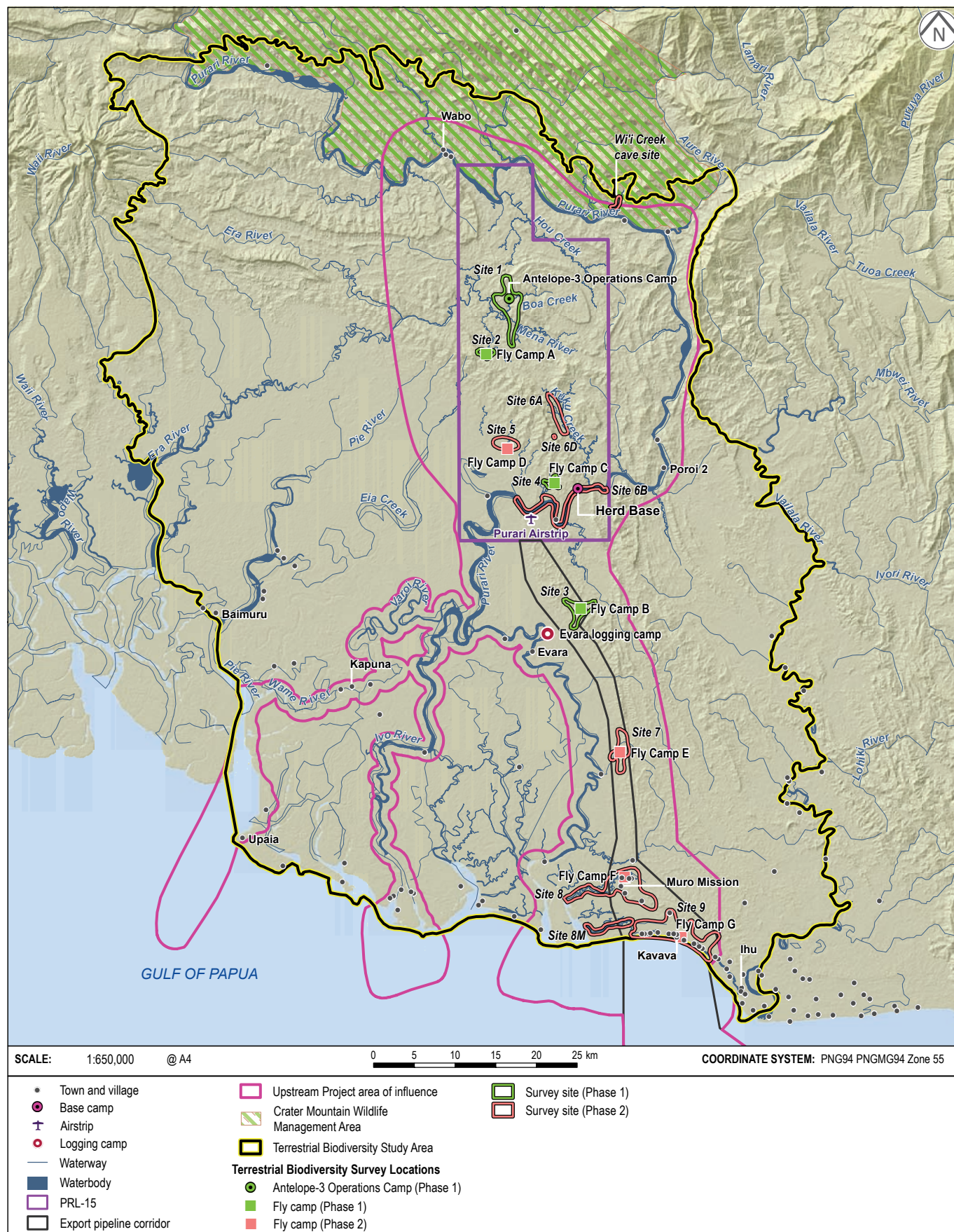


TERRESTRIAL BIODIVERSITY SURVEY SITES

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FIGURE 7.16

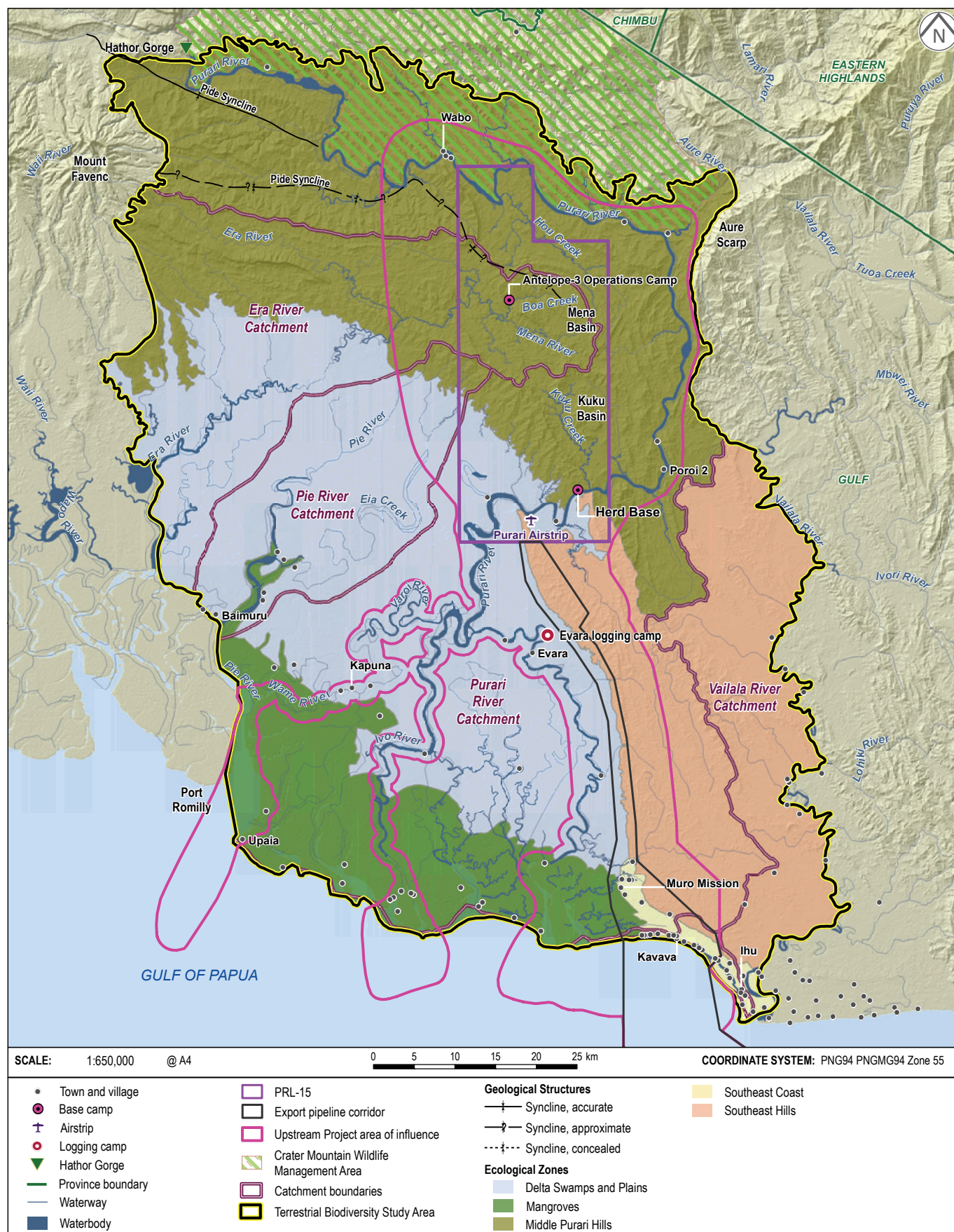


Communities outside of the Project area of influence have not been verified. Only government administrative centers and notable locations have been labeled for context.

TERRESTRIAL BIODIVERSITY STUDY AREA, ECOLOGICAL ZONES AND MAJOR CATCHMENTS

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FIGURE 7.17



Communities outside of the Project area of influence have not been verified. Only government administrative centers and notable locations have been labeled for context.

The study area covers more than 21% of the land surface of Gulf Province, spans an elevational range of 600 m from sea level to the Kereru Range and encompasses a wide variety of terrestrial vegetation types and coastal marine and freshwater ecosystems occurring across five major catchments (see Figure 7.17), notably including the middle and lower reaches of the Purari River, Papua New Guinea's third largest watercourse (Petr, 1983a).

7.7.3 Ecological Zones

The study area is divided into five ecological zones, defined primarily according to landform and vegetation, catchment boundaries or areas of marine tidal influence (see Figure 7.17). Each ecological zone is expected to support a distinct assemblage of terrestrial flora and fauna, although boundaries are notional with populations of most species spanning zonal borders. The physiographic features important in shaping the biological environments of the ecological zones are summarized in Table 7.7.

7.7.4 Regional and Biogeographic Setting

7.7.4.1 Regional Biodiversity Setting

