clearing – primarily of grasslands and introduced raintrees. The latter will provide biomass supply to the new power plant for its first few years of operation.
- Site preparation – including soil cultivation and application of FSC-approved herbicides.
- Progressive planting of approximately 20 million tree seedlings (at 1,333 stems/ha) and application of chemicals (e.g., fertiliser, hydrogel, FSC-approved herbicides).
- Plantation management on a rotation with up to two coppice cycles.
- Mechanical harvesting with leaves, much of the bark and small branches left behind as mulch, while timber is transported to the power plant via trucks.

All timber will initially be grown for biomass for the power plant, with a supply contingency buffer. Commencing in Year 4, part of the plantation estate will be managed to generate timber for solid timber products such as veneer and sawlogs.

2.2 Biomass Power Plant

2.2.1 Construction

Construction of the initial 15 MW power plant unit will take about 26 months and will involve the following steps:

- Site preparation – providing site access and undertaking clearing, cut and/or fill, and site compacting, as well as establishing site drainage, roads/parking/fencing, and temporary laydown areas, warehouses and construction site offices/cabins (including stores, toilets and workers' eating facility).

- Building construction – including an administration building, weigh bridge building and truck scale, workshop and warehouse, control room and other facilities.
- Mechanical equipment, structures and pipework installation – including installation of pipe racks, piping, tanks, boiler, cooling water tower, water supply bores, water treatment plant and similar.
- Electrical and instrument installation – including installation of cables, cable trays, ducts, lighting, transformers, switchgear, lightning and earthing protection systems, plant lighting and fire detection and alarm systems, and similar.

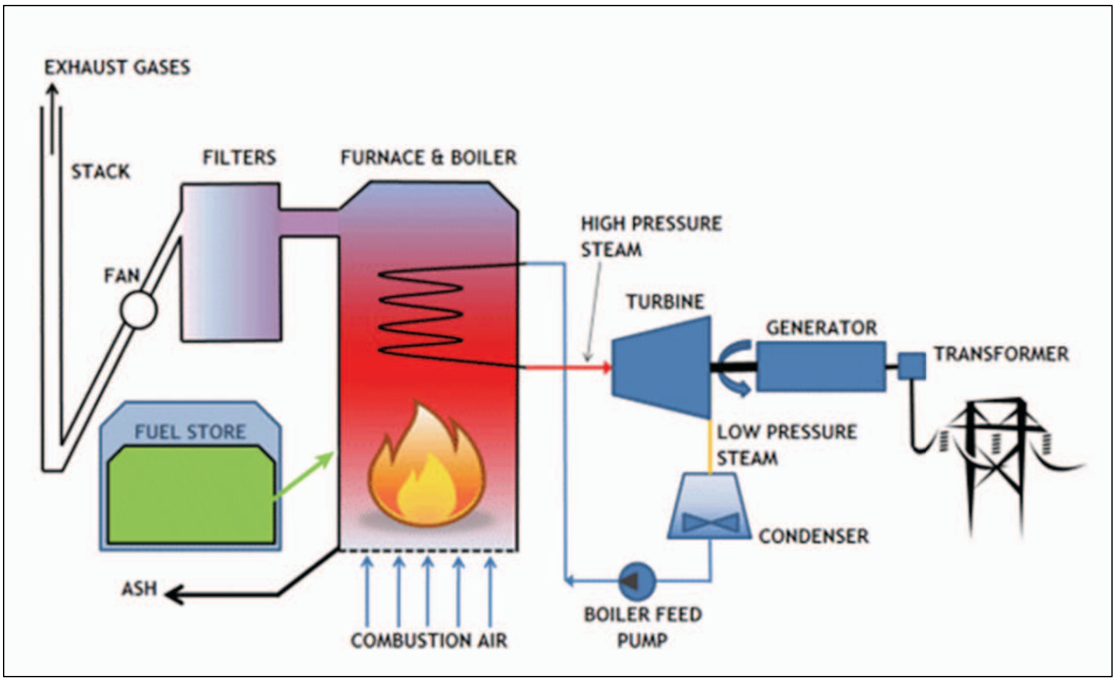
The power plant footprint that is initially established will allow for the second 15 MW unit, which will be constructed several years after the first unit.

2.2.2 Operation

Trees grown in the plantations will be used as biomass fuel for a 30 MW power plant consisting of two 15 MW modules, which will be located close to the Highlands Highway (see Figure 1.1) and an existing electricity transmission line. The power plant site (plus log yard) is expected to cover a total area of about 31 ha.

Each power plant module will consist of a biomass boiler and steam turbine (Plate 2.1), fuelled by wood chips supplied from the dedicated plantations. Fuel security is assured through the Project owning and operating the plantations in partnership with local landowners. The power plant will employ conventional thermal boiler technology. The proposed configuration of each module will be a single boiler and a single steam turbine. Cooling will involve a wet evaporative mechanical system, using water abstracted from groundwater bores installed on site.

Plate 2.1 – Biomass Power Plant Schematic



Source: AEL, 2016.

Key stages and aspects of power plant operation include:

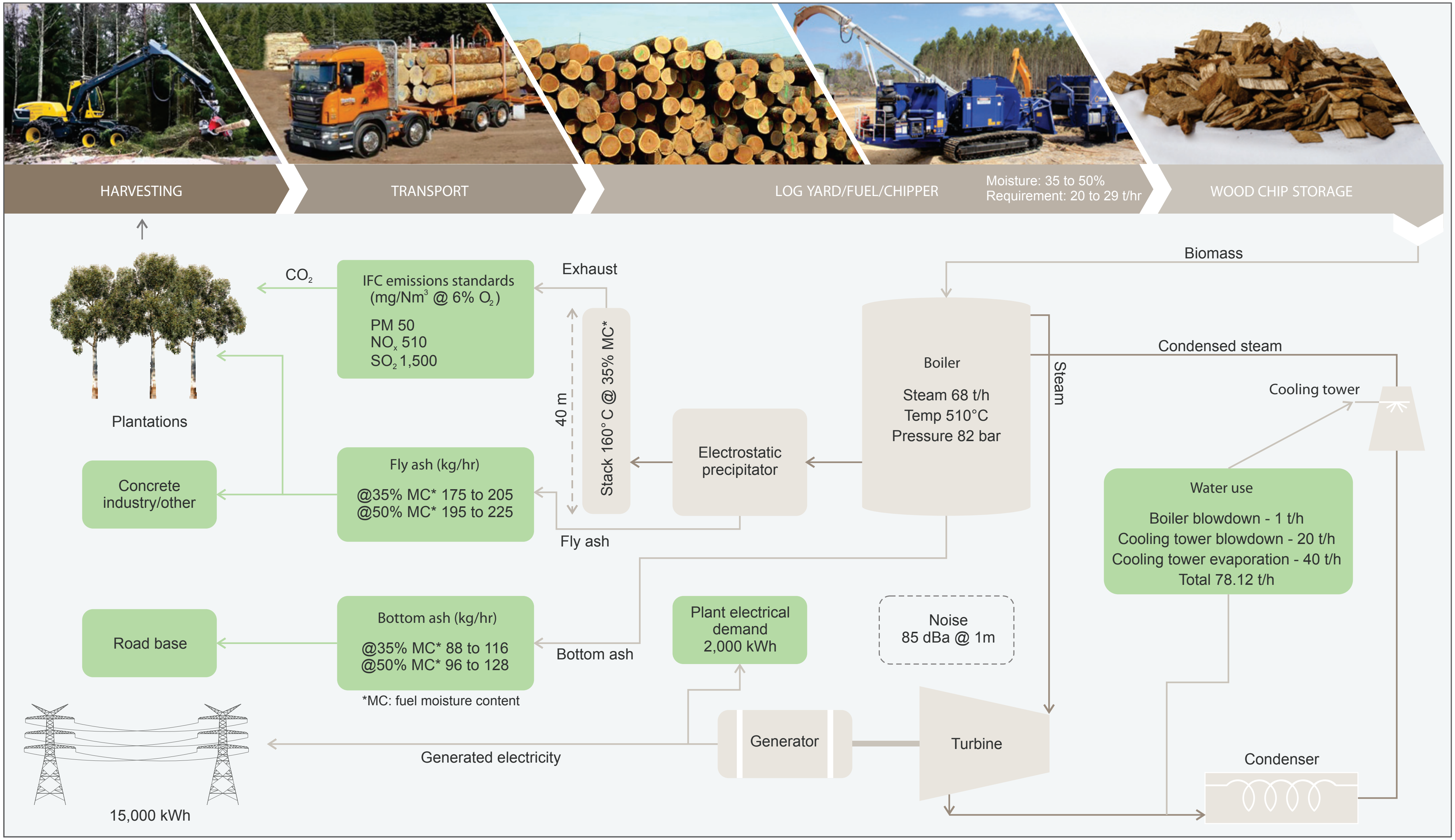
- Transport of biomass supply – biomass log demand (for the power plant) is expected to reach 175,300 BDMt/yr (bone dry metric tonnes per year) by 2023 and then be maintained at this level.
- Stockpiling and chipping – the biomass fuel (logs) will be brought to site by truck and placed in the log yard, which will have a capacity of around 90 days storage. The logs will be allowed to dry naturally before being chipped. The woodchips will be stored in the open (outdoor) storage yard, which will be sized for a storage capacity of 10 days at full capacity.
- Power generation – combustion of dry biomass will boil water in the power plant boilers to create steam, which in turn will drive turbines and generate electricity. High furnace temperatures will ensure that combustion is complete and that emissions are limited to applicable international standards. A proportion of the fly ash will be trapped in a dust collector, with the remaining material being collected in an electrostatic precipitator (ESP).
- Water input – total water required for use power plant is conservatively estimated to be about 160 t/h (0.044 m^3/s), and this is likely to be extracted from water bores to be constructed at the power plant site or next to the Markham River. Three 50% power plant capacity submersible raw water pumps may also be installed to allow raw water to be pumped from the Markham River to the pre-treatment plant as an alternative water supply.
- Emissions/discharges, including:
  - Steam and gaseous emissions, primarily from the power plant stacks.
  - Ash (two types) generated by combustion of biomass. ‘Fly ash’ may be incorporated within plantation area soils to enhance soil properties or sold to local industries as an input for concrete production, while ‘bottom ash’ can be used in road construction.
  - Wastewater discharges from the power plant, which will be treated before release to ensure that IFC discharge guideline values for thermal power plants (IFC, 2008) are met. This treated wastewater will either be used for irrigation or discharged to a man-made drainage line that reports to the Markham River.
- Generated electricity – the power plant will be connected to the Ramu grid through a Loop In Loop Out (LILO) interconnection arrangement which will assist grid stability. Power will be generated by the steam turbine generator at 11 kV and then delivered via a step-up transformer and a 132 kV circuit breaker to the grid connection.
- Maintenance – the power plant will be maintained at regular intervals to ensure minimal downtime and high reliability.

Project inputs and outputs are summarised in Figure 2.1.

PROJECT INPUTS AND OUTPUTS

PNG Biomass Markham Valley I Environmental Management Plan

FIGURE 2.1



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3. Legislation, Policy and Guidelines

3.1 Context

This section describes the key PNG Government development goals and planning strategies, and environmental and socio-economic legislation and agreements that are relevant to the Project, along with international standards and principles that the Project has adopted. While minor aspects of many other acts and regulations will be relevant to the Project, such acts and regulations have only been listed rather than specifically discussed, as they do not relate directly to environmental project approvals or require specific action.

3.2 Constitutional Goals and Directives

The Project is consistent with the constitutional goals and directives of Papua New Guinea, which promote the development of its resources through various policies aimed at encouraging investment. While encouraging foreign investors, a priority of the PNG Government is that the people of Papua New Guinea must benefit from any such development.

As outlined in the Constitution of Papua New Guinea (PNG Government, 1975), key relevant aspirations and principles for the development of the nation are presented in Goals 2, 3 and 4:

> We declare our second goal to be for all citizens to have an equal opportunity to participate in, and benefit from, the development of our country.
>
> We declare our third goal to be for Papua New Guinea to be politically and economically independent, and our economy basically self-reliant.
>
> We declare our fourth goal to be for Papua New Guinea's natural resources and environment to be conserved and used for the collective benefit of us all, and be replenished for the benefit of future generations.

Markham Valley Biomass will ensure that use of skills and resources available in the local area, Morobe Province and, finally, the rest of Papua New Guinea is maximised, thereby providing opportunities for PNG citizens to participate in, and benefit from, the Project. In developing the plantations and power plant, the Project will provide significant employment opportunities during construction and operations, and will enhance the capacity of the local and/or regional workforce and infrastructure to support future development projects. This in turn will also contribute to the economy, employment opportunities, and longer term improvements in infrastructure and services. Furthermore, the Project will create employment in a region distant from conventional energy resources, in a manner that creates social, environmental and development opportunities for PNG citizens.

Development of the power plant will diversify the electricity supply industry in Papua New Guinea, which is currently dominated by hydropower, oil (diesel) and gas. The Project is therefore consistent with the PNG Government's initiatives and policies to provide a long-term energy solution that provides secure, sustainable, baseload power.

3.3 PNG Government Plans and Policies

In 2009, the PNG Government, through the National Strategic Plan Taskforce, released 'Vision 2050' (NSPT, 2009). This describes the country's long-term strategy and reflects the aspirations of Papua New Guineans, with the goal that Papua New Guinea will be ranked in the top 50 countries in the United Nations Human Development Index by 2050 (NSPT, 2009). The NSPT (2009) lists seven strategic areas, of which the development of the Project particularly aligns with the following:

- 1: Human Capital Development, Gender, Youth and People Empowerment.
- 2: Wealth Creation.
- 5: Environmental Sustainability and Climate Change.

In addition, the Project is consistent with the Papua New Guinea Development Strategic Plan (PNGDSP) 2010-2030 (DNPM, 2010), which states that the nation's long-term goal for energy development is that:

> All households have access to a reliable and affordable energy supply, and sufficient power is generated and distributed to meet future energy requirements and demands.

The Project will also contribute to PNGDSP and PNG Forest Authority goals and targets concerning forestry in Papua New Guinea.

Further to the PNGDSP, the PNG Department of National Planning and Monitoring has developed shorter-term initiatives in the form of medium-term development plans that have goals stemming from Vision 2050, aim to implement the PNGDSP, and are the benchmark for all sectoral, provincial, district and local level government plans. The Papua New Guinea Medium Term Development Plan 2016-2017 (DNPM, 2015) defines forestry assets as strategic and states that:

> …government investment will focus on developing and strategically positioning these assets to meet the needs of current as well as future generations of Papua New Guineans.

The Project also directly addresses a number of relevant PNG Electricity Industry Policy (PNG Government, 2011) objectives, particularly with regards to:

- Actively seeking landowner participation and establishing arrangements with landowners.
- Using technologies for electricity generation that are environmentally and socially sound (i.e., biomass power as opposed to fossil fuels).
- Emissions reduction (as discussed above), which qualifies the Project under the Kyoto Clean Development Mechanism or similar international emissions reduction schemes.

The Project will contribute to the local region, Morobe Province, and Papua New Guinea as a whole, in terms of economic, social and environmental sustainability benefits. As such, the Project aligns with the government's overall priorities.

3.4 Regulatory and Policy Framework

3.4.1 Environmental Legislation

The *Environment Act 2000* (the Act) prescribes requirements for proponents seeking environmental approvals for new developments or changes to existing developments, and is administered by the Conservation and Environment Protection Authority (CEPA). The related Environment (Prescribed Activities) Regulation 2002 (the Regulation) lists the types of approvals required for different levels of activities under the Act.

On 4 September 2015, MVB submitted to CEPA an application for an environment permit and notification of intention to carry out preparatory work. Subsequently, CEPA formally advised (by letter dated 8 March 2016) that the Project would be classified as a Level 2 (Subcategory 10.2) activity. Subcategory 10 relates to energy production, with clause 10.2 specifically addressing power stations:

> 10.2. Operation of fuel burning power stations with a capacity of more than 5 MW, but not including emergency generators.

As such, and in accordance with the Department of Environment and Conservation (DEC; now superseded by CEPA) Operational Procedure – Information Requirements for Permit Applications and Registration of Intention to Carry Out Preparatory Work (DEC, 2013) prepared in accordance with the Act (s.132), the Project prepared the following:

- An EA report reflecting the findings of baseline environmental and social studies.
- An EMP (this document) developed on the basis of the environmental risks posed to the identified environmental values, as well as mitigation and management measures required to minimise those risks.

Other associated and subsidiary Project activities also classified as Level 2, including the plantations, will be permitted under the umbrella of the approvals pursued for the main Level 2 activity. The Project EA report and EMP need to be consistent with Schedule 3 – General Guidelines on the Additional Information Required to Support a Permit Application for a Level 2 Activity (DEC, 2013).

Part VII of the Act provides for permits for the use of water resources in Papua New Guinea, including dams and diversions, discharges of wastes and/or contaminants, water investigations and the taking of water resources via specific conditions in an environment permit.

3.4.2 Forestry Legislation

The *Forestry Act 1991* (Forestry Act) (and its amendments from 1993, 1996, 2000 and 2005) is the primary piece of legislation governing the management, protection and use of forests and forest resources in Papua New Guinea. The Forestry Act is administered by the Papua New Guinea Forest Authority (PNGFA) and is supported by the Forest Regulation 1992 and the Forestry Regulation 1998 (in operation from January 1996).

Under the Forestry Act (Part IV), to engage in forest industry activities involving harvesting, chipping and selling of the finished timber product, MVB must be registered as a Forest Industry Participant (FIP). This FIP registration does not relate to the planting of the eucalypt plantations.

A Forest Clearing Authority (FCA) (s.90B of the Forestry Act) will also be required and MVB will apply for this prior to harvesting of the plantation trees.

3.4.3 Other Relevant Legislation

In addition to legislation discussed in Sections 2.4.2 and 2.4.3, the legislation, industry codes and plans listed in Table 3.1 are also relevant to the Project.