New Guinea¹⁸ is among the most biologically diverse and endemically rich regions on Earth (Olson & Dinerstein, 1998; Brooks et al., 2006; Jenkins et al., 2013; Mittermeier et al., 1997; Wikramanayake et al., 2002). It supports the third largest block of unbroken tropical rainforest in the world and the largest tract of primary rainforest remaining in the Asia-Pacific region (Beehler, 2007; Bryan & Shearman, 2015). Its forests support more than 5% of the world's plant and animal species on less than 1% of its land surface (Faith et al., 2001). As a result, the area of New Guinea within which the study area is located has featured in multiple global biodiversity priority assessments that identified various high-level values.

7.7.4.2 Biogeographic Regions

The study area is located at the eastern end of New Guinea's Southern Lowlands region, within which smaller biogeographic regions are recognized. The arrangement of these smaller biogeographic regions, both within and beyond the study area, differs among major taxonomic groups. Those relevant to the study area are outlined in Table 7.8 and the elevations of the regional area are shown in Figure 7.18.

7.7.4.3 Protected Areas and Proposed World Heritage Sites

Two protected areas are declared under the *Fauna (Protection and Control) Act 1966* in the vicinity of the study area, and one proposed world heritage site is under consideration by the United Nations Educational, Scientific and Cultural Organization (UNESCO). These are outlined in Table 7.9 and shown in Figure 7.18.

¹⁸ Refers to mainland New Guinea, the eastern half of which forms part of Papua New Guinea.

Table 7.7 – Ecological Zones within the Upstream Terrestrial Biodiversity Study Area

Ecological Zone	Description	Area (km ²) (Percentage (%))			
		Study Area Total	Upstream PAOI	PRL-15	Export Pipeline Corridor
Middle Purari Hills	♦ Uplifted erosional landforms – an extensive area of low relief, even-peak foothills that extend north across a 30 to 40 km expanse from the head of the Purari River delta to the 500-m contour of New Guinea's central cordillera*, the northern boundary of the study area (see Figure 7.18). ♦ Elevation ranges from approximately 40 m asl to more than 600 m asl; primarily lies below 300 m asl. ♦ Geology is dominated by Tertiary sandstones and mudstones. Surface limestone occurs in limited areas outside of PRL-15, in the west along the Kereru Range and in the extreme north (Bain & MacKenzie, 1974; Pieters, 1980).	2,655.99 (36.4%)	596.34 (33.2%)	595.55 (77.0%)	0 (0%)
Southeast Hills	♦ Uplifted erosional landforms that lie between the Purari and Vailala rivers, south of the Middle Purari Hills and north of the Southeast Coast, and drain into the: – Delta Swamps and Plains ecological zone (Purari River catchment), or – Vailala River (Vailala River catchment). ♦ Geology and topography are similar to those of the Middle Purari Hills although no major limestones are present (Ruxton, 1969a; Pieters, 1980; Bryan & Shearman, 2008). ♦ Contains large areas of alluvial plains and back swamps interspersed among the ridge system. ♦ Elevation ranges from less than 10 m asl on the floodplains to more than 350 m asl on the ridge separating the Vailala River and Purari River catchments (see Figure 7.4); primarily lies below 200 m asl.	1,291.80 (17.7%)	397.33 (22.1%)	20.58 (2.7%)	89.34 (43.9%)
Delta Swamps and Plains	♦ Recent alluvial landform supporting a variety of freshwater swamp and alluvial forest habitats. Levee banks produced by regular flood deposits border the main distributaries and slope gently away into the backwater swamps (Bryan & Shearman, 2008). ♦ Composed of sediments (mud, silt, sand and gravel) deposited by the Purari, Pie and Era rivers (Pieters, 1980; Thom & Wright, 1983). ♦ Elevation ranges from less than 5 m asl to more than 60 m asl on a few isolated foothills near the base of the Middle Purari Hills; primarily lies below 25 m asl. ♦ Together with the Mangroves ecological zone it comprises the easternmost component of a much larger depositional system that stretches west and south along the Gulf of Papua to include the deltaic systems of the Kikori, Turama and Fly rivers (Thom & Wright, 1983).	2,411.81 (33.1%)	571.50 (31.8%)	157.40 (20.3%)	52.30 (25.7%)

Table 7.7 – Ecological Zones within the Upstream Terrestrial Biodiversity Study Area (cont'd)

Ecological Zone	Description	Area (km ²) (Percentage (%))			
		Study Area Total	Upstream PAOI	PRL-15	Export Pipeline Corridor
Mangroves	- Recent alluvial landform under marine tidal influence. - Forms the eastern part of the largest area of mangroves in Papua New Guinea, stretching west along the coast for approximately 150 km to the mouth of the Omati River (Percival & Womersley, 1975; Saulei & Beehler, 1993). - Deltaic front is morphologically dynamic in response to active river dynamics, tidal flows, wave action and sediment deposition (Ruxton, 1969a; Thom & Wright, 1983; Shearman et al., 2013).	855.57 (11.7%)	170.72 (9.5%)	0 (0%)	17.16 (8.4%)
Southeast Coast	- An aggrading series of sub-parallel beach ridges and intervening swales and plains comprising recent littoral sands (Ruxton, 1969b; Ruxton et al., 1969; Bryan & Shearman, 2008). - Also includes some minor mangrove and swamp areas.	77.62 (1.1%)	61.59 (3.4%)	0 (0%)	44.70 (22.0%)
Total		7,292.79	1,797.48	773.53	203.50

* Lands north of the study area rise much more abruptly, attaining heights of 1,000 m within a distance of 5 km.

Table 7.8 – Biogeographic Regions Relevant to the Study Area

Region Name	Relevant Taxonomic Group	Identified/ Defined by	Location/Description	General Overlap with Study Area
Kikori-Purari	Warm-blooded vertebrates (mammals and birds)	Beehler, 1993	This region is contained in the Gulf Province lowlands (below 500 m asl) and extends from the Turama River east to the Vailala River. The Lakekamu Basin east of the study area is outside of this biogeographic region.	Study area is contained entirely within the region.
Gulf Lowlands	Lower vertebrates (fish and herpetofauna) and terrestrial insects	Allison, 1993; Miller, 1993	Lowlands spanning the Gulf of Papua, from the Fly River (Western Province) east across Gulf Province to near Hall Sound (Central Province). Includes the Lakekamu Basin.	Includes the southern part of the study area, north to approximately the southern boundary of the Middle Purari Hills ecological zone.
Eastern Highlands			Approximately follows the southern boundary of the Middle Purari Hills ecological zone and extends north to montane environments above 3,000 m asl.	Includes the northern part of the study area.
Papuan Gulf Coastal Lowlands	Aquatic insects*	Polhemus et al., 2004	Includes the southern coastal lowlands below 50 m asl from the Kikori River delta east to Kerema.	Includes the southern part of the study area, including the Delta Swamps and Plains, Mangroves and Southeast Coast ecological zones and parts of the Southeast Hills ecological zone.
Papuan Gulf Foreland			Comprises the basins of the Kikori, Purari, Vailala and Lakekamu rivers at elevations between 50 and 1,200 m asl.	Includes the northern part of the study area, including the Middle Purari Hills and parts of the Southeast Hills ecological zones.

* Including odonates (dragonflies/damselflies), an insect group with both aquatic (larva) and terrestrial (adult) life stages.