Table 3.1 – Other Legislation, Industry Codes and Plans Applicable to the Project

Environment
♦ *Conservation Areas Act 1978 and Conservation Areas (Amendment) Act 2014* ♦ Environment (Council's Procedures) Regulation 2002 ♦ Environment (Fees and Charges) Regulation 2002 ♦ Environment (Water Quality Criteria) Regulation 2002 ♦ Environment (Permits) Regulation 2002 ♦ *Fauna (Protection and Control) Act 1966, Fauna (Protection and Control) Act 1974 (Chapter 154)* and *Fauna (Protection and Control) (Amendment) Act 2014* ♦ *International Trade (Fauna and Flora) Act 1979 (Chapter 391)* and *International Trade (Fauna and Flora) (Amendment) Act 2014* ♦ *Plant Disease and Control Act 1953 (Chapter 220)* ♦ Public Health (Drinking Water) Regulation 1984 (Chapter 226)
Forestry
♦ *Forestry (Amendment) Act 1993* ♦ Forest Regulation No. 15 1992 ♦ Forestry Regulations 1996 ♦ *Forest (Timber Permits Validation) Act 2007* ♦ National Forest Policy 1991 ♦ National Forest Development Guidelines of 1993 ♦ National Forest Plan 1996
Protection and Preservation of Sites/Features of Archaeological and Cultural Heritage Significance
♦ *National Cultural Property (Preservation) Act 1965* and National Cultural Property (Preservation) Regulation 1965 ♦ *National Museum and Art Gallery Act 1992*
Land Acquisition and Compensation
♦ *Business Groups Act 1965* ♦ *Land Act 1996* ♦ *Land Dispute Settlement Act 1975* ♦ *Land Groups Incorporation Act 1974* and *Land Groups Incorporation (Amendment) Act 2009* ♦ Land Groups Incorporation Regulation 1974 ♦ *Land (Ownership of Freeholds) Act 1976* ♦ *Land Registration Act 1999* and *Land Registration (Amendment) Act 2009* ♦ Land Registration Regulation 1999 ♦ *Land Registration (Customary Land—Amendment) Act 2009* ♦ Land Regulation 1999 ♦ *Valuation Act (Chapter 327) 1967*

Table 3.1 – Other Legislation, Industry Codes and Plans Applicable to the Project (cont'd)

Power Generation, Transmission and Distribution
♦ *Electricity Industry Act (Chapter 76) 2002* ♦ Electricity Code ♦ Third Party Access Code ♦ Grid Code
Power Plant Construction
♦ *Physical Planning Act 1989* ♦ Physical Planning Regulation 2007 ♦ *Building Act (Chapter 301) 1971* ♦ Building Regulations 1994

In addition to the items listed in Table 3.1, a number of other acts and regulations may be of relevance to the Project in relation to matters such as public and workforce health and safety, and commercial and professional matters. These matters are beyond the scope of this EMP.

3.4.4 International Standards, Agreements and Guidelines

3.4.4.1 International Financing Standards and Guidelines

The EMP has been prepared to satisfy PNG regulatory requirements and be consistent with the requirements of the Equator Principles and associated International Finance Corporation (IFC) Environmental and Social Performance Standards (IFC, 2012).

The Equator Principles provide a risk management framework that is adopted by financial institutions for determining, assessing and managing environmental and social risk in large infrastructure and industrial projects. The principles refer to the IFC performance standards as well as the World Bank Group Environmental, Health and Safety (EHS) Guidelines.

The IFC performance standards (IFC, 2012) are directed towards project proponents and provide guidance on how to identify and manage environmental and social risks and impacts. They also establish the standards that proponents are to meet throughout the life of an investment by the IFC.

The World Bank Group EHS Guidelines are technical reference documents that are specifically referred to in the performance standards and provide both general and industry-specific examples of good industry practice. The General EHS Guidelines provide guidance to users on common EHS issues that are potentially applicable to all industry sectors (IFC, 2007) and should be used in conjunction with the relevant industry sector guidelines, e.g., the thermal power plants guideline (IFC, 2008).

3.4.4.2 Forest Stewardship Council

The Forest Stewardship Council (FSC) is an independent, not for profit, non-government organisation, which is dedicated to the promotion of responsible forest management. The FSC Principles and Criteria (P&C) describe the essential elements or rules to support environmentally appropriate, socially beneficial, and economically viable management of the world's forests. There are ten principles, each supported by several criteria that provide a way of judging whether the principle has been met in practice, thereby forming the basis of FSC certification of forest management. All ten principles and criteria apply to all forest types and to all areas within the management unit included in the scope of the certificate, and must be applied to any forest management unit before it can receive FSC certification. The P&C are not specific to any particular country or region; they are applicable worldwide and are relevant to forest areas and different ecosystems, as well as cultural, political and legal systems.

The FSC’s 2010 National Forest Management Standards for Papua New Guinea (FSC, 2010) is an adaptation of the FSC P&C (FSC's International Standard) in relation to the specific conditions in Papua New Guinea. The National Forest Management Standards for Papua New Guinea set the principles, criteria, indicators and verifiers by which all forest operations in the country can be judged, and are tailored to reflect the country’s unique social, economic and environmental situation.

The ten principles of the National Forest Management Standards for Papua New Guinea – including requirements to conserve environmental values, maintain high conservation forests, and manage plantations in a manner than complements sustainable management of natural forests – have been taken into account by the Project.

The 2010 version of the National Forest Management Standards for Papua New Guinea is currently under review and a 2016 draft version has been released for public consultation (FSC, 2016). Finalisation of the document will occur in the first half of 2017, and subsequent approval by FSC is likely to occur in Q4 2017 (Dam, pers. com., 2017).

The FSC's position on plantations (FSC, 2014) is described as:

> FSC supports the responsible use of plantations as a strategy to complement conservation and the sustainable use of natural forests. While plantations cannot replace the richness, stability and beauty of natural forests or the complexity of the services they provide, applying the FSC standards to them ensures that their management is defined by transparency and fairness and minimizes negative environmental and social effects.

This allows for plantation certification, apart from any plantation that was established as a result of forest conversion after 1994, and efforts have been made by the FSC over the past decade to better integrate its requirements for plantation management into those that apply to all types of forests.

3.4.4.3 International Conventions, Treaties and Protocols

Relevant international treaties, conventions and protocols that the PNG Government has signed, ratified or acceded to, are shown in Table 3.2.

Table 3.2 – Applicable International Conventions, Treaties and Protocols

Title	Summary/Objective
Paris Agreement (2015)	Strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5°C

Table 3.2 – Applicable International Conventions, Treaties and Protocols (cont'd)

Title	Summary/Objective
Kyoto Protocol to United Nations Framework Convention on Climate Change (1997)	Stabilise greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system Places onus on industrialised (Annex 1) countries to reduce emissions; developing countries such as Papua New Guinea are exempt from this requirement
Vienna Convention for the Protection of the Ozone Layer (the Vienna Convention) (1993) and the Montreal Protocol on Substances that Deplete the Ozone Layer (1992)	Protect the ozone layer
Convention to Ban the Importation into Forum Island Countries of Hazardous Wastes and Radioactive Wastes and to Control the Transboundary Movement and Management of Hazardous Wastes Within the South Pacific (Waigani Convention) (2001)	Reduce and eliminate transboundary movements of hazardous and radioactive waste, to minimize the production of hazardous and toxic wastes in the Pacific region and to ensure that disposal of wastes in the Convention area is completed in an environmentally sound manner
Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal (Basel Convention), 1989	Protect human health and the environment against the adverse effects of hazardous wastes
Stockholm Convention on Persistent Organic Pollutants (POPs) (2004)	Protect human health and the environment from chemicals that remain intact in the environment for long periods, become widely distributed geographically, accumulate in the fatty tissue of humans and wildlife, and have harmful impacts on human health or on the environment)
International Tropical Timber Agreement (ITTA, Geneva), 2006	Promote the expansion and diversification of international trade in tropical timber from sustainably managed and legally harvested forests and to promote the sustainable management of tropical timber producing forests This replaces the International Tropical Timber Agreement, 1994
Convention on Biological Diversity (1993)	Preserve and sustain biological diversity, sustainable use of its components and the fair and equitable sharing of benefits from genetic resources
Convention on Wetlands of International Importance Especially as Waterfowl Habitat (RAMSAR Convention), 1971 and the international regime for the 'conservation and wise use' of wetlands and waterfowl populations	Halt the worldwide loss of wetlands and promote the conservation and wise use of all wetlands through cooperative management
Convention on International Trade in Endangered Species (CITES) of Wild Fauna and Flora (1975)	Ensure that international trade in specimens of wild animals and plants does not threaten their survival
International Plant Protection Convention (Rome), 1951 (revised 1997)	Prevent and control the introduction of pests of plants and plant products
Convention for the Safeguarding of Intangible Cultural Heritage (UNESCO) (2003)	Safeguard intangible cultural heritage, ensure respect for the intangible cultural heritage of the communities, groups and individuals, and raise awareness at the local, national and international levels of the importance of intangible cultural heritage

Table 3.2 – Applicable International Conventions, Treaties and Protocols (cont'd)

Title	Summary/Objective
Convention Concerning the Protection of World Cultural Heritage and Natural Heritage (1972)	Identify, protect and conserve cultural and natural heritage

3.4.4.4 Industry Standards and Codes of Practice

Project adherence to standards and guidelines will follow a hierarchical approach:

1 Applicable Papua New Guinea acts, regulations and standards.
2 International standards and guidelines.

The Papua New Guinea Logging Code of Practice (PNGFA/DEC, 1996) and, where appropriate, the Forest Practices Code developed by Tasmania's Forest Practices Authority (2015) will be used by the Project.

In the absence of PNG standards or where additional guidance is warranted alongside the use of PNG standards, internationally recognised standards and guidelines will be applied including, for example, those developed by the Australian and New Zealand Environment and Conservation Council/Agriculture and Resource Management Council of Australia and New Zealand (e.g., ANZECC/ARMCANZ, 2000), the World Health Organization (e.g., WHO, 2011) and the International Finance Corporation (e.g., IFC, 2012).

3.5 Company Policies and Standards

Markham Valley Biomass is committed to operating the Project in a manner that meets the environmental and social sustainability principles that Oil Search (as the owner of MVB) has developed through its Health, Safety, Environment and Security Policy (Box 3.1) and its Social Responsibility Policy (Box 3.2).

Box 3.1 – Oil Search Health, Safety, Environment & Security Policy

Oil Search

Health, Safety, Environment & Security Policy

Oil Search is committed to achieving incident free operations through the provision of effective Health, Safety, Environmental and Security (HSES) Management across all of its operations and worksites that benefit employees, contractors and the community.

The Company is committed to:

- Promoting HSES objectives, leadership, responsibilities and behaviour as an integral part of the duties of management and all employees;
- Complying with applicable laws and other obligations and requirements that the company subscribes to, and where adequate laws do not exist, adopting and applying standards that reflect Oil Search's commitment to HSES outlined in this policy;
- Reporting and evaluating risks, threats, hazards and impacts to company operations that have the potential to adversely affect the environment or the health and safety of employees, contractors or the community;
- Implementing appropriate control and contingency measures to prevent pollution and minimise and manage these risks, threats, hazards and impacts to an acceptable level;
- Establishing and ensuring that standards are followed and effective practices promoted to ensure that the environment, people, property and information are protected from harm;
- Selecting and engaging contractors whose management systems are acceptable to Oil Search and whose commitment to this policy is clearly and continuously demonstrated;
- Providing competent human resources to manage relevant aspects of health, safety, environment or security;
- Communicating openly with all stakeholders on HSES related issues;
- Providing training, instruction and supervision to personnel to enable them to attain the knowledge and skill levels necessary to perform their work incident free;
- Maintaining appropriate contingency arrangements;
- Continually monitoring, reviewing and improving HSES performance and associated management systems so that our activities can continue without interruption and;
- Ensuring that oversight of accident, incident and near miss investigations is assumed by the appropriate executive manager and that those investigations are conducted to a level of detail that is appropriate to the event's actual and potential severity.
- A consistent and equitable approach to the prevention of HIV among employees, families and their communities; the management of the consequences of HIV including the care and support of employees and their families; and protecting the rights of employees living with HIV from discrimination, victimisation or harassment.

Every employee and contractor working for the Company has a responsibility to promote a culture whereby their actions and those of their colleagues are consistent with this Policy.

Richard Lee	**Peter Botten**
Chairman	Managing Director

EMS-PRO-000006 Updated: 7 December 2015

Box 3.2 – Oil Search Social Responsibility Policy

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Oil Search

Social Responsibility Policy

With operations in environmentally, culturally and socially sensitive locations, Oil Search's commitment to social responsibility stems from a culture that strives for the highest ethical, social and moral values and a desire to be recognised as delivering "excellence in socially responsible oil and gas exploration and production".. We set ourselves apart from our peers by our sustainable development approach and our ability to contribute positively and creatively to the growth and development of communities in which we operate.

The Company is committed to:

- Operating with integrity at all times as well as adopting and advocating for principles, practices and standards that respect diversity, local culture, human rights, labour rights, women's protection and empowerment, and the environment, and which contribute towards combatting corruption;
- Generating shared value by ensuring positive, sustainable outcomes for the communities in which we operate, while at the same time ensuring secure and continued operations and being mindful of our responsibility to shareholders and other stakeholders;
- Maintaining and enhancing our social license to operate through high levels of stakeholder engagement; establishing and maintaining strong and mutually beneficial community relationships; leaving a long-term positive social development legacy; and monitoring the impact of our activities on our project area communities;
- Continuous performance improvement by continuing to grow and leverage our social responsibility capability; seeking ways to enhance our approach; and improving measurement and reporting of performance.
- Seek ways to manage natural resources responsibly by minimising our environmental impact and operating in an environmentally sustainable way by adoption of the precautionary principle and giving consideration to effective and efficient use and re-use of resources and;
- Upholding the Ten Principles of the UN Global Compact, the Voluntary Principles for Security & Human Rights, and contributing to the progress of the Sustainable Development Goals in its countries of operation.

To achieve this commitment, Oil Search will:

- Ensure governance systems are in place to oversee, monitor, measure, report and drive social responsibility performance and decision making including social responsibility objectives and leadership responsibilities.
- Comply with all social and environmental laws, regulations and obligations and, where these do not exist adopt and apply standards that are in alignment with the intent of this policy and internationally accepted norms of behaviour.
- Proactively identify, evaluate, transparently report and manage any risks, threats or impacts related to our operating context that have the potential to adversely affect the environment, the well-being of the local community or our social license to operate. Appropriate control and contingency measures will be adopted to minimise and manage concerns and opportunities.
- Use our sphere of influence to advocate for the commitments contained in this policy, including but not limited to our supply chain and local content.

Every employee and contractor working for the Company has a responsibility to promote a culture whereby their actions and those of their colleagues are consistent with this Policy.

Richard Lee	**Peter Botten**
Chairman	Managing Director

EMS-POL-000009 Approved: 7 December 2015

4. Environmental and Social Setting

4.1 Environmental Setting

4.1.1 Physical Environment

The Project area is situated on broad, flat alluvial plains associated with the Markham River and its tributaries, where the river flows in a generally west to east direction and forms the area's southern border (see Figure 1.1). The area itself straddles the northern floodplain of the Markham River between Leron and Nadzab, and encompasses the Leron, Erap, Rumu and Maralumi sub-catchments. These four main waterways are all considered to be ephemeral.

The geology of the Project area is relatively young, deep Quaternary alluvial fan deposits, consisting of rounded coarse gravels, sand and silt laid down during both the Pleistocene and Holocene periods. The area is seismically active, with seismicity of up to 7.0 M_W recorded along the northern margin of the Markham Valley.

Soils vary across the Project area but are generally deep alluvial deposits consisting of well to imperfectly drained, undifferentiated soils subject to seasonal moisture stress due to low water holding capacity.

The Project area has a tropical climate with distinct wet (October to April) and dry (June to August) seasons. Annual rainfall for the Project area is in the range of 1,200 to 1,400 mm. Rainfall varies considerably between years, and also between different locations within the Markham Valley. Mean annual maximum temperature in the Project area is around 31°C, with the coolest months being June to September (mean monthly maximum of 29.2°C). Wind speeds are generally light to moderate, most frequently from the east and associated with the southeast trade winds from May to October.

The Markham River has a braided form along its entire length, with the braids, islands and bars of the river channel continually changing. The four sub-catchments in the Project area consist of very steep headwaters, draining onto flat alluvial fans, which is indicative of very high sediment loads. However, in addition to sediment-rich and turbid waterways, a number of smaller clearwater streams appear to originate downslope of the fans produced by the high-energy headwater streams.

Water quality in the Project area is generally consistent with similar watercourses elsewhere in Papua New Guinea, i.e., generally good quality water in terms of maintaining aquatic ecosystems and potentially providing drinking water for local communities, but with elevated suspended solids concentrations in some rivers and elevated faecal coliform levels at most sites. Similarly, sediment quality is consistent with other similar watercourses in Papua New Guinea, and is indicative of generally good sediment quality in terms of maintaining aquatic ecosystems.

Groundwater in the area comprises two main types: deep (4 to 70 m) and shallow (0 to 3 m). Deep groundwater movement is not related to the surface drainage, in contrast to the lateral movement of shallow groundwater. The water table fluctuates seasonally and reflects rainfall patterns with a delayed response time, with recent data indicating a maximum increase in groundwater depth during the dry season of a little more than 2 m. Groundwater quality is 'fresh', i.e., total dissolved solids (TDS) levels are less than 500 mg/L, with generally alkaline or near-neutral pH values. Hardness is variable, ranging from soft through to very hard, with the latter being more common.

Background air quality is expected to be generally good with negligible concentrations of gaseous pollutants, reflecting the Project's location and the virtually complete absence of nearby industrial sources. Potential particulate matter air pollutants are expected to be low, although not negligible. The ambient background noise levels are expected to be consistent with insects, heavy rain, birds, domestic animals, wind noise in foliage, and typical village domestic activities.

4.1.2 Biological Environment

The Project area is dominated by vegetation in a degraded, highly modified condition, with natural vegetation being an extremely limited component of the landscape. No intact vegetation was recorded during a terrestrial ecology survey of the area. No Kunai grassland habitats within the Project area are considered to be in a natural condition due to the importance of anthropogenic influences in the origin and maintenance of such grasslands. No critically endangered or endangered flora species have been detected and none are considered likely to occur. Furthermore, no habitat areas of significant importance to endemic or restricted-range species were identified and there is no evidence to suggest that habitats support key evolutionary processes, most of which have been substantially modified by repetitive anthropogenic disturbance. No forest in the Project area qualifies as High Conservation Value Forest.

Four main terrestrial fauna habitat types have been characterised within the Project area: alluvial forest and woodland; grassland; watercourses and wetlands; and highly disturbed anthropogenic habitats. A field survey recorded a total of 89 terrestrial vertebrate fauna species, and discussions with local informants identified at least a further 10 mammal species, 8 bird species and 5 reptile species that are likely to occur in the Project area. Anabat detectors identified the presence of 8 microbat species. However, no threatened or near-threatened terrestrial vertebrate fauna species were detected and no threatened or near-threatened species are considered likely to occur in the area. Two introduced fauna pest species, the giant African snail (*Achatina fulica*) and cane toad (*Bufo marinus*), were common throughout the survey area and were the only fauna trapped.

Four broad aquatic habitat types have been characterised within and near the Project area that reflect factors including bed structure, sediment loads and hydrology. Fish species recorded from the Project area are characteristic of lowland rivers and tributaries in northern Papua New Guinea. Fish species richness (16 species total) in the Project area is within the range of that recorded from previous surveys in the Lower Watut and Markham rivers (11 to 21 species). However, the generally reduced diversity of in-stream and off-river habitats, the turbid and semi-ephemeral nature of streams in the Project area are expected to limit fish species diversity. Introduced fish species dominated at a number of sites, and introduced exotic and translocated fish species represent a major stressor on the system.

4.2 Socio-economic Setting

The Markham Valley, within which the Project is located, runs through the centre of Morobe Province. Morobe Province is headquartered in Lae and occupies an area of 33,525 km^2, extending from the Owen Stanley Range northeast across two major fault valleys to coastal ranges and offshore islands. The province is one of the three most populated provinces in Papua New Guinea and contains almost 9.3% of the country's total population (674,810 persons in the 2011 census).

The Highlands Highway connects the Project area and Lae, and has a network of smaller feeder roads. The power plant site is located about 10 km west of Lae Nadzab Airport.