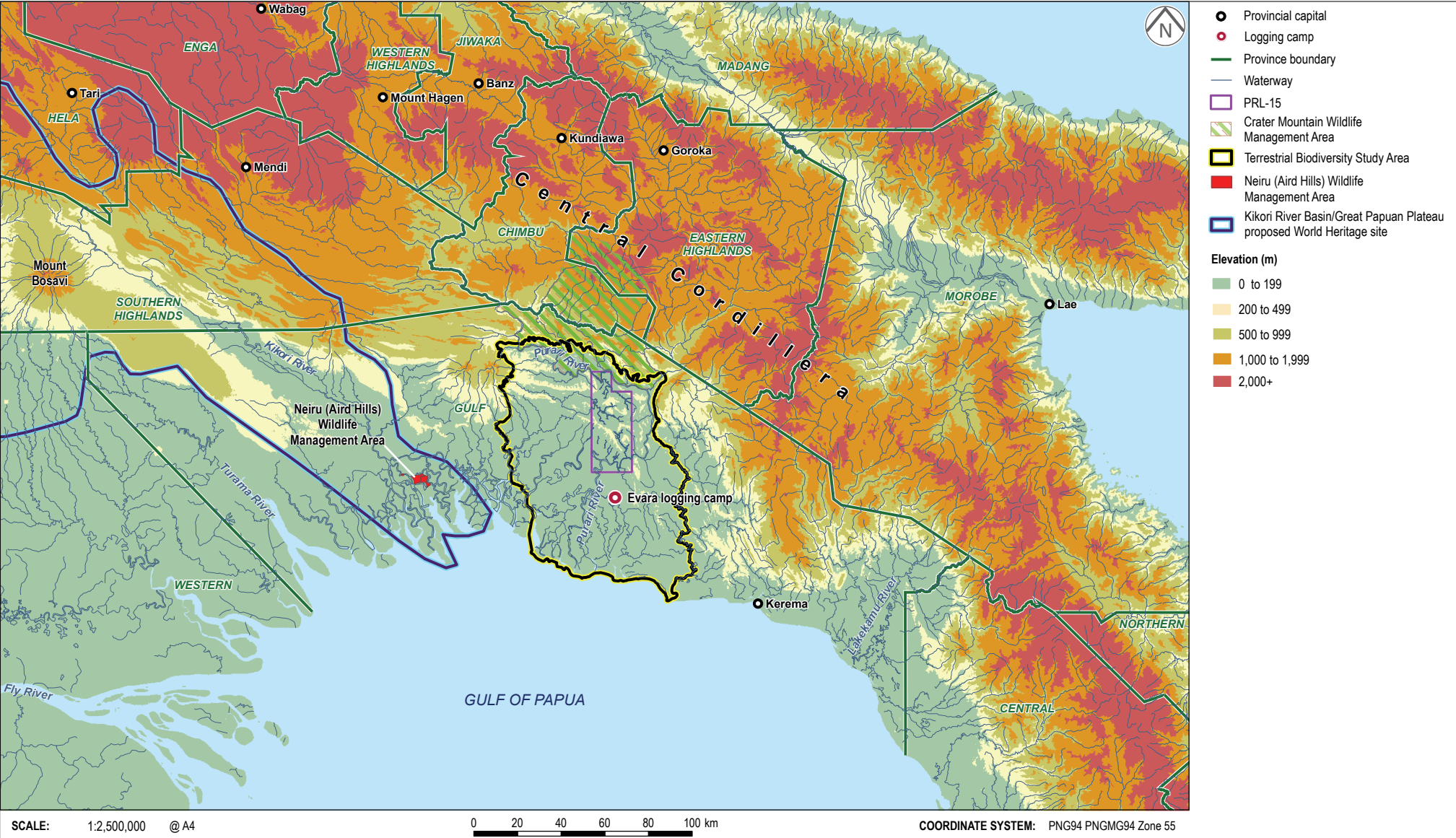
Table 7.9 – Protected Areas and Proposed World Heritage Sites Relevant to the Study Area

Name	Location/Description	Study Area Locality
Crater Mountain Wildlife Management Area (WMA)	Comprises approximately 2,700 km ² of northern central Gulf Province and parts of Chimbu Province and Eastern Highlands Province to elevations over 3,100 m asl.	Northern extremity of the study area overlaps the southern portion of this WMA.
Neiru (Aird Hills) WMA	Covers approximately 25 km ² of the Kikori River catchment lowlands, located west of the study area within 50 km of its southwestern boundary.	No overlap with the study area.
Kikori River Basin/Great Papuan Plateau proposed World Heritage site	Covers more than 20,000 km ² and over 6% of PNG's land mass. The site extends more than 300 km northwest from the Purari River delta to encompass Mount Bosavi, the Great Papuan Plateau and parts of the Southern Fold Mountains. Its southeastern boundary lies approximately 15 km from the study area at its closest point in the Purari River delta.	No overlap with the study area.

REGIONAL SETTING OF THE TERRESTRIAL BIODIVERSITY STUDY AREA

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FIGURE 7.18



7.7.5 Vegetation

7.7.5.1 Approach

The following sections describe vegetation communities present in the study area. Natural vegetation types are first described (Section 7.7.5.2), followed by overlying patterns of anthropogenic disturbance within the study area (Section 7.7.5.3) and description of the vegetation types and condition present in key Project areas (Section 7.7.5.4).

The classification of natural vegetation types is based on the Forest Inventory Mapping System (FIMS) dataset (Hammermaster & Saunders, 1995a, 1995b). The FIMS vegetation maps were revised to improve resolution and accuracy in key Project component areas in the PAOI and along the coastal boundary of the study area through examination of recent aerial or satellite imagery, LIDAR digital elevation modeling, and ground and aerial surveys. Outside of these areas, vegetation mapping at the FIMS scale was accepted as reasonable; and no further refinement was undertaken.

Two types of anthropogenic disturbance to natural vegetation are distinguished:

- ♦ Degradation – degraded vegetation retains a natural species composition, although altered in structure or proportional floristic composition. It has been mapped in this study as natural vegetation and includes areas of post-logging secondary forest.
- ♦ Loss – habitat loss results from the removal of natural vegetation or its replacement with predominantly non-native plant communities, including gardens and agroforestry. Vegetation loss is recorded here in two ways:
 - 1 As converted land under the Land use (O) and Urban areas (U) FIMS types.
 - 2 In areas of vegetation loss that are too small to be mapped at the FIMS scale, as numeric disturbance codes appended to the vegetation mapping units: from 4 (40% intact) to 9 (90% intact). Disturbance codes are displayed in the detailed vegetation maps shown in Figures 7.19 and 7.20. The vegetation types associated with the FIMS codes are shown in Table 7.10.

Recent vegetation losses, additional to those mapped under FIMS (original and revised) as converted lands, were identified based on areas of non-vegetation mapped as roads and bare ground under the Upstream Deforestation Baseline Report (Part 7 of Volume 2).

Overlay maps of post-logging secondary forest were prepared by combining harvested areas mapped under the Upstream Deforestation Baseline Report (Part 7 of Volume 2) and areas of secondary forest digitized from the PNG Forest Observatory website (& Shearman, 2015b). Logged areas in PRL-15 and the export pipeline corridor were verified and adjusted as required, based on visual assessment of aerial or satellite imagery and ground-truthing from flora and fauna surveys.

7.7.5.2 Vegetation Types

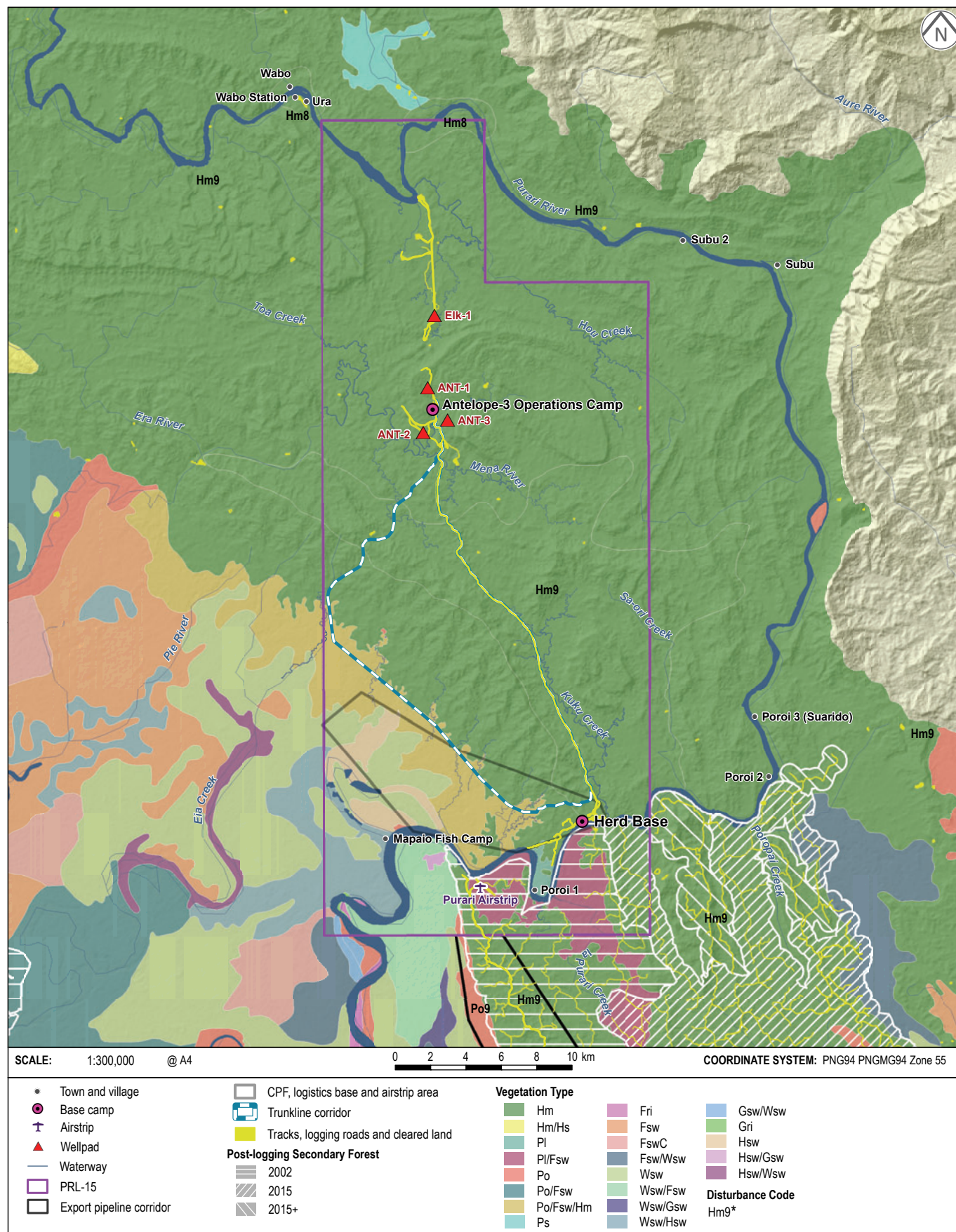
The study area land surface is covered almost entirely in natural vegetation (98.9%), including primary and secondary forest types. Five broad vegetation groups (BVGs) are identified within the study area, based on vegetation structure and floristics and on landform affiliations (following Pajmans (1976) and Hammermaster & Saunders (1995a)): hill forest, alluvial forest, freshwater swamp vegetation, mangroves and littoral forest. In the study area, landform, topography and geology are the principal determinants of vegetation community structure;¹⁹ and as a result, these

¹⁹ Climate and elevation have limited effect at the study area scale.