The Project area is inhabited by a single language group (Wampar). Wampar social organisation is based around membership of clan (*sagaseg*) and patrilineal[2] lineage groupings. Nine clans have been identified, although each Wampar village has a multi-clan composition. Previously, these groups were physically demarcated within the settlement, but today clans-people are intermixed residentially.

As a result of over a century's exposure to mission activity, many of the Wampar are converts to various denominations, including Seventh Day Adventists, the Assemblies of God, the Lutheran Renewal and PNG Revival churches. Despite this, traditional beliefs persist with regards to malicious spirits and agencies (*masalai*), which are believed to inhabit rivers, rocks and big trees. Further, traditional beliefs endure regarding sorcery and angry ancestral spirits as the source of sickness and death.

Wide variation in income levels occurs across Project area households. Sale of agricultural products and trade store ownership are the main sources of income, with the local villagers also often receiving income from relatives or friends who receive a wage. Cash income levels in the study area are generally high to very high by rural Papua New Guinea standards, but vary depending on the proximity of communities to the Highlands Highway, the 40 Mile and 41 Mile markets, and other key service centres such as Wawin National High School, and their cultural-linguistic affiliation. Disparities also occur within communities, where these reflect different levels of access to agricultural land, particularly for perennial tree or cash cropping activities.

The proximity of the Project area to Lae, and the longevity of exposure to contact, has meant there has always been a number of people moving into the area from surrounding provinces and rural enclaves. Wampar social networks have been influenced for more than a century by the links the population has had with the occupants of Lae.

Health services and infrastructure, education infrastructure, and other services that concern matters such as law and order, banking and various urban facilities are available to varying degrees either in the Project area or in Lae.

Three broad land use categories occur within the Project area: smallholder agriculture, capital agriculture and 'no' agriculture. Most Wampar people maintain gardens that supply food for their families (i.e., smallhold agriculture). The dominant staple crop is triploid banana (*kalapua* variety),

[2] Relationships are traced through the father of a family.

a high-yielding cultivar that tolerates poor and challenging growing conditions. Gardens usually also include sweet potato, taro and diploid banana (often inter-planted with corn, sugarcane and greens), as well as yam and cassava. Chinese taro (another hardy staple species) is often planted beneath triploid banana. A number of other fruits and vegetables and perennial tree crops are also commonly planted in gardens, and some are planted in older gardens, areas of woody regrowth and near residences in established settled areas. Sago is the most important staple food not grown in garden plots.

Local communities make extensive use of other natural resources, with relevant activities including foraging, hunting and fishing. These natural products used include bark, cane, clay, flowers, grass, leaves, river stones, sap, seeds/fruits, timber and vines/stems. Village chickens and pigs are kept for sale and self-consumption (particularly on special occasions), and some families raise cattle (for meat) and horses (for riding). Households buy only very small quantities of locally grown food; markets are primarily used for convenience or ‘top-up’ purposes. Processed foods are also purchased and can constitute between a third and one half of some families’ diets, particularly rice, tin fish and meat, noodles, salt and cooking oil.

Food shortage is not a major issue for villagers in any of the communities surveyed, with people generally reporting surplus production and a ready market for most of their crops in Lae. Any disruption to their food supply is readily compensated by purchased food, particularly imported rice and flour.

Beyond subsistence gardening, the market economy in the area is increasingly important and many Wampar are engaged in commercial activities including the services economy and agribusiness/capital agriculture. However, this is constrained by the fact that most land within the Project area has low agricultural potential caused by poor soils, low (within the PNG context) average annual rainfall, a long dry season, and frequent inundation in floodplain areas.

Sixty two cultural heritage and archaeological sites have been identified in the Project area during Project-specific surveys, although none were associated with the proposed power plant site.

Ecosystem services are benefits that ecosystems provide to people. For the Project area, resource use or ‘provisioning’ services are key, where these include:

- Fresh water (including groundwater) for drinking, washing and similar.
- Food from crops or livestock (domestic or commercial), wild fish catch, and hunting/foraging (as discussed above).
- Biological raw materials from plants and animals for non-food uses (e.g., wood products, hemp, rope, leather, flowers).
- Other services, such as biomass fuel for energy production (wood, charcoal, dung), genetic resources used for animal breeding/plant improvement, and natural medicines and biocides from plants.

5. Environmental Management Framework

5.1 Background

Markham Valley Biomass is developing an integrated management system (IMS) that, as well as addressing other areas of the Project, will contain elements of an environmental management system (EMS) that are consistent with the requirements of AS/NZS ISO 14001:2016 (Environmental Management Systems). The management system is being developed in a staged manner that is commensurate with Project activities.

The environmental management elements required to manage power plant construction and plantation development are described in this chapter. As the Project proceeds to power plant operation, these will evolve into a whole-of-project EMS as part of the broader IMS.

AS/NZS ISO 14001:2016 specifies that an EMS should consist of the following, which are tailored specifically to the activities of the business: leadership, planning, support and operation, performance evaluation, and improvement.

These elements as they relate to the Project are described in the following sections.

5.2 Leadership

The leadership element, as described in AS/NZS ISO 14001:2016, encompasses leadership and commitment, environmental policy, and organisational roles, responsibilities and authorities.

Oil Search is committed to managing its activities in Papua New Guinea in an environmentally and socially responsible manner that is consistent with the environmental and social sustainability principles that it has developed through its Health, Safety, Environment and Security Policy (see Box 3.1) and its Social Responsibility Policy (see Box 3.2), as well as those of the PNG Government. This commitment is equally applicable to MVB.

These policies provide the framework for the Project's approach to environmental management and establish the principles and goals for environmental performance against which the effectiveness of the system will be evaluated. Oil Search, as Project proponent and operator, holds full and ultimate responsibility for the implementation of these policies. These responsibilities will be clearly explained to all Oil Search/MVB personnel and in turn to primary contractors and sub-contractors.

The MVB Stakeholder Engagement Manager is accountable for ensuring compliance with national legislation, the Project’s environment permit, and company environmental policies.

The key roles and responsibilities to ensure protection of the environment and to meet environmental objectives for the Project are described in Table 5.1.

Table 5.1 – Environmental and Social Performance Management Responsibilities

Role	Responsibility
Corporate (Markham Valley Biomass)	
Project Director	♦ Ensure that Project activities are completed in an environmentally and socially responsible manner ♦ Ensure that the Project is compliant with the EMP ♦ Suspend works should an incident cause, or have the potential to cause, serious environmental harm or in instances where the environment is deemed to be at risk ♦ Participate in the annual review process of the EMP and the EMS
Stakeholder Engagement Manager	Environmental: ♦ Report to the Project Director ♦ Provide environmental leadership, advice and support ♦ Implement the relevant components of the Project's management system and demonstrate commitment to Health, Safety, Environment and Security (HSES) and Social Responsibility (SR) policies and objectives ♦ Define roles and responsibilities, and allocate resources, to ensure that environment permit requirements, as well as other compliance requirements, are implemented and maintained during Project activities ♦ Ensure that all personnel and contactors are aware of their obligations under the EMP ♦ Ensure that sufficient resources are available to support the implementation of the Project's management system ♦ Ensure that contractors are aware of the conditions and requirements of the Project's environment permit and integrate these in their terms and condition and operations ♦ Monitor, evaluate and review the suitability and effectiveness of the EMP, update accordingly and take appropriate preventive and corrective actions in case of unsatisfactory environmental performance ♦ Ensure that all required environment permits are acquired, maintain a permits register, and monitor adherence to the relevant environmental legislative requirements, commitments, conditions and procedures ♦ Oversee environmental monitoring plans and studies, and relevant databases ♦ Ensure that EMP compliance audits are conducted ♦ Ensure that contractors are competent and adequately trained and resourced to implement requirements of the EMP ♦ Liaise closely with the contractors' Health, Safety, Environment (HSE) officers concerning environmental performance and management ♦ Review environmental audit results and determine corrective actions, if any, to ensure continual improvement ♦ Ensure that corrective action requests or incident response actions are completed in the specified timeframe. ♦ Review and approve Environmental Performance Reports ♦ Lead the annual review process of the EMP and management system
	Stakeholder engagement: ♦ Develop and maintain good working relations with stakeholders ♦ Develop and implement stakeholder activities as per stakeholder engagement plan ♦ Support the organisation and participate in meetings and consultations with stakeholders ♦ Liaise with key regulatory stakeholders (e.g., CEPA, PNGFA) in the event of an incident or unplanned event ♦ Act as key contact person, communicator and conduit between stakeholders and MVB, receiving requests and/or complaints, managing issues and providing information and feedback

Table 5.1 – Environmental and Social Performance Management Responsibilities (cont'd)

Role	Responsibility
Corporate (Markham Valley Biomass) (cont'd)	
Stakeholder Engagement Manager (cont'd)	♦ Ensure that the grievance and complaint procedure is implemented and understood by all stakeholders ♦ Identify and provide alerts on areas of concern such as environmental, security and other issues
All other personnel	♦ Conduct all activities in compliance with the EMP, as well as applicable legislation and statutory obligations ♦ Follow good housekeeping procedures and work practices ♦ Report all incidents to the stakeholder engagement manager or contractor HSE officers, as applicable ♦ Ensure that any corrective action requests, or incident response actions, nominated to specific personnel are completed within the specified timeframe ♦ Actively participate in tool box talks, lessons learned sessions, and technical and environmental safety awareness initiatives
Contractors	
HSE officers	♦ Ensure that relevant environmental legislative requirements, commitments, conditions and procedures are being applied consistently across all relevant site activities ♦ Provide resources to ensure that environment permit requirements, as well as other compliance requirements, are implemented and maintained during Project activities ♦ Maintain clear communication with other contractors and MVB on environmental issues ♦ Conduct and coordinate emergency response training, including in the use of spill response equipment ♦ Perform environmental incident investigations ♦ Oversee environmental audits ♦ Monitor and verify closeout of corrective actions arising from environmental audits ♦ Ensure that stocks of spill clean-up and response equipment are regularly checked and replenished to ensure appropriate supply quantities are on hand at all times ♦ Attend and participate in daily toolbox talks. Suggest preventive and corrective measures and provide feedback on their implementation ♦ Perform routine inspections to ensure equipment functionality and compliances with permit conditions ♦ Implement waste management plan and maintain register of waste and garbage ♦ Ensure that environmental matters are a regular agenda item in HSE meetings ♦ Examine all certification and maintenance records to assess their validity ♦ Conduct and coordinate HSES and SR inductions for all new contractor employees ♦ Conduct and coordinate emergency response training, including in the use of spill response equipment ♦ Report to MVB's stakeholder engagement manager on environmental performance, such as waste management activities, wastewater and drainage control, spill prevention activities and general housekeeping
All other personnel	♦ Conduct all activities in compliance with the EMP, as well as applicable legislation and statutory obligations ♦ Follow good housekeeping procedures and work practices ♦ Report all incidents to the MVB stakeholder engagement manager or contractor HSE officers, as applicable ♦ Ensure that any corrective action requests, or incident response actions, nominated to specific personnel are completed within the specified timeframe ♦ Actively participate in toolbox talks, lessons learned sessions, and technical and environmental safety awareness initiatives

Different contractors will be engaged during the construction phase to execute various activities. It is therefore essential that each contractor (and sub-contractor) is inducted to the requirements of the EMP to ensure compliance with their environmental obligations.

Each contractor (and sub-contractor) will be responsible for ensuring full environmental compliance within their area of responsibility and control. Each contractor will therefore provide MVB with its detailed EMPs, as specified in this EMP, together with their environmental organisation and responsibilities, to ensure it is aligned with MVB's expectations and the requirements of the Project. The delivery of these EMPs will be a requirement under the terms and agreement to perform services.

The MVB Project team is ultimately accountable for the implementation of the EMP. However, the construction contractors and any person engaged by MVB to undertake any aspects of construction of the Project, including sub-contractors engaged by the main contractor, also bear this responsibility.

5.3 Planning

Planning requirements include:

- Identifying:
  - The environmental aspects[3] related to Project activities managed under this EMP, taking into account possible changes, abnormal conditions and reasonably foreseeable emergency situations.
  - Compliance obligations applicable to environmental and social management of Project activities.
  - Risks and opportunities that need to be addressed.
- Establishing, implementing and maintaining environmental and social objectives relevant to Project activities, and determining how these can be achieved.

This document incorporates these requirements into the EMP structure as follows:

- Environmental aspects are identified in Table 5.2 and further discussed in Chapter 6.
- Legal and other requirements are detailed in Chapter 3.
- Environmental objectives and associated targets and programs (i.e., mitigation procedures) are presented in Chapter 6.

[3] This is defined in AS/NZS ISO 14001:2016 as 'element of an organization's activities or products or services that interacts or can interact with the environment'. That document further notes that an environmental aspect can cause an environmental impact.

Table 5.2 – Key Project Environmental Aspects and Potential Impacts

Project Environmental Aspect	Potential Impact
Air emissions from operating machinery and equipment, where these can include dust, combustion emissions (from wood and diesel fuel), volatile fuels, particulates from fires and other fugitive emissions	Air quality; sensitive receptors
Air emissions from operating machinery and equipment, where these can include combustion emissions (from wood and diesel fuel), volatile fuels and other fugitive emissions	Greenhouse gases
Soil erosion and sedimentation from establishing plantations, access roads (including watercourse crossings), laydown areas, and other areas of vegetation clearing and ground disturbance, and harvesting plantations	Surface water quality, bed sediment quality, freshwater and/or terrestrial habitats/flora/fauna, ecosystem services
Disturbance of cultural heritage and/or archaeological sites due to vegetation clearing and ground disturbance	Local communities, archaeological community
Noise and light spill from construction works and from operating miscellaneous items of machinery and equipment	Sensitive receptors
Generation and disposal of waste soil and rock from construction activities	Surface water quality, bed sediment quality, freshwater and/or terrestrial habitats/flora/fauna, ecosystem services
Use of hydrocarbons (e.g., fuels, oils) and chemicals (e.g., solvents, cleaning fluids, herbicides)	Surface water quality, bed sediment quality, groundwater quality, freshwater and/or terrestrial habitats/flora/fauna, ecosystem services
Generation of non-hazardous waste	Surface water quality, bed sediment quality, freshwater and/or terrestrial habitats/flora/fauna, ecosystem services
Use of surface water and/or groundwater during construction and operations, and related wastewater discharges (e.g., from the holding pond) and runoff of turbid water	Surface water hydrology, groundwater quantity/hydrogeology, surface water quality, bed sediment quality, freshwater habitats/flora/fauna, ecosystem services
Introduction of invasive alien species (including introduced pests and pathogens) through personnel and equipment movements, and plantation establishment	Freshwater and/or terrestrial habitats/ flora/fauna, ecosystem services
Project physical presence and land alienation	Terrestrial habitats/flora/fauna, ecosystem services, visual amenity
Major accidental event (e.g., forest fire, vehicle collision)	Surface water quality, bed sediment quality, freshwater and/or terrestrial habitats/flora/fauna, ecosystem services

Environmental aspects listed in Table 5.2 can potentially adversely impact on local flora and fauna. For example, vegetation clearing, air and noise emissions, and introduction of invasive alien species can all have deleterious effects on biodiversity conservation values. Similarly, soil erosion, use of hydrocarbons and chemicals, management of waste soil and rock, and general waste management can all affect water quality in local watercourses and the associated beneficial values.

5.4 Support and Operation

5.4.1 Resources

As noted in Table 5.1, a key task for both the stakeholder engagement manager and the contractors' HSE officers is to provide resources to ensure that environment permit requirements, as well as other compliance requirements, are implemented and maintained during Project activities.

5.4.2 Competence and Awareness

Contractors will ensure that their personnel are fit for work and are appropriately trained, qualified and experienced to perform the tasks required, taking into account relevant environmental aspects and issues.

Contractors will develop management procedures for relevant Project activities. These procedures will detail key safety mechanisms that include but are not limited to the following:

- Inductions.
- Safety meetings.
- Reporting lines.
- Permit to Work system.
- Job safety analysis.
- Hazard and management control.
- Hydrocarbon and chemical spill contingency.

Personnel will similarly undergo an environmental induction to inform them of their obligations and Project-specific environmental management procedures. Environmental inductions will be linked to safety inductions for efficiency, with additional training undertaken on an as-needs basis. Inductions will address relevant policies, legislative and regulatory compliance, local environmental sensitivities including the environmental aspects and issues described in Chapter 6, the specific roles and responsibilities of personnel in relation to environmental management and performance, chains of command and communications, and the implications of not conforming with the Project's requirements. In terms of issue-specific management procedures, the inductions and subsequent training will address matters including, but not limited to, the following:

- Cultural heritage and archaeology.
- Vegetation clearing, earthworks, topsoil management and rehabilitation.
- General waste management.
- Hydrocarbon, chemical and hazardous waste management.
- Noise management.

- Air emissions and air quality management.
- Invasive alien species management.
- Surface water and groundwater management.
- Watercourse crossings management.
- Environmental incident and non-compliance reporting.
- Emergency response plans and drills.
- Environmental auditing.

Markham Valley Biomass will ensure that each contractor identifies the environmental training needs relevant to their personnel and the activities being performed, together with induction and task training to ensure conformance with Project's environmental requirements. Appropriate records of environmental management training will be maintained.

As well as this EMP and the various environmental procedures described above, MVB will submit a Forest Management Plan (FMP) for the plantation operations to PNGFA, for their approval. This plan will be consistent with the requirements of the FSC standards for Papua New Guinea and will address a range of matters, from a description of the markets and compliance requirements through to plantation design and areas to be planted, species and genetics, plantation and stand management regimes, planned harvesting and other forestry operations methods. It will be, in effect, a five-year tactical forestry plan.

Implementation of the FMP will be supported by a Project-specific Forest Management Information System (FMIS; GIS-linked software) that will collate and manage information and allow planning regarding the following aspects of plantation operation:

- Stand management (asset registry) – stand/asset registry attributes; spatially overlay features with environmental reference layers to identify potential concerns; volume/inventory information.
- Silviculture activity management – planning/scheduling activities such as site preparation, weeding, harvest; budget estimated costs.
- Nursery management – batch/seedlot information; seedling requests; mother plant management.
- Roads – road attributes, e.g., ownership; plan road construction/maintenance activities.
- Integration of field and office activities via a ‘Mobile Builder’, with real-time systems to mobilise management of silviculture activities and incident reporting.
- Incident reporting – record health, safety, environmental and security (HSES) incidents; record spatial location of incident.

- Stakeholder engagement – spatially overlay features with political reference layers to identify potential concerns; stakeholder group information/members; land group/community, e.g., family, clan, incorporated land group; agreements; documentation of communications.
- Contract management and accounting.

Markham Valley Biomass will also prepare a number of social management plans during Front End Engineering and Design (FEED) and detailed design. These will address a range of matters including Project-induced in-migration, a resettlement policy framework, and communal resource plan.

5.4.3 Communication

Markham Valley Biomass will engage with personnel (employees and contractors) concerning matters such as environmental aspects/issues that impact on them or their area of responsibility, changes to the management system, and ways to improve environmental performance. Relevant information will be communicated to the workforce by a number of methods, including but not limited to:

- Induction and awareness training (as described above). These will be conducted multiple times to accommodate shift changes for all personnel, including third-party contractors.
- General signage, noticeboard announcements and newsletters to establish and maintain awareness.
- Meetings and presentations, e.g., weekly health, safety and environment meetings (held twice to ensure that all shifts are covered).
- Toolbox sessions. These will be held daily before each shift to raise HSES and social responsibility (SR) matters as well as general work practice issues from the previous shift, and discuss changes needed and lessons learnt.
- Training sessions with signed attendance sheets to confirm personnel participation.

Communication will be integral to the Project's environmental performance and will continue through plantation establishment, construction (of the power plant, nursery and roads) and operations. All regular meetings will be required to have HSES and SR issues as a standing agenda item and shall commence with an appropriate HSES and SR discussion topic.

All personnel working on the Project will have the opportunity to express their opinions on any relevant HSES and SR issue to the relevant HSE officer or MVB's stakeholder engagement manager. Markham Valley Biomass and its contractors will provide all necessary means to allow site workers the opportunity to highlight concerns they may have and/or provide suggestions on ways to improve HSE and SR standards or systems. Any such suggestions or concerns will be relayed to management.

The Project will establish a grievance mechanism to be adopted by contractors in order to record and respond to concerns/complaints. The purpose of the grievance mechanism, which will be based on current procedures, is to provide workers (and other stakeholders) the opportunity to raise grievances about the Project without redress and to ensure that concerns are adequately responded to in a timely manner, with appropriate corrective actions being implemented and the complainant being informed of the outcome.

Practical recommendations arising from stakeholder communication and feedback will be incorporated into the management plans where appropriate.

Communication with external stakeholders concerning environmental matters will be undertaken as part of the Project's broader stakeholder engagement plan, including matters relating to compliance obligations. This is discussed further in Chapter 7.

5.4.4 Documented Information

Information storage and retrieval is an important part of environmental management, particularly in terms of achieving issue resolution and continuous improvement. Environmental management plan documentation includes documents and records necessary to ensure the effective planning, operation and control of processes that relate to significant environmental aspects. Markham Valley Biomass will maintain a database for storage and retrieval of environmental data, records and other relevant Project information, and will implement appropriate document control procedures.

5.4.5 Operational Planning and Control

Markham Valley Biomass will comply with applicable Papua New Guinea legislative requirements related to environmental management. In the absence of such requirements or relevant national policies or guidelines, appropriate industry practices will be adopted.

The Project will adopt the following principles in relation to environmental management and mitigating adverse impacts:

1. Avoid, i.e., avoid creating impacts from the outset.
2. Minimise, i.e., reduce the duration, intensity and/or extent of impacts that cannot be completely avoided.
3. Restore or rehabilitate, i.e., return an area to its original condition (restore) OR restore basic ecological functions and/or ecosystem services (rehabilitate).

However, waste generation is unavoidable, and hence the Project's waste minimisation strategy will reflect the need to (in order of priority):

1. Avoid waste generation.
2. Reduce waste generation.
3. Reuse waste (where feasible).
4. Recycle waste (where feasible).
5. Treat waste (where required).
6. Dispose of waste (where necessary).

Markham Valley Biomass will ensure a high level of staff, employee and contractor awareness of these principles. Development and implementation of specific controls will incorporate the following:

- Engineered Controls (Best Available Technology) – where practicable, these are the first level of preferred mitigation because, when installed and operating properly, they provide consistent, uninterruptable mitigation for potential impacts. Examples of engineered controls include secondary containment and fail-safe systems.
- Operational Controls (SOPs) – where Project activities do not warrant the long-term protection provided by engineered controls, operational controls are the second preferred approach. Examples include maintenance and treatment.
- Monitoring and Inspection – early detection programs that provide advance notice of a potential problem or, at the least, discover the problem before it becomes unmanageable.

Environmental management procedures that address specific issues are provide in Chapter 6.

5.4.6 Emergency Preparedness and Response

Emergency preparedness and response is addressed in Procedure 11 (PR11) Emergency Response Plans and Drills procedure in Chapter 6. This procedure will ensure an appropriate response to unplanned events, based on the potential emergency scenarios identified by a risk assessment process. These events can include natural disasters and operational or process hazards that cause releases into the environment, such as heavy rainfall/floods, high winds, lightning, major seismic events, fire, ground subsidence, vehicle accidents involving transport of hazardous substances, and hazardous chemical/reagent release or spill.

As noted in PR11, the emergency response plan (ERP) will allow for:

- Hazard identification and risk assessment (including periodic review and update).
- Preventative measures.
- Organisational responsibilities.
- Response procedures.
- Communications prior to, during and after an emergency.
- Training and exercises.
- Coordination of emergency responders.

A process to review the emergency system after a drill or incident, as well as routine auditing, will also be implemented. The ERP will be further developed during detailed design.

5.5 Performance Evaluation

5.5.1 Monitoring and Internal Audits

Procedures in this EMP contain relevant monitoring requirements, which will be used to determine the effectiveness of mitigation measures, confirm impact predictions, and demonstrate compliance with environment permit conditions. Monitoring will also allow the need for corrective actions to be identified and implemented as required.

In addition to implementing these requirements, the Project will implement a monitoring program to assess compliance with the EMP, as detailed in the environmental auditing procedure (PR12). Ad hoc audits will also be undertaken as required, e.g., following events such as an environmental incident, a major storm, an environment-related community complaint, or the occurrence of Project-related impacts on sites that are environmentally or culturally sensitive.

5.5.2 Records and Reporting

The outcomes of the auditing and monitoring programs will be routinely recorded and reported to the Project's senior management, with appropriate corrective action being undertaken as required. Reporting of auditing and monitoring results to regulatory authorities will be undertaken in accordance with regulatory requirements. Details of reporting are provided in the specific procedures in Chapter 6.

A compliance register has been developed and will be maintained by the stakeholder engagement manager. All environmental (and other) permitting requirements will be identified, applied for in a timely manner and tracked to ensure full regulatory compliance.

5.5.3 Management Review

Management reviews will be undertaken to ensure that environmental and social management systems remain suitable, adequate and effective, and appropriately communicated to all relevant parties. In particular, the reviews will focus on ensuring that all aspects of the environmental and social management systems remain relevant to the specific tasks being undertaken on site and the associated environmental and social risks. The management reviews will therefore typically include consideration of matters such as:

- The extent to which the EMP has been implemented and the effectiveness of the procedures contained within the EMP.
- Results of audits and monitoring data, and performance against objectives and targets.
- Communications from (and with) internal and external stakeholders (including complaints).
- Environmental incidents or non-compliances/non-conformities, and actions taken to address these events.
- Actions from previous management reviews.
- Changing circumstances, such as in relation to:
  - Significant environmental aspects.
  - Legislation, government policies or other aspects of compliance obligations.
  - Risks and opportunities.
  - Other relevant issues.
- Adequacy of resources.

- Opportunities for continuous improvement.

The results of reviews will be appropriately documented, including information concerning the review conclusions, decisions about continual improvement opportunities or changes to the management system, actions when environmental objectives haven't been achieved, opportunities to improve integration with other business processes, and implications for the organisation's strategic direction.

Findings from reviews will be communicated and discussed with the operating personnel to better understand the root causes and systemic failures, if any. Markham Valley Biomass will immediately bring to the attention of relevant personnel and contractors any consequent modifications to the EMP.

5.6 Improvement

Markham Valley Biomass will establish and maintain procedures for inspections, handling non-conformance and taking corrective actions, the results of which will be recorded.

Routine inspections provide the basis for effective management of any issue arising from equipment malfunction, non-compliances or failures in operational control procedures. This ensures that all issues are systematically identified, investigated, reported, communicated and managed to identify root causes and contributing factors. This also allows corrective actions to be implemented to ensure that such events are effectively closed out and do not recur. It also enables the effective implementation of the measures described in the EMP.

All employees and contractors are responsible for identifying non-conformances of operational, procedural or accidental incidents. Corrective actions will be the responsibility of the relevant superintendents, since they are usually aimed at the behavioural elements of individuals. The Project will establish an 'Action Log' (i.e., a database that will facilitate data interrogation) as part of the IMS that will record and manage accidents/incidents, forest fires, management corrective and preventative actions, training (including dates for refresher training) and job observations, and will also include a meetings register.

In addition, management review (as discussed above) is essential for the continual improvement of the management system and EMP. Corrective actions will be communicated to appropriate personnel to ensure continual improvement, with subsequent follow up to ensure their effectiveness. One objective of the review process is to continually improve the management system to enhance the Project's environmental performance.

The EMP is a living document that will be reviewed and updated as required during Project development. Contractors will be contractually required to prepare their own EMPs aligned with this EMP, which will include detailed SOPs. This will ensure that contractors and sub-contractors are aware of, and aligned with, their explicit environmental obligations.

6. Environmental Management Procedures

The various environmental concerns discussed in Chapter 5 are addressed via the procedures outlined in this section, as follows:

- Cultural heritage and archaeology (PR1).
- Vegetation clearing, earthworks, topsoil management and rehabilitation (PR2).
- General waste management (PR3).
- Hydrocarbons, chemical and hazardous waste management (PR4).
- Noise management (PR5).
- Air emissions and air quality management (PR6).
- Invasive alien species management (PR7).
- Surface water and groundwater management (PR8).
- Watercourse crossing management (PR9).
- Environmental incident and non-compliance reporting (PR10).
- Emergency response plans and drills (PR11).
- Environmental auditing (PR12).

The construction phase involves the use of only conventional practices in a generally non-sensitive environment. The adoption of well-established industry norms, international good practices and established SOPs will therefore minimise risks and potential adverse impacts, both in construction and continuing through operations. This also applies to plantation development, where environmental management procedures will be supported by documents such as 'Management Prescriptions', which describe what Project foresters need to do, and 'Best Operating Practices' (BOPs) that provide instructions for workers. Examples of each are provided as Attachments A and B, respectively.

<table>
<tr><th colspan="2">PR1 – Cultural Heritage and Archaeology Procedure (p1)</th></tr>
<tr><td colspan="2">Purpose</td></tr>
<tr><td colspan="2">This procedure describes the minimum requirements that will be followed to ensure that sites and artefacts of cultural and archaeological significance are identified, protected and managed in accordance with legal requirements to avoid or minimise impacts. The scope of this procedure applies to planning, clearing, plantation establishment and construction activities</td></tr>
<tr><td colspan="2">Context</td></tr>
<tr><td colspan="2">Clearing, plantation establishment and construction activities have the potential to uncover and damage artefacts and sites of archaeological and cultural heritage significance. This procedure will ensure that all sites and artefacts of cultural, historical and archaeological significance are identified, protected and managed in accordance with statutory requirements</td></tr>
<tr><td colspan="2">Proposed Management and Mitigation Measures</td></tr>
<tr><td>Planning</td><td>The likelihood of impacting on sites of cultural heritage or archaeological significance can be reduced with appropriate planning before commencing field activities. The following practices will be undertaken before any ground disturbance commences:
♦ Conduct focused stakeholder engagement to determine community sensitivities and establish site and clan-specific protocols, taking into account the various types of sites (i.e., spirit sites, former settlement sites, burial/cemetery sites, skull house site, historic sites, archaeological sites)
♦ Restrict access to known cultural heritage and archaeological sites in the vicinity of the clearing and construction activities with temporary fencing or markers and appropriate buffer zones
♦ Ensure that, where practicable, clearing and construction activities are aligned and sited to avoid all known archaeological and cultural heritage sites
♦ Prior to commencing ground disturbance, prepare a cultural heritage clearance request (CHCR), review the cultural heritage database and develop site-specific mitigation measures
♦ Conduct cultural heritage and archaeology inductions for Project staff and contractors to generate awareness of local cultural heritage sensitivities, including management and avoidance strategies
♦ If disturbance of an archaeological or cultural heritage site is unavoidable, seek approval from the PNG National Museum and Art Galley for removal of the artefacts. Note that artefacts will NOT be removed without prior approval from the PNG National Museum and Art Gallery</td></tr>
<tr><td>Ground disturbance</td><td>Upon approval of ground disturbance, the following will be implemented:
♦ A qualified archaeologist will monitor the large-scale ground disturbance associated with construction at the power plant site
♦ All works must take place within the areas approved for ground disturbance. Should there be any changes to the scope and location of work, approval of a revised CHCR must be sought
♦ All personnel will observe access restrictions to sites of cultural heritage significance, i.e., fencing
♦ Ground disturbance will not occur within the areas fenced for protection, i.e., direct impacts to known sites will be avoided
♦ Vehicles will stay on established tracks or designated right of ways
♦ Should previously unrecorded cultural material be discovered during ground disturbance, actions will be taken as described below
♦ No items of cultural material will be removed or interfered with by any unauthorised person
♦ If Markham Valley Biomass personnel or contractors disturb or interfere with a site of cultural heritage or archaeological significance, an incident report will be completed so that necessary mitigation/remediation procedures can be initiated</td></tr>
</table>

PR1 – Cultural Heritage and Archaeology Procedure (p2)	
Proposed Management and Mitigation Measures (cont'd)	
Discovery of a site	It is possible that unknown archaeological or cultural heritage sites may be discovered, despite actions taken prior to ground disturbance to identify such sites. If unknown sites are discovered the following steps will be implemented: ♦ In the event of the discovery of suspected human remains and/or cultural heritage artefacts, cease work immediately, secure the site from interference and notify the HSE officer or senior person on site, who will notify the police if the human remains appear to be suspicious (i.e., recent and not part of a cultural burial) ♦ Inspect the site to ensure it is sufficiently protected. This is a responsibility of the HSE officer or senior person on site ♦ Record details regarding the site including photographs, GPS coordinates, activity being undertaken at time of discovery and hand drawings of the site (if these can be obtained without disturbing the site) ♦ If the discovery relates to cultural heritage, contact an archaeological specialist to obtain further advice on management of the site. This is a responsibility of the HSE officer or senior person on site ♦ Notify the PNG National Museum and Art Gallery of the discovery once information has been obtained from the archaeological specialist. This is a responsibility of the HSE officer or senior person on site ♦ Prohibit entry into the area until advice has been sought from the archaeological specialist and all required actions have been completed. Material will not be removed without prior approval from the PNG National Museum and Art Gallery

Proposed Monitoring and Reporting

Action	Frequency	Reporting
Maintain records of planning to avoid such sites	Ongoing/as required	Quarterly
Maintain records of approval from the PNG National Museum and Art Galley for removal of artefacts	Ongoing/as required	Quarterly
Report unauthorised disturbance of such sites	Event based	Reported as an incident
Record number of new sites discovered	Ongoing/as required	Quarterly
Record number of complaints related to disturbance of such sites	Ongoing/as required	Quarterly

PR2 – Vegetation Clearing, Earthworks, Topsoil Management and Rehabilitation Procedure (p1)	
Purpose	
This procedure describes the requirements that will be followed to ensure that vegetation clearing, earthworks and soil management activities are undertaken to minimise potential impacts on the environment, and to rehabilitate areas disturbed by Project activities. The scope of this procedure applies to planning, clearing, access/roading, plantation establishment and construction activities	
Context	
Vegetation clearing can cause loss of habitat, fauna and/or flora of biodiversity or resource significance, as well as erosion and subsequent sedimentation of waterways, reduced water quality and amenity. This activity can also result in reduced visual amenity of an area from both the ground and air At the completion of ground disturbance activities, it is essential that, where feasible, all disturbed areas that are not designated for an agreed new land use (e.g., plantations, roads, power plant, nursery) shall be rehabilitated to minimise ongoing soil erosion and promote the natural revegetation of these areas The aim of rehabilitation is to restore and return disturbed sites as close as possible to their original state or to an otherwise agreed end land use. Early and effective planning, before a site is disturbed, will assist in the successful stabilisation and/or regeneration of cleared areas, as appropriate	
Proposed Management and Mitigation Measures	
General	General measures that will be implemented during vegetation clearing, earthworks and similar activities include the following: ♦ Prohibit disturbance/harassment of sensitive wildlife, hunting of fauna, gathering or possession of wildlife products by Project workers, their resident families or contractors while working, travelling in Project vehicles, and residing in Project field or private accommodation ♦ Prohibit pets, particularly cats and dogs, at Project facilities ♦ Prohibit lighting of fires by staff and contractors without the explicit authority of a Departmental Manager ♦ Control access of wildlife to waste facilities (e.g., rubbish) by fencing where required ♦ Shield external lights and direct lights onto work areas wherever practicable ♦ Implement appropriate speed limits on Project roads and vehicle crossings ♦ Follow PNG quarantine requirements for soil or other plant material ♦ Follow the principles of the PNG Logging Code of Practice
Planning	Determining the vegetated areas to be cleared requires consideration of the following: ♦ Determine whether vegetation clearing is actually required ♦ Determine if existing cleared areas can be used ♦ Consult with landowners prior to vegetation clearing to determine additional requirements that may be important ♦ Where practicable, avoid the removal and disturbance of listed fauna habitats, ecologically sensitive habitats and useful resources ♦ In relation to *Cycas schumanniana*: – Avoid clearing habitat for *Cycas schumanniana* as far as possible – Implement a buffer of 20 m around plants – Should avoidance not be possible, the affected plants will be translocated to suitable habitat and records kept of original location, translocation site and methods used ♦ Limit clearing to the minimum areas required to accommodate the Project footprint and locate plantations and infrastructure in already disturbed habitats as far as possible ♦ Retain existing vegetation where practicably possible ♦ Obtain approval from the Markham Valley Biomass harvesting manager prior to commencing vegetation clearing ♦ Ensure that, where possible, areas to be cleared avoid locations of high erosion potential (e.g., steep slopes), drainage channels and sensitive vegetation

PR2 – Vegetation Clearing, Earthworks, Topsoil Management and Rehabilitation Procedure (p2)	
Proposed Management and Mitigation Measures (cont'd)	
Planning (cont'd)	♦ Co-locate linear infrastructure such as powerlines and access roads where feasible ♦ Identify appropriate areas which could be used for the disposal of excess soils, outside of riparian buffer zones ♦ Design roads to balance earthwork quantities where feasible, thereby minimising the use of borrow pits and soil dumps ♦ Plan to construct roads during the dry season and avoid major earthworks during the wet season where feasible ♦ Align cleared areas to: – Avoid wet areas to the extent possible – Minimise habitat loss and fragmentation ♦ Plan erosion and sediment control measures together with locations and types of control devices (e.g., sediment pond, silt fence, diversion drain)
Vegetation clearing	The actual clearing of vegetation will be consistent with the following guidelines: ♦ Only clear the area to the size required for its designated use, and ensure that the boundaries of areas to be cleared are physically demarcated prior to commencement ♦ Clearly communicate to all staff (contractors and employees) vegetation clearance boundaries and protocols to be implemented to ensure clearing and earthworks contractors avoid impacts on buffer zones and other areas not designated for clearing ♦ Complete a GPS survey of cleared areas ♦ Ensure that removed topsoil and vegetation is stockpiled for later use during rehabilitation OR recycled (for plantations, this includes leaving harvest slash within compartments) ♦ Retain groundcover vegetation if possible ♦ Avoid burning of cleared or standing vegetation wherever practicable ♦ Do not push stripped soil and cleared vegetation into watercourses, surface water drainage lines or standing vegetation ♦ Install sediment controls (e.g., silt fences and sediment ponds) as required ♦ Install runoff controls (e.g., erosion control berms, cut-off drains) to divert water around and away from exposed surfaces or loose soils such as stockpiles, where practicable ♦ Regularly maintain erosion and sediment control structures by: – Cleaning accumulated material from behind sediment fences and barriers, cut-off drains and diversion drains – Re-erecting, tensioning or replacing collapsed, partially collapsed, ripped or otherwise damaged sediment fences or barriers – Installing additional erosion and sediment control structures if the existing measures are found to be inadequate or ineffective ♦ Minimise the length of time that cleared/disturbed areas are exposed to the greatest extent practicable ♦ Ensure that the maximum cleared forest edge to cleared forest road width is 40 m ♦ Minimise the amount of vegetation cleared during road construction ♦ Establish riparian buffer zones as follows: – 100 m from the banks of the Markham River – 60 m from the banks of the Leron and Erap rivers, and also from the edges of lakes, lagoons and swamps – 30 m from the banks on either side of other permanent watercourses with bed widths >5 m – 20 m from the banks on either side of watercourses with average width >1 m but <5 m – At least 5 m from the banks on either side of watercourses with an average width <1 m. In buffer zones for <1 m streams only, vegetation clearing will be minimised to the extent practicable (rather than excluded, as for buffers on larger watercourses)