VEGETATION AND ANTHROPOGENIC DISTURBANCE IN THE PRL-15 AREA

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FIGURE 7.19

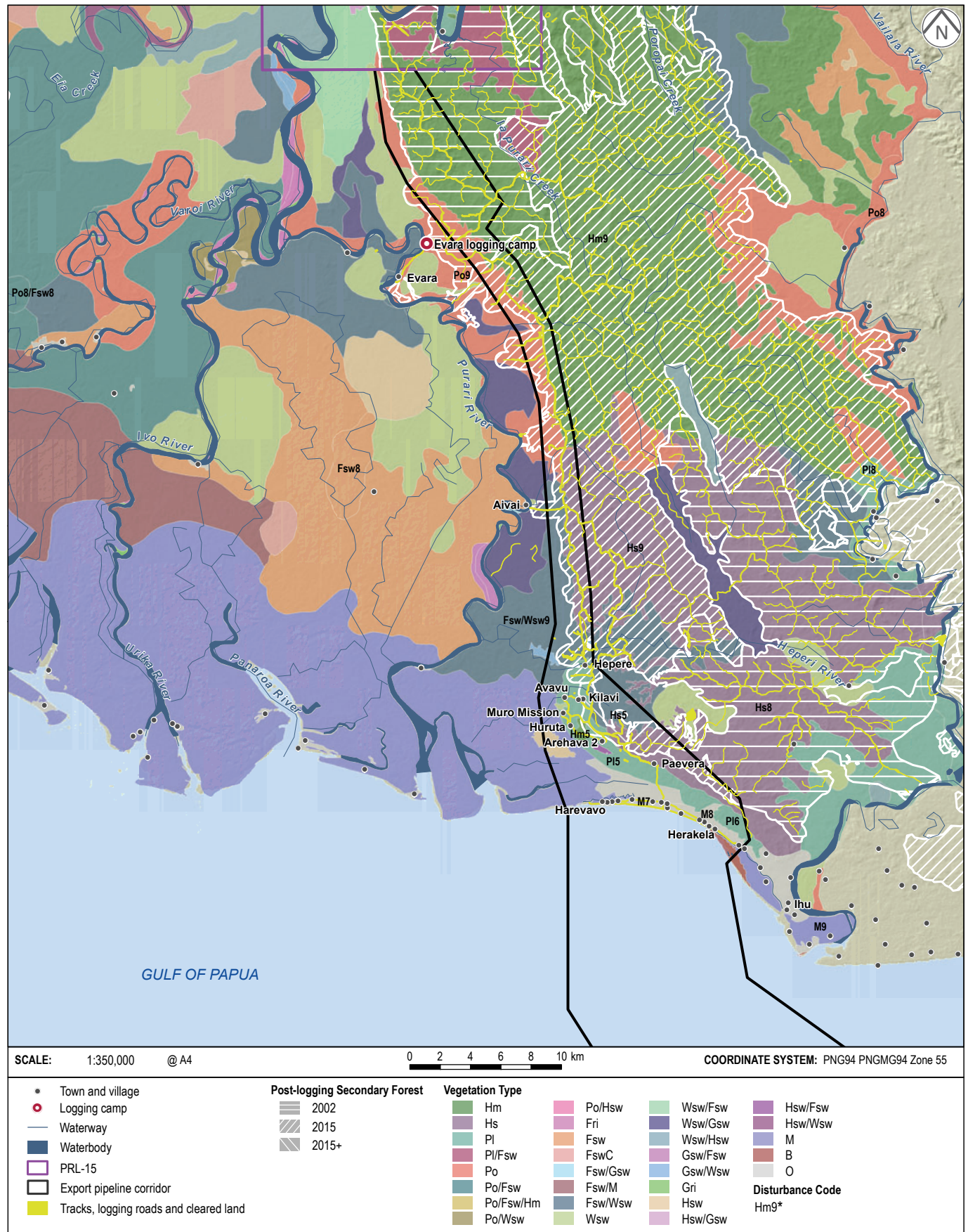


* A numeric disturbance code is appended to the vegetation mapping unit. The higher the code, the more intact the vegetation (e.g., 4 = 40% intact). Where there is no code, the vegetation can be assumed to have little disturbance (more than 90% intact).

VEGETATION AND ANTHROPOGENIC DISTURBANCE IN THE EXPORT PIPELINE CORRIDOR AND RIVER TRANSPORT ROUTE AREAS

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FIGURE 7.20



Communities outside of the Project area of influence have not been verified. Only government administrative centers and notable locations have been labeled for context.

* A numeric disturbance code is appended to the vegetation mapping unit. The higher the code, the more intact the vegetation (e.g., 4 = 40% intact).
Where there is no code, the vegetation can be assumed to have little disturbance (more than 90% intact).

BVGs each occupy a distinct physical environment, linked to the ecological zones, which are also defined principally according to landform and vegetation (see Section 7.7.3). The BVGs are summarized in the following points and shown in Figure 7.21, and their proportions in the study area and each ecological zone are shown in Figure 7.22:

- ♦ Hill forest – this BVG is the natural vegetation type occurring on all areas of hill terrain in the study area, which are predominantly uplifted landforms of the Middle Purari Hills and Southeast Hills ecological zones. It is the most widespread BVG, covering more than 3,400 km² and 48.7% of the study area land surface in its various forms. Hill forest is floristically rich, and its structure varies with terrain and substrate. Relatively fertile and stable soils in the study area support forest 25 to 30 m tall with emergent trees to 40 m. On low nutrient or unstable, shallow soils the hill forest reaches 20 to 30 m tall with fewer emergents.
- ♦ Alluvial forest – occurs on recent depositional landforms in areas well drained or subject to periodic inundation, on the Delta Swamps and Plains, and also in the Southeast Hills and the Southeast Coast ecological zones. Alluvial forest often occurs as a dominant type (50% to 80% of the mapping unit) in complexes with other BVGs, most commonly freshwater swamp vegetation types. In its various forms, including complexes, it covers more than 1,160 km² (16.6%) of the study area. It is tall and floristically rich. Forest structure is variable, with drainage and soils among the dominant abiotic factors. Canopies are often open with numerous gaps and with a dense understory rich in saplings, palms, pandanus, gingers, lianes and epiphytes.
- ♦ Freshwater swamp vegetation – this is the second most widespread BVG within the study area, covering nearly 1,800 km² and 25.6% of its land surface in its various forms. It occurs in areas subject to frequent or permanent flooding. It is most widespread on the composite levee plains of the Delta Swamps and Plains and interior margins of the Mangroves ecological zones, predominantly on the poorly drained back plains spanning the vast interfluvial areas behind riverine levee banks, with other major occurrences in the Purari River and Vailala River catchments in the Southeast Hills and, to a lesser extent, the Southeast Coast ecological zones.