PR2 – Vegetation Clearing, Earthworks, Topsoil Management and Rehabilitation Procedure (p3)	
Proposed Management and Mitigation Measures (cont'd)	
Earthworks	Earthworks will be consistent with the following guidelines: ♦ Follow PNG quarantine requirements for management of soil and plant material ♦ Prevent fauna access to open trenches with fencing or other means e.g., cover ♦ Install trench exit ramps for fauna and restrict the length of trench open at any one time ♦ Check excavations, trenches and similar and rescue trapped fauna on a daily basis ♦ Backfill trenches as soon as practicable ♦ Use compaction equipment (rollers) on both formation earthworks and surfacing layers during construction ♦ During (or following) wet weather, when operations may damage the soil, consider dry weather logging, and/or moving to another log landing or a production area reserved for wet weather logging
Topsoil management	Procedures for managing topsoil include: ♦ Carefully remove and stockpile topsoil when an area is being cleared for subsequent use in rehabilitation where feasible ♦ Stockpile topsoil separately from subsoils (using sediment fences if required) and cleared vegetation ♦ Locate stockpiles with diversion banks on the upper side and sediment fences 1 to 2 m down gradient, and at least 10 m from natural drainage lines and watercourses ♦ Consider the need to re-access the stockpile for use at a later date ♦ Ensure that stockpiles are low in height (generally less than 2 m), have a reasonable surface area and are gently battered (generally <15°) ♦ Do not store topsoil for more than 12 months if possible, as storage time diminishes seed viability and microbial activity ♦ Promote revegetation of the stockpiles to protect the soil from erosion, discourage weeds and maintain soil microbe populations
Rehabilitation	Disturbed areas not designated for an agreed new land use will be rehabilitated in accordance with the following guidelines: ♦ Rehabilitate progressively where possible and commence rehabilitation activities promptly, using revegetation and seeding on bare soil, where appropriate ♦ Remove all structures, equipment, waste material and contaminated soil ♦ Fill all pits and sumps, remove drainage diversion structures and re-establish natural drainage lines ♦ Ensure that all rehabilitation work promotes the contouring and subsequent blending of the area back to the original landform ♦ Loosen areas (e.g., ripping or harrowing (along the contours of sloping sites)) of compacted subsoils and effectively re-distribute stored topsoil and stockpiled vegetation (if available) over re-contoured areas ♦ For borrow pits, regrade and shape the pits to create a well-contoured level surface that is self-draining, rip the floor of the pit to a 50 cm depth at a 2 m line spacing, rip along in-pit contours and install controls to divert run-on water from above the pit

Proposed Monitoring and Reporting

Action	Frequency	Reporting
Visually monitor erosion and sediment control devices at the power plant site	Fortnightly and following prolonged heavy rainfall or storm events	Monthly
Visually monitor stormwater runoff from disturbed areas at the power plant site to identify poor quality runoff and, if required, implement management measures	Fortnightly and following prolonged heavy rainfall or storm events	Monthly

PR2 – Vegetation Clearing, Earthworks, Topsoil Management and Rehabilitation Procedure (p4)		
Proposed Monitoring and Reporting (cont'd)		
Action	**Frequency**	**Reporting**
Record number of hectares cleared (recorded monthly; reported quarterly)	Monthly	Quarterly
Record number of hectares rehabilitated (recorded monthly; reported quarterly)	Monthly	Quarterly
Visually monitor success of regenerated areas, including areas prone to erosion	Monthly	Quarterly
Record number of animal deaths, injuries and/or entrapments as a result of Project activities	Daily	Monthly
Visually monitor riparian buffer zones, particularly along plantation borders after herbicide use	Monthly	Quarterly

PR3 – General Waste Management Procedure (p1)	
Purpose	
This procedure describes how general waste generated by Project activities is handled and managed in a responsible manner	
Context	
Domestic and industrial non-hazardous wastes such as steel, paper and cardboard, wood, tyres, plastics, cans, putrescible wastes and power plant ash waste will require disposal to keep the Project area tidy and safe, and to ensure that landowner expectations are met, that land and water contamination through inappropriate disposal does not occur, and that pest fauna are not encouraged This document does not include procedures for managing hazardous waste (PR4) or wastewater (PR8)	
Proposed Management and Mitigation Measures	
General	The approach to general waste management will be based on the following principles: ♦ A site specific waste management plan must be developed prior to Project execution which identifies waste streams and details the identified waste management practices for each stream ♦ Instruct site personnel in the recognition, handling and the appropriate and safe disposal of wastes at Project sites/areas ♦ Minimise waste through efficient use of resources ♦ Maximise reuse and recycling opportunities ♦ Minimise volumes of waste disposed to landfill (by prioritising waste reduction, reuse and/or recycling) ♦ Segregate wastes at the source ♦ Appropriately treat wastes where applicable and possible ♦ Ensure handling, storage and disposal practices meet environment permit requirements ♦ Prohibit littering ♦ Mitigate adverse environmental impacts ♦ Facilitate disposal of waste in a responsible manner ♦ Promote continual improvement in areas such as material handling and waste management training ♦ Follow the principles of the PNG Logging Code of Practice where applicable ♦ It will be the contractors' responsibility to remove from site all relevant waste ♦ A waste register that records all incoming and outgoing waste must be implemented and maintained. The register must as a minimum include waste type, volume, name of the waste producer, nominated disposal/treatment/storage facility ♦ Waste receiving facilities and waste management contractors must be assessed to determine suitability and risk based controls implemented ♦ Waste management/receiving facilities must be inspected by the environment discipline ♦ Waste management practices must be regularly audited by the environment discipline
Putrescibles/ biodegradable solids	Measures to minimise impacts associated with putrescible wastes will include: ♦ Waste generation will be lessened by minimising over-ordering of goods such as food ♦ Putrescible and biodegradable litter will be collected in lidded containers located at designated points at the power plant and nursery sites before collection and burial in the onsite landfill (that will be constructed and operated in accordance with the Environmental Code of Practice for Sanitary Landfill Sites (OEC, 2001)) ♦ Alternatively, putrescible waste may be disposed of by incineration, aerobic composting in bins or other containers, recycled as stockfeed where appropriate, or transported to an urban waste disposal facility ♦ No logs, timber off cuts or trimmings will be placed in rivers or other watercourses

PR3 – General Waste Management Procedure (p2)	
Proposed Management and Mitigation Measures (cont'd)	
Non-hazardous recyclable waste	Measures to minimise impacts associated with non-hazardous recyclable wastes (e.g., cardboard, paper, scrap metal, aluminium cans, tyres, wood and glass) include: ♦ Waste generation will be lessened by minimising over-ordering of goods. Where possible, goods will be purchased in bulk to reduce packaging, and suppliers will collect their own packaging after use ♦ Where recycling facilities are available (e.g., within the region), commonly-generated recyclable waste materials (e.g., glass, paper, aluminium cans) will be collected in clearly-signed lidded containers located at designated points within the power plant and nursery sites. Other recyclable wastes (e.g., poly pipe, printer cartridges, ferrous and non-ferrous scrap metal, tyres) will also be placed in appropriate designated locations in the power plant before collection and transport off site to appropriate licensed recycling facility/ies, where these exist (e.g., within the region)
Non-hazardous non-recyclable waste	Measures to minimise impacts associated with non-hazardous non-recyclables (e.g., general litter, plastic drums) include: ♦ Waste material will be collected in clearly-signed lidded containers located at designated points around the Project area (e.g., general litter, plastic wrapping, small inert products) before collection and disposal in the onsite landfill ♦ Plastic drums containing non-hydrocarbon/non-hazardous substances will be rinsed and cleaned. If not recyclable, the drums will be crushed and disposed of in on site landfill. If recyclable, the drums will be periodically transferred to an appropriate licensed recycling facility, if one exists (e.g., within the region) ♦ Cleared vegetation will be stockpiled next to cleared areas for use in future rehabilitation
Waste ash from the power plant	Measures to minimise impacts associated with waste ash generated by the power plant include: ♦ Ash to be reused in road construction (bottom ash) or as fertiliser for the plantations (fly ash) will be tested in accordance with the Australian Standard Leaching Procedure for confirmation of the anticipated low risk, prior to its reuse

Proposed Monitoring and Reporting

Action	Frequency	Reporting
Undertake reconciliation of quantities of material ordered versus quantities used	Monthly	Quarterly
Maintain records of waste disposal to on site landfill	Ongoing/as required	Quarterly
Maintain records of waste disposal to licensed recycling facility	Monthly	Quarterly
Audit waste storage facilities and waste management practices	Quarterly	Quarterly
Test fly ash and bottom ash in accordance with the Australian Standard Leaching Procedure	Once off	Once off

<table>
<tr><th colspan="2">PR4 – Hydrocarbons, Chemical and Hazardous Waste Management Procedure (p1)</th></tr>
<tr><td colspan="2">Purpose</td></tr>
<tr><td colspan="2">This procedure identifies and describes the method by which hydrocarbons, chemicals and hazardous wastes are handled, stored and disposed of during Project activities</td></tr>
<tr><td colspan="2">Context</td></tr>
<tr><td colspan="2">Hydrocarbons (e.g., fuels, oils), chemicals (e.g., herbicides, solvents, cleaning fluids) and hazardous wastes (e.g., waste chemicals, gas cylinders, other ignitable, corrosive, reactive and/or toxic substances) have the potential to cause environmental degradation (and/or health and safety issues) if they are not managed in a safe and secure manner
This procedure does not include procedures for managing non-hazardous waste (PR3) or wastewater (PR8)</td></tr>
<tr><td colspan="2">Proposed Management and Mitigation Measures</td></tr>
<tr><td>General</td><td>The approach to management of hydrocarbons, chemicals and hazardous waste will be based on the following principles:
♦ Design and plan hydrocarbon, chemical and hazardous waste management, containment and removal prior to Project execution
♦ Include conditions for the use of hazardous substances in all contractor contracts
♦ Contractors are to notify of, and obtain approval for, hazardous substances to be used before these are brought to site
♦ Minimise use of hazardous substances and select alternatives where possible
♦ Keep inventory levels as low as possible through formal review of hazardous substance requirements and via a hazardous substance approval process
♦ Maintain an up to date manifest of hazardous substances detailing the volume, type and location of each hazardous substance
♦ Minimise waste through efficient use of resources
♦ Maximise reuse and recycling opportunities
♦ Segregate at the source
♦ Appropriately treat where possible
♦ Ensure handling, storage and disposal practices meet environment permit requirements
♦ Mitigate adverse environmental impacts
♦ Facilitate disposal in a responsible manner
♦ Conduct inductions and training for Project staff and contractors concerning appropriate safe and environmentally sound handling, storage, transport and disposal of hydrocarbons, chemicals and other hazardous material
♦ Promote continual improvement in areas such as material handling and waste management training
♦ Follow the principles of the PNG Logging Code of Practice, where applicable
♦ Implement the relevant requirements of the Environmental Code of Practice for Machinery Workshops and Petroleum Storage/Resale/Usage sites (DEC, 1997)
♦ It will be the contractors' responsibility to remove all relevant waste from site</td></tr>
<tr><td>Storage of fuels and oils</td><td>Fuel and oil storage requires that safety considerations are met and sufficient secondary containment is provided to contain potential spills. Specifically, the storage of fuels and oils will involve the following measures:
♦ Site permanent fuel storages sites at least 50 m from any office, living quarters, water body or watercourse
♦ Construct a diversion drain to prevent surface water entering the fuel storage area
♦ Bund to a volume of 110% of the largest container of stored fuel
♦ Store in an undercover area and do not exceed the maximum allowable storage quantities
♦ Ensure that a spill response kit is available to clean up spills
♦ Ensure that adequate fire extinguishers are available</td></tr>
</table>

PR4 – Hydrocarbons, Chemical and Hazardous Waste Management Procedure (p2)	
Proposed Management and Mitigation Measures (cont'd)	
Storage of fuels and oils (cont'd)	♦ Ensure that fuels and oils are located in an area cleared of all vegetation to a radius of 3 m around the facility ♦ Ensure that storage containers are appropriate, safe and secure, appropriately labelled and routinely inspected for leaks ♦ Implement off-site disposal or recycling if possible ♦ Ensure that stormwater drainage and liquid waste from fuel storage areas (and workshops) is appropriately treated prior to discharge ♦ Site field fuel tanks, re-fuelling points and maintenance areas at least 50 m from any water body or watercourse, outside of riparian buffer zones, and in well-drained areas ♦ Construct workshop floor/s from nonporous material
Use of hydrocarbon products	All refuelling of vehicles and equipment will be managed in accordance with this procedure to limit the probability of spills and subsequent damage to the environment. To achieve this, the following work practices will be adhered to: ♦ Refuel and service vehicles and equipment in a designated bunded area close to the fuel storage area, in a manner that minimises the probability of spills, including checking fuel hoses for splits/excessive wear, ensuring supervision at all times during refuelling, placing drip trays under refuelling points and minimising the distance from the fuel storage to the vehicle ♦ Undertake all unloading, loading or handling of fuels away from drainage lines ♦ Remove all soil contaminated by fuels or oil spills for bioremediation or other appropriate disposal options ♦ Properly stockpile empty fuel and oil drums (lids firmly secured) to eliminate spillage of residual oils and fuels ♦ Periodically remove all empty drums and containers from site for appropriate disposal or recycling, if possible ♦ Regularly maintain designated machinery and storage and washdown/maintenance areas ♦ Where such areas are exposed to rain, erosion or runoff, protect the area with hardstand, bunds, drainage and diversion systems and sediment control devices such as silt socks or silt curtains as appropriate ♦ Report all spills via the incident reporting form and procedure (PR10) provided in this EMP
Use and management of chemicals and other hazardous wastes	Measures to minimise impacts associated with the use and management of chemicals and generation of other hazardous wastes include: ♦ Minimise the amount of hazardous waste kept on the Project site; maintain the number and range of chemicals and fuels used on site to a minimum ♦ Select chemicals with proven environmental safety which are not subject to bans or phase-outs; chemicals used in plantations will be approved for use under FSC guidelines ♦ Ensure that safety data sheets (SDS) are available for all chemicals used on site ♦ Use, store and transport chemicals and hazardous wastes in accordance with the relevant SDS, and ensure that all chemicals are: – Clearly labelled and held in appropriate storage containers – Stored within the manufacturers recommended temperature range for safe storage – Stored in a secure facility – Stored away from accommodation areas – Appropriately segregated ♦ Label containers used to store hazardous waste with the following information: – Clearly marked as 'Hazardous Waste' – Date filled – Type of waste (e.g., waste oil, paint, grease etc.)

PR4 – Hydrocarbons, Chemical and Hazardous Waste Management Procedure (p3)

Proposed Management and Mitigation Measures (cont'd)

Use and management of chemicals and other hazardous wastes (cont'd)	– Company name and contact details – Dangerous Goods signage (if required) – Hazardous properties (if required) – PPE requirements (if required) – For transport, also display the appropriate transport placard ♦ Ensure that all staff and field personnel are aware of the potential hazards involved with the handling of chemicals and use appropriate personal protective equipment (PPE), and that clean up procedures in the event of a spill are clearly understood ♦ Securely store supplies of chemicals that are surplus to requirements until they can be removed from the site and disposed of in an appropriate manner ♦ Develop an Emergency Response Plan (ERP) that will include a Spill Response Plan for hazardous substances and provide for appropriate spills containment training of staff as part of the induction process ♦ In relation to herbicides: – Mix, store, secure and dispose of herbicides so that leaks and spillages are avoided – Ensure that no herbicide spraying occurs within riparian buffer zones – Preferentially use formulations of glyphosate that do not include polyethoxylated tallowamine surfactant (POEA) – Avoid or minimise use of residual herbicides – Limit spraying next to riparian buffers when rain is expected in the immediate future – Limit harvesting to the drier months in areas next to riparian buffers, where feasible – Implement an adaptive management approach that seeks to maximise efficiencies between weed control and volume application of glyphosate – After use of liquid herbicides, rinse containers then put holes in them to prevent reuse as water vessels by the community

Proposed Monitoring and Reporting

Action	Frequency	Reporting
Undertake reconciliation of quantities of material ordered versus quantities used	Monthly	Quarterly
Maintain safety data sheets (SDS) records	Ongoing/as required	n/a
Maintain personnel training records	Ongoing/as required	n/a
Maintain an inventory of hazardous wastes that have been segregated and stored for land disposal	Monthly	Quarterly
Maintain records of waste disposal to approved hazardous waste facilities	Monthly	Quarterly
Audit storage facilities	Quarterly	Quarterly

PR5 - Noise Management Procedure (p1)	
Purpose	
This procedure describes the minimum requirements that will be followed to mitigate potential noise impacts on the local community and wildlife as a result of construction and operation of the power plant and nursery, as well as noise impacts of plantation establishment and harvesting activities	
Context	
Project activities, particularly those related to wood chipping at the power plant, will be undertaken in a manner that limits to the extent practicable the amount of noise being generated. This will avoid unacceptable impacts on local communities and minimise impacts on fauna populations	
Proposed Management and Mitigation Measures	
Planning	In planning construction and operations activities, the following will be considered: ♦ Ensure that equipment selection includes assessment of noise emissions and type of equipment to be used, with consideration of the lowest noise emission level ♦ Consult with local landowners concerning the construction and operations programs, hours of operation and duration ♦ Provide local landowners with advanced notice of high noise activities ♦ Confirm that equipment to be used is fitted with appropriate noise suppression equipment ♦ Plan to install acoustic enclosures for permanent facilities/equipment generating noise, where required and practicable ♦ Plan for appropriate mitigation strategies if it is believed that noise emissions may be an issue, e.g., limit hours of operation and/or high noise generating activities, and consider additional noise suppression equipment ♦ Establish and maintain appropriate buffer/offset distances from noise sources to receptors ♦ Ensure that the complaints management system can appropriately address incidents or substantiated complaints relating to noise ♦ Consider implementing the following measures: – Cooling towers: fit a straight lined ducting cowl or suitable attenuator to the vertical discharge fans and implement variable fan speed controls; consider lower speed, larger diameter fans – Turbine building: fit a suitable acoustic enclosure and install ducting – Wood chippers: orientate the feed chute openings away from the direction of nearest residential areas and/or fit acoustically lined shrouds which absorb and screen noise; select suitable wood chippers with lowest noise emissions (LWA values)
Construction and operations	During construction and operations, the following practices will be implemented: ♦ Where practicable, limit the hours of operation of noisy equipment or activities, especially vehicles, plant and equipment operating close to community areas, including respite periods for high noise activities ♦ Position potentially problematic noise generators, e.g., wood chippers, away from sensitive receptors, and ensure the offset distance between noisy plant items and nearby noise sensitive receptors is as great as practicably possible ♦ Limit machinery movements where possible ♦ Monitor noise suppression equipment and undertake plant and machinery maintenance to ensure that it is functioning as intended by the manufacturer and to minimise noise emissions ♦ As far as possible, undertake maintenance work on all construction plant away from noise sensitive receptors and during standard daytime construction hours ♦ Keep site access roads well maintained so as to mitigate the potential for vibration from trucks which induces noise ♦ Minimise the number of individual vehicle pass-bys through villages during the construction phase by grouping vehicles into convoys to the extent possible ♦ Minimise the use of access roads during the night period

PR5 - Noise Management Procedure (p2)		
Proposed Monitoring and Reporting		
Action	**Frequency**	**Reporting**
Undertake ongoing liaison with local communities regarding noise issues related to the Project	Ongoing/as required	Monthly
Measure noise levels at sensitive receptors to ensure that noise mitigation strategies are working as planned	Event-based	Monthly
Record and report complaints related to noise	Ongoing/as required	Monthly

<table>
<tr><th colspan="2">PR6 – Air Emissions and Air Quality Management Procedure (p1)</th></tr>
<tr><td colspan="2">Purpose</td></tr>
<tr><td colspan="2">This procedure describes the minimum requirements that will be followed to mitigate potential impacts on the local community and vegetation/wildlife within the Project area resulting from emissions to air (e.g., power plant stack emissions, exhaust gases, dust) from construction and operation activities</td></tr>
<tr><td colspan="2">Context</td></tr>
<tr><td colspan="2">Project activities, particularly those related to power plant stack emissions, will be undertaken in a manner that limits to the extent practicable the generation of air emissions. This will avoid unacceptable impacts on local communities and minimise impacts on fauna populations and vegetation</td></tr>
<tr><td colspan="2">Proposed Management and Mitigation Measures</td></tr>
<tr><td>Planning</td><td>In planning construction and operations activities, the following will be considered:
♦ Position point source emissions, e.g., power plant stacks, away from sensitive receptors, and ensure that appropriate offset/buffer distances are maintained between emissions sources and nearby sensitive receptors
♦ Plan to install appropriate control equipment for permanent facilities/equipment generating air emissions, where required and practicable
♦ Plan for appropriate mitigation strategies if it is believed that air emissions may be an issue, e.g., limit cultivation and/or excavation during dry windy periods
♦ Consult with local landowners concerning the Project activities
♦ Confirm that vehicles and equipment to be used are fitted with appropriate exhausts and emission control systems
♦ Plan work to minimise the amount of vegetation clearing, cultivation and earthworks to the extent practicable, thereby limiting dust generation
♦ Ensure that the complaints management system can appropriately address incidents or substantiated complaints relating to air quality
♦ Establish clear communication methods to ensure that affected communities have access to effective communication links to the operational managers</td></tr>
<tr><td>Construction and operations</td><td>During construction and operations, the following practices will be implemented:
♦ Obtain approval via a clearance request (VCR) prior to vegetation clearing, and include plans for managing dust generation from cleared areas and soil stockpiles
♦ Apply dust suppression measures as required, such as spraying exposed surfaces, roads, soil stockpiles and other exposed areas contributing to dust generation with (non-saline, uncontaminated) water
♦ Maintain trafficable areas in a compact condition
♦ Vehicles will maintain speed limits
♦ Where loads of materials likely to generate dust (e.g., fly ash or bottom ash) are being transported to or from the power plant, these will be covered if practicable
♦ Limit truck queuing, unnecessary idling of trucks and unnecessary trips through logistical planning of materials delivery and work practices, while ensuring that vehicles keep to marked trafficable areas
♦ Locate stockpiles away from areas prone to erosion or sensitive receptor locations
♦ Avoid burning of cleared or standing vegetation, or waste materials, where practicable. Obtain approval from the Fire Coordinator prior to lighting fires associated with land clearing activities
♦ Minimise the length of time that cleared/disturbed areas are exposed (e.g., prior to establishing plantations or constructing hardstands)
♦ Employ soil stabilisation methods such as matting, grassing or mulch, where practicable
♦ Ensure clean up and restoration proceeds as soon as is practicable after works are completed
♦ Limit machinery movements where possible</td></tr>
</table>

<table>
<tr><th colspan="3">PR6 – Air Emissions and Air Quality Management Procedure (p2)</th></tr>
<tr><td colspan="3">Proposed Management and Mitigation Measures (cont'd)</td></tr>
<tr><td>Construction and operations (cont'd)</td><td colspan="2">♦ Maintain exhaust systems and emission control devices on vehicles and equipment to ensure that they are functioning as intended by the manufacturer.
♦ Store fuels and chemicals as specified in their SDS in closed containers
♦ If all available methods of dust management fail to adequately suppress dust and unacceptable impacts on sensitive receptors become evident, temporarily halt construction/plantation establishment activities until dust generating conditions subside
♦ Continually review energy efficiency, and identify and implement opportunities for efficiency improvements</td></tr>
<tr><td colspan="3">Proposed Monitoring and Reporting</td></tr>
<tr><th>Action</th><th>Frequency</th><th>Reporting</th></tr>
<tr><td>Undertake ongoing liaison with local communities regarding air quality issues related to the Project, including visual observations of emissions</td><td>Ongoing/as required</td><td>Monthly</td></tr>
<tr><td>Monitor dust generation (visual)</td><td>Event based</td><td>Monthly</td></tr>
<tr><td>Monitor dust deposition rates</td><td>Monthly</td><td>Quarterly</td></tr>
<tr><td>Monitor and report on fuel use (as documented in yearly reporting under Carbon Disclosure Reporting)</td><td>Monthly</td><td>Quarterly</td></tr>
<tr><td>Monitor point source (e.g., power plant stacks) emissions – upon commissioning each boiler unit, this monitoring will include as a minimum measurement of in-stack concentrations and emission rates (post ESP) of:
♦ Particulate matter
♦ Oxides of nitrogen
♦ Sulfur dioxide
♦ VOCs
♦ Carbon monoxide
♦ Determinations of gas temperature, stack gas velocity, moisture content, CO_2/O_2 content and exhaust gas flow rate</td><td>Annually</td><td>Annually</td></tr>
<tr><td>Record and report number of complaints related to air quality</td><td>Ongoing/as required</td><td>Monthly</td></tr>
<tr><td>Record and report on project-related GHG emissions</td><td>Ongoing/as required</td><td>Annually</td></tr>
<tr><td>If plantation access road construction areas are not located greater than 350 m from existing village/s, consideration will be given to a monitoring program that involves:
♦ PM_{10} baseline monitoring using, e.g., beta-attenuation monitors (BAMs), in villages close to the proposed access road area prior to construction works starting
♦ PM_{10} monitoring downwind of construction activities should complaints regarding dust be received during road construction
♦ PM_{10} monitoring to investigate other complaints or concerns, and to collect baseline monitoring away from the active work areas</td><td>As required</td><td>Quarterly</td></tr>
</table>

PR7 – Invasive Alien Species Management Procedure (p1)	
Purpose	
This procedure describes the minimum requirements that will be followed to prevent the introduction and spread of invasive alien species (including introduced pests and plant pathogens) as a result of Project activities	
Context	
Project activities (e.g., importation of equipment and personnel, plantation development) have the potential to introduce invasive alien species including weeds, plant pathogens or pest fauna into the area or facilitate the spread of existing weeds, plant pathogens and pests beyond their initial range	
Proposed Management and Mitigation Measures	
Training and awareness	Being aware of invasive alien species that are currently in the area, and/or those that could potentially establish in the area, is key to managing this issue. Selected Project personnel will be trained in: ♦ Identifying weed species currently in the area and those that could establish ♦ Identifying plant pathogens and evidence of their presence ♦ Identifying pests known to be in the area and those that could establish ♦ Techniques to prevent and, if necessary, control infestation of invasive alien species
Planning	In planning new activities involving vegetation disturbance, the following will be considered: ♦ Identify existing weeds within the vicinity of areas to be cleared ♦ Determine if there is evidence of plant pathogens on the proposed site ♦ Develop control strategies for weed species already established, using a risk-based approach to prioritise implementation, with a focus on noxious weeds ♦ Ensure that chemicals used to control weeds and equipment are on site and in good condition ♦ Should dieback be identified: – Exclude access to these areas OR – Provide boot-washing facilities for staff leaving the area to prevent further spread of the pathogen ♦ Identify existing pests and those that have the potential to establish in the area ♦ Consult with landowners concerning areas known to be infested by invasive alien species
Movement of machinery/ equipment	Use of machinery and equipment from outside the Project area and subsequent movements within the Project area are likely to be the most common causes of invasive alien species being introduced and/or spread. To minimise the likelihood of this occurring, the following practices will be implemented: ♦ Follow PNG quarantine requirements for importation of construction materials, soil or other plant material to the Project area ♦ Check equipment arriving on site to ensure that it is clean. Collect soil or vegetative matter in a plastic bag for subsequent burial in the Project landfill ♦ Minimise movement of equipment and machinery between areas ♦ Before any equipment is moved, remove soil, seeds and vegetation by washing down, paying particular attention to wheels, under-carriage areas and/or tracks
Construction and operations	During construction and operations, the following will be undertaken: ♦ Control the establishment of noxious weeds and pest animals at the edges of cleared or disturbed areas ♦ Place wastes (food in particular) in a bin (with secure lid) or otherwise in a manner that excludes pest animals such as rodents, and does not allow pest animals to access putrescible waste as a food supply ♦ Do not leave food wastes outside ♦ Initiate weed, pathogen and pest control programs as soon as possible, as required, using species-appropriate methods

<table>
<tr><th colspan="3">PR7 – Invasive Alien Species Management Procedure (p2)</th></tr>
<tr><td colspan="3">Proposed Management and Mitigation Measures (cont’d)</td></tr>
<tr><td>Construction and operations (cont’d)</td><td colspan="2">♦ Control pest rodents including black rat (Rattus rattus) and house mouse (Mus musculus) when detected in Project infrastructure areas
♦ Areas adjacent to and downslope of Acacia test plantings will be monitored for spread of these species. Any identified recruitment of Acacia plants from seed or suckering outside of the test planting areas will be controlled using an appropriate herbicide
♦ When plots of Acacia are harvested or cleared, where practicable these plots will not be burnt (to minimise germination of seeds). Plots will be monitored for recruitment of new Acacia plants, which will be controlled using an appropriate herbicide as required
♦ Implement riparian buffer zones with no plantations being established within the buffers</td></tr>
<tr><td colspan="3">Proposed Monitoring and Reporting</td></tr>
<tr><th>Action</th><th>Frequency</th><th>Reporting</th></tr>
<tr><td>Record and report weed, pathogen and pest presence or changes in extent of existing populations within the Project area</td><td>Quarterly</td><td>Quarterly</td></tr>
<tr><td>Monitor Acacia species within the Project area</td><td>Quarterly</td><td>Quarterly</td></tr>
<tr><td>Record and report pest animal sightings</td><td>Event-based</td><td>Monthly</td></tr>
<tr><td>Audit truck/machinery washing/cleaning facilities</td><td>Quarterly</td><td>Quarterly</td></tr>
</table>

PR8 – Water Management Procedure (p1)	
Purpose	
This procedure describes how surface water and groundwater resources are managed appropriately to minimise impacts on the environment and beneficial uses. The measures described herein will be progressively reviewed and modified as additional information about groundwater and plantation interactions is obtained	
Context	
Inappropriate management of water generated from, or used by, Project activities can impact on surface water and groundwater quality, and surface water and groundwater flow regimes, and associated beneficial values	
Proposed Management and Mitigation Measures	
General	Ensure that the relevant management and mitigation measures detailed in other management procedures, e.g., vegetation clearing (PR2), general waste management (PR3), hydrocarbons and chemicals management (PR4), and watercourse crossing management (PR9), are implemented
Planning	In planning Project activities, the following will be considered: ♦ Design access roads, facility sites and supporting infrastructure to allow adequate surface drainage and avoid redirection of stream flows and drainage lines where practicable ♦ Maximise water reuse and recycling ♦ Identify suitable extraction sites (water and gravel) that are likely to require the least disturbance of vegetation, expose minimal surfaces to erosion and cause least disruption to channel alignment and river depth. Take into consideration access routes to and from extraction sites that also require minimal disturbance ♦ Undertake a risk assessment in relation to acid sulfate soils and, if required, prepare an acid sulfate soils management plan ♦ Preferentially undertake construction activities requiring major earthworks in dry periods ♦ Ensure that appropriate consideration is given to flood prevention and mitigation measures for the power plant and central nursery ♦ Ensure that no plantations are established in areas that may act as water sources for Klin Wara and Maralumi River until additional information is obtained about these areas, where such information could include: – Groundwater and surface water contributions to downstream flows – Environmental characteristics (including terrestrial vegetation, soil characterisation and seepage characteristics of these areas, as well as downstream aquatic ecology) ♦ Where consolidated areas of plantations >100 ha are to be situated upslope of pre-existing water supply well/s, establish buffer zones of at least 300 m between the plantation boundary and the well/s ♦ Establish riparian buffer zones as follows: – 100 m from the banks of the Markham River – 60 m from the banks of the Leron and Erap rivers, and also from the edges of lakes, lagoons and swamps – 30 m from the banks on either side of other permanent watercourses with average widths >5 m – 20 m from the banks on either side of all watercourses with an average width >1 m but <5 m – At least 5 m from the banks on either side of watercourses with an average width <1 m ♦ Prior to construction, develop an ambient surface water monitoring program that takes into consideration flow/hydrology, water quality and geomorphology monitoring in selected major and/or clearwater watercourses within the Project area (and where practicable), and includes environment permit requirements once these are known

PR8 – Water Management Procedure (p2)	
Proposed Management and Mitigation Measures (cont'd)	
Construction and operations	During construction and operations the following will be undertaken: ♦ Install appropriate erosion and sediment control measures including but not limited to settling ponds, cut off drains, sediment traps, downslope silt fencing, revegetation and matting, and other measures described in PR2 ♦ Construct cut-off drains and sedimentation ponds around soil stockpiles ♦ Prevent surface runoff from potential sources of contamination reporting to surface water. If prevention is not possible, segregate this runoff from less contaminated runoff to reduce the volume of water requiring treatment ♦ Do not wash vehicles, equipment or machinery near or within watercourses ♦ Ensure that wastewaters (e.g., treated sewage, holding pond discharge) meet environment permit conditions before discharge into the environment ♦ Protect watercourse channel stability by limiting in-stream and bank disturbance, and ensure that the following activities are excluded from riparian buffer zones: – Machinery access – Felling of trees or clearing of vegetation except where required for designated stream crossings (note that within buffer zones for <1 m streams only, vegetation clearing will be minimised to the extent practicable, rather than excluded) – Establishment of plantations – Storing of logs, soil, machinery, fuels, oils, lubricant or herbicides, or placement of other Project-related infrastructure – Construction of roads, except where required for designated stream crossings or bridges – Crossing of harvesting machinery, except at appropriately constructed permanent crossing points (bridges) or at designated temporary crossings for dry watercourses. Harvesting machinery can cross watercourses where log crossings or culverts are provided ♦ Keep stormwater runoff that has come into contact with power plant, log yard and nursery areas from runoff that has not ♦ Implement bank protection measures downstream of discharge points and sediment basin spillways ♦ Include litter screens at the inlet of sediment traps, where practicable, to reduce waste delivery to watercourses. Regularly remove and dispose of waste trapped by screens ♦ Install and maintain oil-water separators and grease traps as appropriate at refuelling facilities, workshops, light and heavy vehicle washdown pads, parking areas, fuel storage and containment areas ♦ Divert and contain water used to clean vehicles, plant and equipment into an oil/water separator and do not allow uncontrolled release to watercourses or drainage lines ♦ Provide culverts and turnouts on all roads ♦ Maintain road V-drains to prevent damage to roads, and install energy dissipaters or erosion control structures on steep slopes ♦ Install culverts under roads at creek crossings to collect and divert runoff into the natural drainage ♦ Avoid gravel extraction from non-approved sites and reduce the number of gravel extraction sites to limit the area of river disturbance ♦ Establish, and train personnel in, gravel extraction methods that minimise bank disturbance, sediment remobilisation and sediment spills from excavators to watercourses, including undertaking gravel extraction from rivers during periods of low water flow where feasible ♦ Locate groundwater bores for the power plant downslope of plantations and the water supplies of villages and hamlets, where practicable

PR8 – Water Management Procedure (p3)		
Proposed Monitoring and Reporting		
Action	**Frequency**	**Reporting**
Monitor flow/hydrology, water quality and geomorphology as specified in the ambient surface water monitoring program developed prior to construction (and including environment permit requirements); include glyphosate in the monitoring program	TBD	Quarterly
Monitor stormwater quality (visual appearance)	Event-based	Monthly
Record volumes of water extracted by the Project (by source)	Daily	Monthly
Record volumes of water recycled/reused	Daily	Monthly
Record floodplain water depths (during flood events)	Opportunistically	Monthly
Monitor groundwater levels and quality (via monitoring bores)	Monthly	Monthly
Monitor erosion, bank slumping and scouring (visual inspection/photographic record)	Fortnightly and following prolonged heavy rainfall or storm events	Monthly
Monitor erosion and sediment control devices, diversion drains and settling ponds (visual inspection)	Fortnightly and following prolonged heavy rainfall or storm events	Monthly
Record complaints in relation to water quality/quantity	Ongoing/as required	Monthly
Undertake aquatic ecology survey (fish, macrocrustaceans)	As required in response to specific events or concerns	Annually