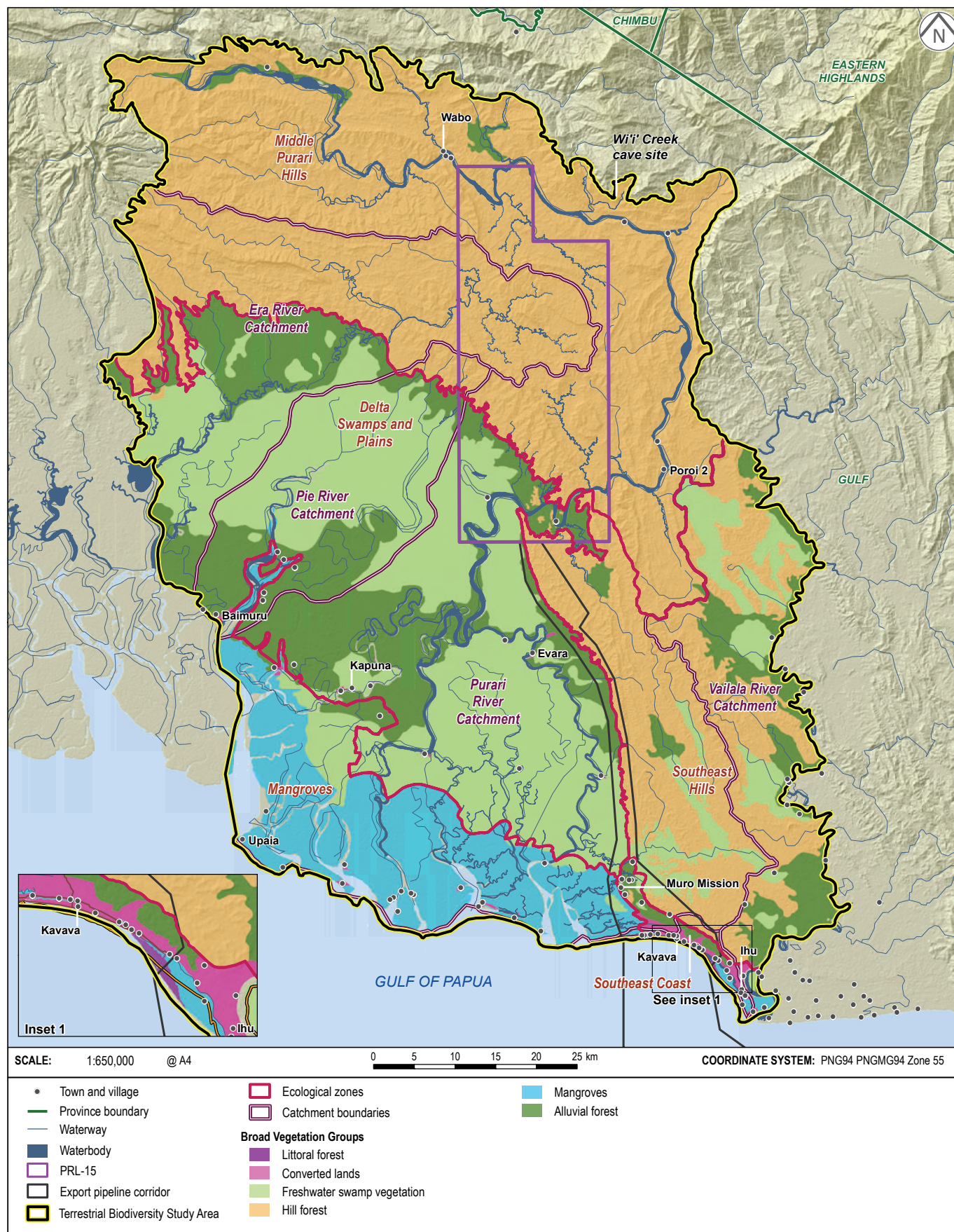
Freshwater swamp vegetation within the study area encompasses five distinct base vegetation types, each occupying a discrete environment defined by variation in the depth, movement or periodicity of inundation. These grade into one another and into adjacent alluvial forest and mangrove vegetation through a variety of complex forms, as relatively minor changes in topography influence local hydrological and overlying vegetation patterns in a low relief environment.

- ♦ Mangroves – the mangrove ecosystem (mangal) is a community of salt-tolerant plant species growing in coastal, estuarine and riverine areas that are subject to periodic tidal inundation and protected from heavy wave action (Giri et al., 2011). Plant diversity in mangrove forest is low compared to non-saline lowland rainforest ecosystems. Mangroves cover 603.6 km² of the study area, 97.9% of which occur within the Mangroves ecological zone, with minor occurrences in the Southeast Coast (11.6 km²) and the Delta Swamps and Plains (1.1 km²) ecological zones.

BROAD VEGETATION GROUPS OF THE STUDY AREA

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FIGURE 7.21



Largely represents the terrestrial biodiversity baseline survey area.