PR9 – Watercourse Crossing Management Procedure (p1)	
Purpose	
This procedure describes the minimum requirements that will be followed to ensure that watercourse crossings are constructed and rehabilitated in a responsible manner to minimise impacts on the environment	
Context	
Project construction and plantation development will require the installation of a number of watercourse crossings. Poorly designed and constructed crossings can cause river bed and bank erosion and/or modifications to drainage conditions and flow, with subsequent impacts on water quality and aquatic/riparian habitats	
Proposed Management and Mitigation Measures	
Planning	The following measures will be implemented during planning for watercourse crossing installation: ♦ Where practicable, minimise the number of watercourse crossings ♦ Locate watercourse crossings away from watercourse bends or rapids sections ♦ Ensure that watercourse crossings are designed to be perpendicular (within 10°) to water flow ♦ Where harvesting machinery is required to cross watercourses, construct log crossings or culverts ♦ Ensure that spill response and clean up equipment is on site prior to commencing works (see PR4) ♦ Schedule watercourse crossing works for periods of low flow where possible and complete the works in the minimum time required ♦ Ensure that construction machinery is weed free before accessing the watercourse (see PR7) ♦ Locate crossings in riparian grassland where practicable ♦ Consider the flow characteristics of the watercourse being traversed and the characteristics of the resident fauna ♦ Follow the principles of the PNG Logging Code of Practice, where applicable
Clearing and grading	Clearing and grading will involve the following: ♦ Avoid steep approaches to river crossings wherever possible ♦ Only clear riparian vegetation (plants within buffer zones as defined by PR8) where necessary to allow the installation and operation of the watercourse crossing ♦ Do not clear slopes leading to the watercourse and any riparian vegetation until such time as construction of the crossing is about to commence ♦ Ensure that any vegetation (aquatic or riparian) to be removed will be cut to ground level and the roots left in the ground to aid in erosion prevention. If deep excavation is required, remove roots within the construction footprint only ♦ Where grading adjacent to watercourses is required to enable access, grade the soil away from the watercourse ♦ Place topsoil at least 10 m away from the top of the stream banks where practical and erect silt fences or containments berms around stockpiles to minimise loss due to erosion
Erosion control	Erosion control will involve the following: ♦ Install erosion and sediment controls on or near slopes adjacent to watercourses during initial road grading activities, and maintain until final construction clean-up is completed ♦ Direct runoff water discharge to stable areas or via sediment settling basins and do not discharge directly into watercourses ♦ Divert road drainage within the last 50 m of the water crossing away from the watercourse into surrounding vegetation, ensuring suitable stabilisation measures are installed to avoid erosion and scour (e.g., riprap aprons) ♦ Minimise continuous slopes where scouring can occur ♦ Ensure that vehicles keep to well-defined roads

<table>
<tr><th colspan="3">PR9 – Watercourse Crossing Management Procedure (p2)</th></tr>
<tr><td colspan="3">Proposed Management and Mitigation Measures (cont’d)</td></tr>
<tr><td>Construction</td><td colspan="2">Construction activities will involve the following:
♦ Ensure that all material used in construction works will be benign in terms of generating potentially harmful leachates and runoff
♦ Construct log crossings using the most durable timber available
♦ Install ford crossings at the existing natural bed level, and align the lowest point of the crossing with the natural low flow channel
♦ Minimise vegetation clearing, bank modification and disturbance of the streambed when constructing water crossings
♦ Install culverts where required to minimise impacts on water flow, especially where fish movement is likely to be required
♦ Minimise earth moving and changes to the streambed during construction
♦ Avoid the creation of barriers to fish movement that can include hydraulic barriers (e.g., high flow velocity, reduced water depth, steps between culvert and river bed) or physical barriers (e.g., trapping of sediment/logs)
♦ Ensure that loose material is extracted and transported from construction areas at water crossings in a manner that does not allow it to report directly to the watercourse
♦ Keep heavy machinery away from watercourses, unless access is required to construct crossings
♦ Ensure waterway crossings are regularly inspected and maintained</td></tr>
<tr><td>Rehabilitation</td><td colspan="2">For any part of a watercourse bed or banks that has been altered by works, the site will be rehabilitated so that:
♦ Revegetation is undertaken as soon as is practicable
♦ Vegetation is retained or replaced to re-establish plants native to the site
♦ Profiles of bed and banks are reinstated to pre-work profiles and stability
♦ Watercourse bed is retained with natural substrate or reconstructed with substrate comparable to natural substrate size and consistency</td></tr>
<tr><td colspan="3">Proposed Monitoring and Reporting</td></tr>
<tr><th>Action</th><th>Frequency</th><th>Reporting</th></tr>
<tr><td>Monitor sedimentation levels in affected streams/rivers</td><td>Quarterly</td><td>Quarterly</td></tr>
<tr><td>Monitor turbidity levels in affected streams/rivers (upstream and downstream) during and after the cessation of gravel extraction operations/watercourse crossing construction</td><td>Event-based</td><td>Monthly</td></tr>
<tr><td>Monitor stormwater quality (visual appearance)</td><td>Event-based</td><td>Monthly</td></tr>
<tr><td>Monitor erosion, bank slumping and scouring (visual inspection/photographic record)</td><td>Fortnightly and following prolonged heavy rainfall or storm events</td><td>Monthly</td></tr>
<tr><td>Monitor erosion and sediment control devices, diversion drains (visual inspection)</td><td>Fortnightly and following prolonged heavy rainfall or storm events</td><td>Monthly</td></tr>
<tr><td>Monitor crossing integrity</td><td>Fortnightly and following prolonged heavy rainfall or storm events</td><td>Monthly</td></tr>
<tr><td>Record complaints in relation to water quality/quantity</td><td>Ongoing/as required</td><td>Monthly</td></tr>
</table>

<table>
<tr><th colspan="2">PR10 – Environmental Incident and Non-compliance Reporting Procedure (p1)</th></tr>
<tr><td colspan="2">Purpose</td></tr>
<tr><td colspan="2">This procedure describes the minimum requirements that will be followed to ensure that all environmental incidents relating to the Project are reported and recorded, as required. This will enable Markham Valley Biomass to meet its statutory requirements for notifiable incidents and also enable the company to monitor and implement corrective actions for non-notifiable incidents</td></tr>
<tr><td colspan="2">Definitions</td></tr>
<tr><td colspan="2">♦ Notifiable incident – an incident in breach of laws or statutory conditions; must be reported to government. The criteria for defining ‘notifiable’ will be further developed in relation to the Project environment permit, with reporting of ‘significant’ environmental incidents likely to be a condition within the permit
♦ Non-notifiable incident – minor incident that does not need to be reported to government; these are not a breach of compliance but will be reported as part of the Project's internal weekly/monthly reporting system
♦ Incident – requires completing an internal 'Environmental Incident Form'
♦ Non-compliance – any breach of legislation, environment permit condition or approved management plan (e.g., this EMP)</td></tr>
<tr><td colspan="2">Proposed Management and Mitigation Measures</td></tr>
<tr><td>General</td><td>Responses to environmental incidents will involve the following:
♦ Report all environmental incidents, both notifiable and non-notifiable, to Project environment personnel as follows and using the environmental incident form, taking into account the level of risk:
– Level 3, to be reported immediately to the Project Director. Incidents that are likely to affect the business either through likelihood of prosecution or in terms of cost or increased difficulty of doing business if the corporate reputation is affected; environmental impact is major or is a threat to health and safety
Examples include: significant contamination of surface and/or groundwater, multiple fatalities, widespread community unrest
– Level 2, to be reported within 24 hours to the Project Director. Incidents that could potentially result in prosecution, have significant environmental impact, are a threat to the health or safety of employees or the local community, or have potential to adversely affect relationships between the operation and the local community/broader public
Examples include: restricted contamination of surface water and/or groundwater, unauthorised disturbance of significant cultural heritage site
– Level 1, to be reported within 24 hours to Project HSE personnel. Incidents that lead to a minor breach of statutory conditions, have the potential to cause a low environmental impact or are unlikely to provoke a response from members of the local community. Examples include: a minor spill that can easily be cleaned up, minor exceedance of water quality standards
♦ Notify the Director of CEPA of notifiable incidents in accordance with the requirements of the environment permit
♦ Include all environmental incidents, both notifiable and non-notifiable, in the Project's routine internal reporting
♦ Include all environmental non-compliances in the Project's routine internal reporting, taking into account the level of risk:
– Level 3 non-compliance issues could result in prosecution or are of a significant nature with medium- or long-term effects and potentially serious environmental consequences
– Level 2 non-compliance issues may be issues of a continuous nature but with limited environmental impact or short- to medium-term issues with the potential for moderate environmental impacts
– Level 1 non-compliance issues may be technical or procedural issues involving environmental laws and regulations or a minor non-recurrent issue (e.g., a minor breach of a water quality standard)</td></tr>
</table>

PR10 – Environmental Incident and Non-compliance Reporting Procedure (p2)

Proposed Management and Mitigation Measures (cont'd)

Emergency response	Management measures in relation to emergencies will involve the following: ♦ Schedule and conduct regular drills to practice timely and effective emergency response ♦ Establish a recording system for the management of wastes, stormwater and procedures for clean-up of leaks or spills, and other emergency situations (see 'Additional Comment') ♦ In the event of a hydrocarbon or chemical spill, follow the steps outlined in the emergency response plan
Complaints response	Management measures in relation to complaints will involve the following: ♦ Investigate all complaints and undertake monitoring if appropriate ♦ Manage any complaints received in accordance with the Project's grievance mechanism

Proposed Monitoring and Reporting

Action	Frequency	Reporting
Record number and nature of incidents and non-compliances	Event-based	As required
Record nature of incident and non-compliance response	Event-based	As required

Additional Comment

An 'action log' (database) will be established that will allow the following information to be recorded:

- Incidents:
  - Details of injured employees
  - Details of person reporting incidents
  - Details of damage and expected costs of incidents
  - Details of injuries and expected disability periods
  - Medical treatment (time lost) and incident description
  - Root cause analysis
  - Safety notes
  - Control measures to be implemented to prevent re-occurrence
  - Preventative action; corrective action
  - Follow up required
- Forest fires:
  - Details of person reporting fire
  - Details of the location of the fire
  - Details of start and end time of fires
  - Fire cause analysis
  - Details of conditions at the time of the fire starting
  - Human casualties as a result of fires
  - Details of losses as a result of fire, including natural vegetation, agricultural and forestry, structures, livestock, tools and equipment
  - Details of reports to authorities
  - Preventative action; corrective action
  - Follow up required
- Corrective actions:
  - Details of person entering report
  - Type of complaint and description
  - Details of investigation
  - Details of corrective action and authorisation
  - Details of preventative action
  - Details of follow up
  - Details of closure authorisation

PR11 – Emergency Response Plans and Drills Procedure (p1)	
Purpose	
This procedure describes the minimum requirements that will be followed to ensure that an emergency response plan is prepared such that the Project is able to effectively respond to any incident with the objective of minimising adverse consequences on the health and safety of employees and communities, the environment, Project facilities and Markham Valley Biomass' reputation	
Context	
Accidents and incidents can occur during construction and operation. The risk of some of these events having significant consequences warrants the preparation of an Emergency Response Plan	
Proposed Management and Mitigation Measures	
Planning	Preparation of a suitable emergency response plan requires the following: ♦ Identifying all hazards and risks of an unplanned incident, and appropriate preventative and control measures ♦ Developing a response strategy to manage potentially significant unplanned incidents ♦ Ensuring clarity of organisational roles and responsibilities in relation to emergency response ♦ Ensuring an appropriate level of employee, contractor, government agency and public awareness of the identified risks and hazards ♦ Having properly trained and experienced emergency response personnel
Emergency response	Emergency response will involve consideration of the following: ♦ Appropriate communication to employees, contractors and the public and, where appropriate, the recovery needs of the community after an emergency ♦ A training program designed to improve the proficiency of the emergency response team as well as all employees and contractors covering operating procedures, emergency and safety procedures, regulatory compliance requirements and communication responsibilities ♦ Periodic review and update of the risk assessment in relation to an accidental release (e.g., of chemicals or wastewater) or other emergencies to employees, contractors, local communities and adjacent neighbours, and actions required to reduce significant risks ♦ Communication of relevant emergency response planning information to appropriate regulatory agencies and local emergency planning committees ♦ Coordination of the written emergency response plan, community emergency response plan and other facility plans. If no community emergency response plan exists, initiation, where appropriate, of community efforts to create one ♦ Identification of emergency responders and, where relevant, provision of facility tours to promote emergency preparedness and to provide current knowledge of facility operations ♦ Conduct, at least annually, of emergency exercise sessions with emergency responders and others where appropriate, to test the workability of the written emergency response plan ♦ Participation in the development and periodic testing of community emergency response plans ♦ Sharing of information and experience with other nearby facilities in the community relating to emergency response planning, exercises and incident handling

Proposed Monitoring and Reporting

Action	Frequency	Reporting
Audit emergency response plan	Quarterly	Quarterly
Record number of emergency response drills	Ongoing/as required	Monthly

PR12 – Environmental Auditing Procedure (p1)	
Purpose	
This procedure provides guidelines for conducting internal environmental audits by Project staff	
Context	
Internal environmental audits are required to achieve a range of objectives including, but not limited to, ensuring that environmental policies and procedures are working and are effective, the environmental management system (EMS) has been properly implemented and maintained, and areas for improvement are being identified	
Proposed Management and Mitigation Measures	
Planning	Preparation of an environmental auditing program requires the following: ♦ Scheduling audits of the Project's EMS taking into account: – Non-conformances and the outcomes and responses to previous audits – Significant changes in management, organisation, policy, techniques or technologies – Significant changes in legal and other requirements – Risk assessments – Changes to the EMS – Opportunities for continual improvement of the EMS – Issues of concern raised by stakeholders ♦ Responding to problems with the audit schedule and updating this if necessary ♦ Where resources permit, assigning audits to someone who is not directly responsible for the processes being audited
Conducting the audit	Conducting the audit will involve the following: ♦ Providing the auditor with an uncontrolled copy of the document/s to be audited and/or the template Internal Audit Report for that particular document (if available) or a blank internal audit report form ♦ Before the audit, ensuring that the auditor carefully reads the document/s being audited, reviews the outcomes and responses to previous relevant audits, and determines how the audit will be conducted. The auditor can: – Use an existing internal audit template relating to that document (if available) OR – Compose a set of questions using a blank internal audit report form OR – Use the uncontrolled document itself (with internal audit report cover page) ♦ Working through the checkpoints and/or questions with the person/s being audited, checking for, and noting down (on the report or document), evidence of the manner in which the process is being carried out ♦ Undertaking an inspection of the power plant and nursery, as well as selected parts of the plantation, as required ♦ At the end of the audit discussions and site inspection, completing the rest of the internal audit report, ensuring that the report lists and defines findings and observations point by point in a succinct manner, and noting any problems about the process being audited and discrepancies between the actual and documented procedure ♦ Submitting the audit report (within 7 days of completing the audit) to senior Project personnel
Audit follow-up	Following submission of the audit report, the nominated Project personnel will: ♦ Implement timely corrective or preventive action in regard to process/system improvement or non-conformities found during the audit, including opportunities or suggestions for improvements ♦ Maintain appropriate cross-referencing between audit records (audit form/report and plan) and the corrective action register (CAR) ♦ Check that CAR numbers have been raised for all corrective actions required

PR12 – Environmental Auditing Procedure (p2)		
Proposed Management and Mitigation Measures (cont'd)		
Audit follow-up (cont'd)	♦ Where other than text changes to the document is required, ensure that the person(s) responsible for the procedure where corrective action is to occur has been correctly identified in the CAR ♦ Update previous CARs which were checked during the audit ♦ Update the audit schedule to show the audit has been completed ♦ Save the audit electronically in the appropriate folder on the Project server ♦ File the audit report in the appropriate hard copy folder ♦ Follow the corrective action procedure and document control procedure as required ♦ If necessary, note any major problems raised during the audit at the next management meeting	
Proposed Monitoring and Reporting		
Action	**Frequency**	**Reporting**
Undertake reconciliation of audits held versus audit schedule	Quarterly	Quarterly
Review selected past audit reports	Quarterly	Quarterly
Review implementation of past audit findings	Quarterly	Quarterly

7. Stakeholder Engagement

7.1 Context

Appropriate environmental management practices are essential to ensure that Project activities are properly controlled and that community concerns are effectively addressed.

One of the most important factors shaping the relationship between the Project and local communities is the ability of the parties to communicate effectively with each other. This requires that MVB develops an understanding of the communities so that issues can be effectively managed as they arise. The building and maintenance of a relationship with the local community is critical to the ongoing success of the Project.

Markham Valley Biomass has therefore developed a stakeholder engagement plan (SEP) that identifies the current relationships of the Project with the main stakeholders based on a number of years of field trials within the Project area. The SEP demonstrates how these relationships will be maintained and enhanced during Project construction and operations, and key aspects are summarised below.

7.2 Issues Requiring Consultation

A number of issues relating to Project development will require consultation with the local community. These may include:

- Areas of sensitivity to landowners, local communities or other stakeholders.
- Location of Project facilities.
- Construction and operations activities, including likely impacts.
- Use of Project roads by the local community.
- Employment, training and supply opportunities, and compensation.
- Access to land and water.

Markham Valley Biomass will ensure that these and other relevant issues are included in the stakeholder engagement consultation program.

7.3 Stakeholder Engagement Plan

The SEP is a comprehensive document that describes the Project's approach to consulting with, and engaging, stakeholders. The document addresses the following:

- Maintaining the Project's 'social licence to operate', in part by maximising the involvement of local community members.

- The Project's guiding principles, these being a commitment to comply with PNG legislation and adhere to a number of internally generated standards, which requires transparent, open and pro-active communication and cooperation between MVB and stakeholders.
- Identifying various stakeholder groups, ranging from individual families using or owning assets in the Project area through to the provincial and national governments, international finance institutions, and international observers.
- A stakeholder communications/action plan that is aimed at ensuring that all stakeholders have been engaged to the appropriate extent and have a sufficient understanding of Project activities (depending on the stakeholder involved).
- Reviewing and adapting the current grievance mechanism to ensure that it is appropriate for the various stages of Project development, including complaints or issues arising from the activities of construction or other contractors.
- The role of independent third party organisations to provide comfort and reassurance to stakeholders, particularly affected clan landowner members.
- Completing risk assessments or reviewing previous risk assessments in light of changes in Project scope, activities or local socio-economic environment.
- Monitoring, evaluation and reporting, where this includes internal monitoring, outcome evaluation and completion audits.
- Community development opportunities, where the Project's aim is to ensure that the communities directly and indirectly impacted by Project activities are provided every opportunity improve their livelihoods in an ongoing and sustainable manner. These include:
  - Project-supported community development, such as donations or sponsorships.
  - Employment, both direct and indirect.
  - Local business development, including maximising (where appropriate) local national content.

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Attachment 1.
Example of a Management Prescription – Establishment

Integrated Management System

Op.	File	Copy

Document	Silvicultural Manual	Subject	Establishment

1 Scope

This procedure applies to all company forests operations where land is being afforested or reforested.

2 Objective

The objective is optimise land use by ensuring that all planting, watering and blanking is done safely and in such a way as to improve the quality and uniformity of the planted crop, whilst mitigating the impacts of these operations on the environment.

3 Legal Compliance Requirements

Field operations shall comply with all national laws and codes of practice. Where no such code exists, the operation shall comply with the "ILO - Code of Practice on Safety and Health in Forestry"

4 Operational Control

1	Every crew, of more than five people, working in field shall have a first aider present in Field.	**S**
2	First Aiders shall have a first aid kit with them in-field that complies with the company requirements.	**S**
3	Silvicultural employees shall be represented by a SHE representative.	**S**
4	For Personal Protective Equipment (PPE) requirements refer to section 4.1 of the BOP's	**S**
5	Team briefings / team talks / toolbox talks shall be done.	**Q**
6	Daily Production and labour details shall be recorded on the Production Control form.	**P**
7	All silvicultural operations shall have an Annual Plan of Operations (APO) completed before operations commence. (Refer to the Annual Plan of Operations BOP)	**Q**
8	Based on the selection of tending or weeding method refer to relevant BOP's for further health, safety, environmental, quality and productivity standards,	**Q**
9	Ensure compliance with the relevant BOP requirements.	**Q**
10	Sufficient supplies of safe drinking water should be available at the worksite. For physical work in hot climates up to 1 litre per hour may be required.	**S**
11	Non-organic waste shall be disposed of in the correct manner. (Bins/bags shall be provided for such waste disposal).	**E**
12	Areas shall be designated or demarcated in-field (day camp) for: ➢ first aid boxes, food and drinking water storage, ➢ chemical, fuel and oil storage. There should be no risk of food and drinking water being contaminated by chemicals.	**S,E**
13	Smoking shall be restricted to designated areas, as defined by the company.	**E**
14	Refer to the Preventative Action, Corrective Action procedures, and CAR Form where non-compliances to this prescription are observed.	**Q**

4.1 Planting (*consider two sections, establishment and planting*)

Refer to the relevant BOP's for further instruction on the Safety, Environmental and Quality standards for Planting Activities.

1	All planting is to be done in terms of the Establishment Assessment.	**Q**
2	The Establishment Assessment shall be signed by the relevant functions.	**Q**
3	All planting should be done in terms of the Annual Plan of Operations (APO)	**Q**
4	However, the main objective should focus on the quality of preparation, planting and optimum planting windows. This takes precedence over the limiting of the Temporary Unplanted (TU) area.	**Q**
5	When planting on rip lines care must be taken that all air pockets are removed first before planting can take place. Planting on the sides of the rip lines is allowed where not enough soil is left inside the rip line.	**Q**
6	Refer to Policy Manual section 3.3.6.2.2 for planting espacements.	**Q**
7	Complete the relevant sections of the Establishment Assessment form	**P**
8	Refer to the Conservation Management FMP for prescriptions on planting restrictions related to natural areas (including SMZ's) and Areas of Special Interest (ASI's).	**E**

4.2 Refilling (Blanking)

1	Blank within 2 months after planting operation in the same season.	**Q**
2	Aim at a survival rate of 85% plus (see blanking table below).	**Q**
3	If more than 50% blanking is required the planting date shall be altered to the date of blanking.	**Q**
4	Species shall be recorded in the Establishment Assessment Form.	**Q**

5 Responsibility

The following positions are responsible for ensuring compliance with this procedure:

Superior Second Level:	**GENERAL MANAGER - FORESTRY**
Superior First Level:	**SILVICULTURE FORESTER**
This Position:	**PLANNING & RESOURCE SUPERVISOR**

6 Appendix

Establishment Assessment

7 Records

Record	Responsibility	Where kept	Retention
Establishment Assessment	Silviculture Forester	Compartment Register	25 years
Annual plan of operations (APO schedules)	Silviculture Forester	Forest Office	2 years
Monthly Progress reports	Silviculture Forester	Forest Office	2 years
Plantation Audits	Silviculture Forester	Forest Office	5 years

8 References

IMS Manual	OHSAS 18001:2007	ISO 14001:2004	ISO 9001:2000
5.6.2.2	4.4.6	4.4.6	7.1; 7.5.1; 7.5.2
FSC		**Aspect /Impact/Hazard Register**	**BOP**
6.2; 6.3; 6.6; 6.9		Impacts SC150, SC160 Risks G/P/W E04, E05, E06	Refer to Silviculture Site Map

9 Definitions

Attachment 2.
Example of Best Operating Practice – Weeding Using a Slashing Tool

FORESTRY SOLUTIONS

OPERATION	SILVICULTURE	WEEDING – SLASHING

1. SCOPE of the BOP

Land preparation / pit **/** plant / watering / fertilise / blanking / **tending operations**

Species: Pine, *Eucalyptus, Acacia mearnsii*

2. OBJECTIVE

This BOP describes weeding of a designated area of weeds and regrowth using a slashing tool.

3. LEGAL COMPLIANCE REQUIREMENTS (Links to Legal Register)

Field operations shall comply with all national laws and codes of practice. Where no such code exists, the operation shall comply with the "ILO - Code of Practice on Safety and Health in Forestry"

4. OPERATIONAL CONTROL

4.1 ACTIVITY PLANNING

All compartment and daily planning should be carried out according to in house silvicultural planning procedures.

4.2. SAFETY AND THE ENVIRONMENT

Safety Risk factor: Medium
Environmental risk factor: Low

The operation should comply with all in-house safety regulations.

1.	The operator should wear the prescribed Nationally approved safety equipment: a) Overall b) Safety boots – hard tipped toes c) Sunhat / Hard hat (optional) d) All safety equipment shall be in a serviceable condition. All safety equipment shall be in a serviceable condition	**S**
2.	The worker should ensure that when loading and off loading equipment onto the transport vehicle, the correct loading techniques are used. (Bending knees)	**S**
3.	A single worker should not lift loads greater than 25kg.	**S**
4.	Workers should be seated during transportation and all equipment and materials properly secured.	**S**
5.	The workers should pay attention and take note of the points raised in the supervisor during the safety (toolbox) talk.	**S**
6.	The worker may not be under the influence of alcohol or a narcotic, as this impairs his ability.	**S**
7.	Certain animals can be harmful to the worker's health such as bees, wasps and reptiles. These to be reported to the supervisor to remove the threat.	**S**
8.	All non-organic waste is to be removed from infield daily, and disposed of in the appropriate manner.	**E**
9.	Keep clear of Special Management Zones (SMZ's) or Areas of Special Interest (ASI's) SMZ's and ASI's.	**E**
10.	No slashing/weeding activities to take place within the restricted areas in SMZ's and ASI's.	**E**
11.	Remove slash from designated SMZ's and ASI's, which may accidentally have entered these sites.	**E**
12.	The worker should be alerted to endangered species of plant or animals, especially active raptor nests	**E**

4.3. CONTROLS

4.3.1 Daily production control

The manual slashing worker should be allocated a daily production target prior to the commencement of the shift. The supervisor should also allocate and mark out the rows for the worker. Any special instructions should be issued at this time.

1.	Identify the current area to be weeded and determine the planned task level.	**P**
2.	Check the slope, ground cover and soil conditions and ensure that the task level for the conditions corresponds with the plan.	**P**
3.	The workers should use a method and equipment suitable to the conditions being weeded. The equipment should be in a serviceable working condition.	**S**
4.	The operational planning of the compartment should be conducted to ensure that each of the manual slashing workers can function in an organised, safe and continuous manner without interference from or influence of other workers.	**S**
5.	The daily targets set should allow the target to be achieved by the worker, at an even pace, during a working day.	**S**
6.	The daily targets should be realistic and set according to prevailing terrain conditions and prescribed standards	**S**

4.3.2 Job Observation

The Job observation checklist attached in Appendix 2 is to be used to carry out periodic inspections of the required work. This is to be used by the supervisor or various levels of management to evaluate the work performance of the operator/worker. The Job Observation checklist can be applied to either own or contractor operations.

4.4. QUALITY

The manual slashing worker should ensure that the slashing operation meets the correct quality requirements. The supervisor at the operation will carry out regular quality checks. Factors affecting quality are listed in Appendix 1.

4.5. OPERATIONAL DESCRIPTION

The workers clear a designated area of weeds and regrowth using a slashing tool. They should not slash weeds within a 15cm radius of planted trees; here weeds should be hand pulled due to the risk of tree damage with the slashing tool or hoe. Debris should not be left covering planted trees and if necessary, debris should be cut into smaller pieces. While stacking of slash debris is not required, debris should be flush with the ground and not restrict movement in the compartment.

4.5.1 Operational set-up

The worker is issued with a suitable slashing tool. The supervisor will give a 5-minute safety (toolbox) talk and issue any special instruction. The worker then moves to the allocated row(s) and commences working.

1.	Collect and load the required equipment from stores onto vehicle.	**P**
2.	Travel to the compartment.	**P**
3.	Each worker should off load and prepare their slashing equipment.	**P**
4.	Receive any special instruction, quality requirements and daily tasks.	**P,Q**
5.	Position at the allocated row with the hoe and measuring stick if necessary.	**P**
6.	Mark and tag the row to be slashed with worker's identification tag.	**P**
7.	Check whether SMZ's and ASI's have been marked on the compartment map for the area to be worked and ensure that such sites have been communicated to workers.	**E**

4.5.2 Line clean

The line clean operation is the slashing out of regrowth along a pre-specified tree line or between two planted tree rows. The slashing is carried out using a suitable slashing tool, which may vary according to conditions or circumstances. The line clean requires the slashing of all plant material along a specified width. Regrowth material within 15cm of the planted tree should be pulled by hand to avoid any possible damage to the planted tree. Should the pulling of regrowth, however, result in root disturbance to the planted tree then this may be carefully slashed, provided the necessary caution is taken not to damage the above ground tree portion.

1.	Position at the row to be cleared, determine the weed cover, slope, rocks and any additional factor needing to be considered when hoeing.	**P**
2.	Commence slashing / weeding at the start of the first row and work down the line.	**P**
3.	Remove by hand any debris and large stones within the line clean area.	**Q**
4.	Pull all weeds within the 15cm radius of the planted tree; dispense outside of the line clean area.	**Q**
5.	Ensure the slasher is worked flush with the surface so that all regrowth is cut at the plant base and raked out of the line clean area.	**Q**
6.	If there is any soil disturbance, the soil should remain within the line clean area.	**Q**
7.	When working sloped areas, it is preferable to run the line clean across the slope to prevent water run off. If the line clean should run up and down the slope, then soil should be positioned across the line to dam and collect water, thus reducing soil erosion.	**E**
8.	Use only the necessary force when conducting any slashing action.	**S**
9.	Do not work within 2.0 slasher lengths of another worker.	**S**
10.	Do not walk carrying the slasher over the shoulder; the slasher should be carried in the hand at one's side, with the cutting head in front of the hand, pointing towards the ground.	**S**

4.5.3 Slashing for access

Slashing for access normally takes place in new unplanted areas or larger standing trees, prior to pruning or harvesting operations. The slashing worker, equipped with a suitable slasher and works between two tree rows. The slashing worker slashes all regrowth to a prescribed height.

1.	Position at the rows to be cleared. Determine the weed cover, slope, rocks and additional factors that need consideration when slashing.	**P**
2.	The start and completion points of the daily task should be calculated and marked out per the terrain conditions and the firebreak width.	**P**
3.	Slash all regrowth material down to the prescribed height.	**P**
4.	Reslash and process any larger regrowth material into smaller compact work pieces.	**P**
5.	While it is not necessary to stack debris, there should be free access and movement for the subsequent operations.	**P**
6.	Ensure that standing trees are not damaged during slashing.	**P**
7.	Clear all debris from around standing trees.	**P**
8.	Use only the necessary force when completing any slashing action.	**S**
9.	Do not work within 2.0 slasher lengths of another person.	**S**
10.	Do not walk carrying the slasher over the shoulder; the slasher should be carried in the hand at one’s side, with the cutting head in front of the hand, pointing towards the ground.	**S**

4.6 JOB DESCRIPTION

Appendix 3.

4.7 PRODUCTION STANDARDS

The lack of available work-study data and the extensive variation in conditions does not allow for the calculation of a variable points tasking system. The following information has been compiled into a tasking guideline for the slashing operations.

SLASHING ANNUALS – VARIABLE CONDITIONS POINTS TABLE			
Condition	**Variable**	**Points**	**Points**
Slope conditions (%)	0 – 25%	0	
	26 – 35 %	1	
	36 - 50 %	2	
	>50%	3	
Weed cover density	20 – 39 % Light scattered regrowth	0	
	40 – 59 % Consistent scattered regrowth	1	
	60 – 79 % Occasional open areas, height	3	
	80 – 100 % Comp. appears fully covered	6	
Weed height	20 - 40cm	0	
(Average height)	40 – 60cm	1	
	60 - 90cm	2	
	1.0m	4	
Access	Normal to heavy brush residue	0	
	Heavy brush residue – movement restricted	1	
Vegetation type	Annuals	0	
	Annual + scattered woody trees and thorns	1	
	Annuals + mixed woody / thorn < 33%	3	
TOTAL			

SLASHING ANNUALS (bugweed, blackjack Ink berry etc)

Points	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Unit/ha	**1.5**	**2.0**	**2.5**	**3.0**	**3.25**	**3.5**	**3.75**	**4.0**	**4.25**	**4.5**	**4.75**	**5.0**	**5.25**	**5.5**	**5.75**	**6.0**

SLASHING (WOODY WEEDS) – VARIABLE CONDITIONS POINTS TABLE			
Condition	**Variable**	**Points**	**Points**
Slope conditions (%)	0 – 35%	0	
	36 – 50 %	1	
	>50%	2	
Weed cover density	20 – 39 % Light scattered regrowth	0	
	40 – 59 % Consistent scattered regrowth	1	
	60 – 79 % Occasional open areas, height	3	
	80 – 100 % Comp. appears fully covered	6	
Weed height	0 – 1.0 M	0	
(Average height)	1.1 – 3.0M	2	
	> 3.0M	4	
Access	Normal to heavy brush residue	0	
	Heavy brush residue – movement restricted	1	
Vegetation type	Gum, wattle, blackwood regen	0	
	Bramble, Mauritian thorn	4	
TOTAL			

SLASHING ANNUALS

Points	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
Unit/ha	**3**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**

Note: Flexibility should be catered for in the slashing of woody weeds and the table acts as a guideline only. It is not possible to build all the possible conditions into the table due to a lack of available data.

APPENDIX 1

FORESTRY SOLUTIONS

ACTIVITY CHECKLIST

OPERATION:	SILVICULTURE	MANUAL SLASHING

Planning	Attend team / toolbox talk	S
	Issued daily task, start and completion points	P
	Identification and marking of hazardous or environmental areas (SMZ's & ASI's)	SE
	Supervisor checks quality regularly	Q
	Completion of daily production sheets at the end of the shift	PQ
	Prescribed safety equipment issued and used	S
	Operation carried out in accordance to Operational Silviculture Plan and APO	Q
Setup	Correct loading and securing of load during transport	S
	Workers seated during transport and follow the transport perscriptions	S
	Adherence to prescribed safety regulations in BOP	S
Operating Instruction Environmental (Actual)	Correct evaluation, positioning and completion of work areas (work completed correctly)	PQ
	All remaining regrowth slashed	Q
	No spiked stumps remain after slashing	S
	Stumps at the correct height above ground level	Q
	No slash debris left on / covering planted trees	Q
	Where necessary, correct felling techniques are used	Q
	Where possible larger trees directionally felled towards brushlines	Q
	Access pruning using the slasher minimised	Q
	Slashing tool correctly used and does not strike ground or rocks	Q
	Safe working distances maintained (2 slasher lengths)	S
	Slasher carried correctly	S
	Using only necessary force used when completing any slashing action	S
	All non-organic waste removed from infield	E
	No slash into SMZ'S and ASI's	E
	SMZ's and ASI's reported if discovered	E
	No branches/debris into the drainage systems of the forest road network	E

APPENDIX 2

FORESTRY SOLUTIONS

JOB OBSERVATION

OPERATION:	SILVICULTURE	MANUAL SLASHING

Planning	Attend team / toolbox talk	S
	Issued daily task, start and completion points	P
	Identification and marking of hazardous or environmental areas (SMZ's & ASI's)	SE
	Supervisor checks quality regularly	Q
	Completion of daily production sheets at the end of the shift	PQ
	Prescribed safety equipment issued and used	S
	Operation carried out in accordance to OSP (APO)	Q
Setup	Correct loading and securing of load during transport	S
	Workers seated during transport	S
	Adherence to prescribed safety regulations in BOP	S
Operating Instruction Environmental (Actual)	Correct evaluation, positioning and completion of work areas (work completed correctly)	PQ
	All remaining regrowth slashed	Q
	No spiked stumps remain after slashing	S
	Stumps at the correct height above ground level	Q
	No slash debris left on / covering planted trees	Q
	Where necessary, correct felling techniques are used	Q
	Where possible larger trees directionally felled towards brushlines	Q
	Access pruning using the slasher minimised	Q
	Slashing tool correctly used and does not strike ground or rocks	Q
	Safe working distances maintained (2 slasher lengths)	S
	Slasher carried correctly	S
	Using only necessary force used when completing any slashing action	S
	All non-organic waste removed from infield	E
	No slash into SMZ'S and ASI's	E
	SMZ's and ASI's reported if discovered	E
	No branches/debris into the drainage systems of the forest road network	E

Date of observation		**Name of examiner**	
Name of incumbent		**Job title**	
Signature of incumbent		**Signature**	
Total defaults		**Rating of incumbent**	
Comments:			

APPENDIX 3

FORESTRY SOLUTIONS

JOB DESCRIPTION

OPERATION:	SILVICULTURE	WEEDING – SLASHING

1. REPORTING LEVELS

Superior Second Level:	**SILVICULTURE FORESTER**
Superior First Level:	**SILVICULTURE SUPERVISOR**
This Position:	**SILVICULTURE WORKER MANUAL SLASHING**

2. TRAINING

Orientation/Induction
Environmental awareness for workers
Basic safety for workers
Basic fire fighting for workers
Manual slashing or hoe weeding "on the job training"

3. PRE-EMPLOYMENT MEDICAL REQUIREMENTS

1.	Physically strong and fit	
2.	No muscular or skeletal abnormalities or deformities.	
3.	Good co-ordination	
4.	Good eye sight and depth perception.	
5.	No back problems	
6.	2 x Base line Audiometric tests	
7.	No serious medical condition which could jeopardize his, as well as co-workers safety, e.g. diabetes, hypertension, epilepsy – unless such diseases are under control.	

4. PERSONNEL SPECIFICATIONS

Criteria	Specification
Minimum standard of education	Grade 5
Post school education and training	Nil
Linguistic requirements	English
Essential experience	Silviculture worker
Training required till fully proficient	1 Month
Tools/Machines used	Suitable slashing tool
Hours of work	Shift
Working conditions	External manual labour in all weather
Physical requirements	Strong and healthy
Safety of others	Very important
Important people contacts:	
Internal	Silviculture forester, all levels of managements site visitors
External	Contractors, foreign visitors

5. PHYSICAL ATTRIBUTES

Aspects rated on a scale 0-4 (Considering frequency and importance)

0 - None 1 - Low 2 - Average 3 – High 4 - Very high

Physical requirements	**0**	**1**	**2**	**3**	**4**
Climbing onto machinery		*			
Hearing		*			
Lifting				*	
Working bent				*	
Use of left arm					*
Use of right arm					*
Use of left foot				*	
Use of right foot				*	
Use of left leg				*	
Use of right leg				*	
Walking				*	
Standing					*
Sitting		*			
Vision (Sight)				*	
Colour distinction			*		
Depth perception				*	
Eye/Hand/Foot co-ordination				*	

Bio-mechanical

Action repeating					*
High physical exertion		*			

Working environment	**0**	**1**	**2**	**3**	**4**
High temperature				*	
Low temperature		*			
Noise		*			
Humidity				*	
Dampness				*	
Vibration			*		
Height		*			
Abnormal positions				*	

Working conditions

Exhaust fumes		*			
Dust		*			
Hazardous substances	*				

Special requirements

Use of safety visors			*		
Use of hand gloves					*
Use of safety boots/shoes					*
Use of hard hat	*				
Use of safety belt	*				
Use of hearing protection	*				

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