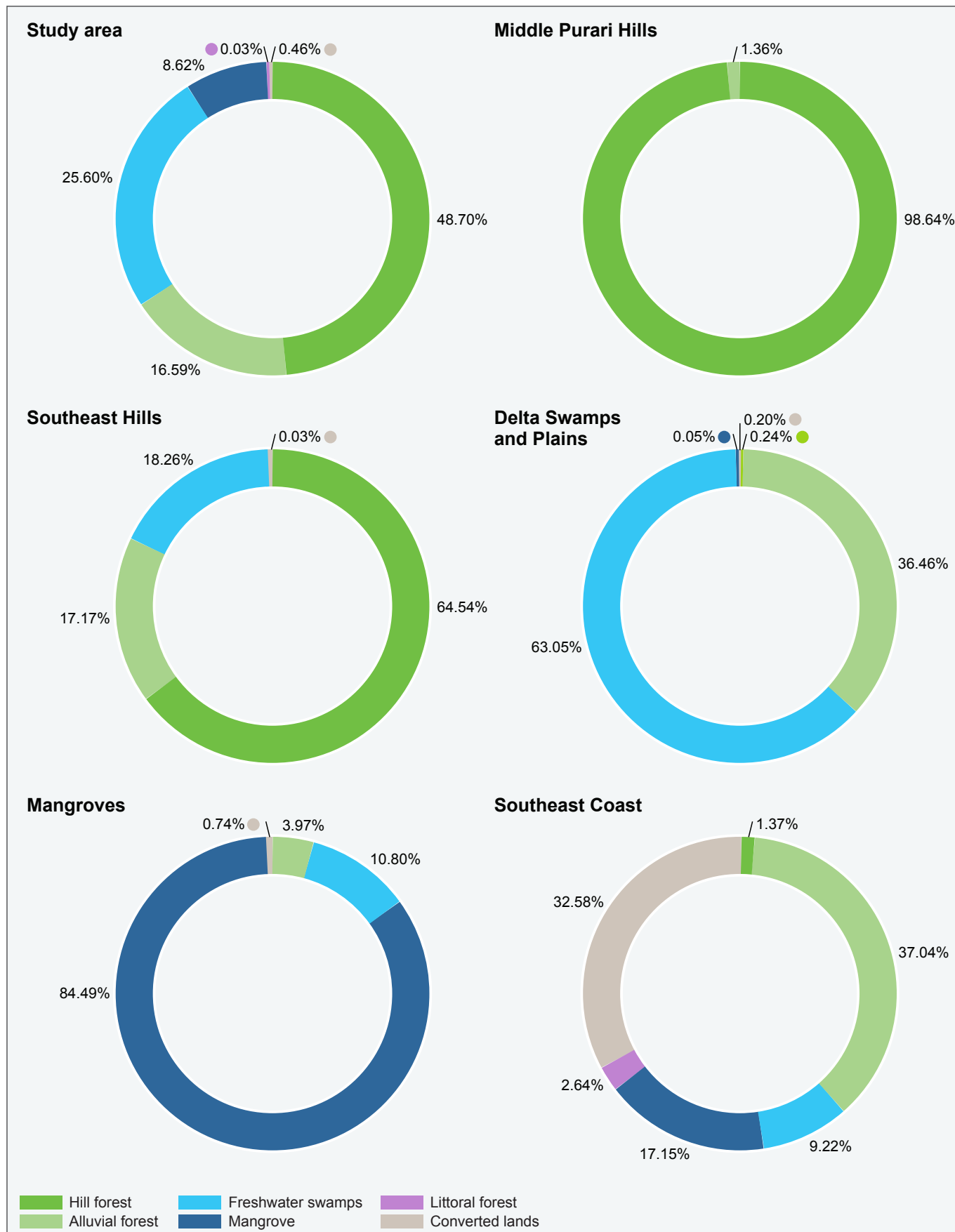
Communities outside of the Project area of influence have not been verified. Only government administrative centers and notable locations have been labeled for context.

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PROPORTION OF BROAD VEGETATION GROUPS AND CONVERTED LANDS IN THE STUDY AREA AND ECOLOGICAL ZONES

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FIGURE 7.22



- ♦ Littoral forest – this vegetation grows on dry sandy beach ridges and plains and comprises a succession of vegetation types. The only mapped occurrences of this BVG in the study area are found in 1.8 km² of coastal habitats (e.g., beach ridges and plains) in the Southeast Coast ecological zone.

Within these environments, further variations in terrain, soils, flooding and tidal regimes influence the distribution, structure and floristics of the component natural vegetation types. At this level, 32 FIMS-coded natural vegetation types are recognized within the five BVGs, plus two land cover types denoting areas where the original vegetation has been converted for anthropogenic land use (converted lands) (Table 7.10; Figure 7.23).

Table 7.10 – Vegetation Types Within the Study Area and Each Project Component Area

Broad Vegetation Group/ Vegetation Type	FIMS Code	Study Area		Project Component Area		
		Area (km²)	Cover (%)	PRL-15*	Export Pipeline Corridor	Riverways
Hill forest BVG		3,409.79	48.70			
Hill forest	Hm	3,013.61	43.04	X	X	–
Hill forest, <i>Araucaria</i> noted	Hm.Ar	19.24	0.27	–	–	–
Small crowned hill forest	Hs	321.08	4.59	–	X	–
Hill forest/Small crowned hill forest	Hm/Hs	55.86	0.80	–	–	–
Alluvial forest BVG		1,161.94	16.59			
Alluvial forest	PI	113.05	1.61	X	X	
Alluvial forest/Swamp forest	PI/Fsw	35.40	0.51	X		
Open alluvial forest	Po	334.46	4.78	X	X	X
Open alluvial forest/Swamp forest	Po/Fsw	441.24	6.30	–	–	X
Open alluvial forest/Swamp forest/Hill forest	Po/Fsw/Hm	78.77	1.12	X	–	–
Open alluvial forest/Swamp forest/Mangrove	Po/Fsw/M	101.38	1.45	–	–	–
Open alluvial forest/Herbaceous swamp	Po/Hsw	0.85	0.01	–	–	X
Open alluvial forest/Swamp woodland	Po/Wsw	8.64	0.12	–	–	X
Small crowned alluvial forest	Ps	39.61	0.57	–	–	–
Riverine seral forest	Fri	8.54	0.12	X	–	X
Freshwater swamp vegetation BVG		1,792.43	25.60			
Swamp forest	Fsw	642.83	9.18	–	–	X
Swamp forest with <i>Campnosperma</i>	FswC	89.10	1.27	X	–	–
Swamp forest/Swamp grassland	Fsw/Gsw	0.33	0.01	–	–	X
Swamp forest/Mangrove	Fsw/M	121.75	1.74	–	–	X
Swamp forest/Swamp woodland	Fsw/Wsw	260.60	3.72	X	X	X
Swamp woodland	Wsw	423.07	6.04	X	X	X
Swamp woodland/Swamp forest	Wsw/Fsw	34.57	0.49	X	–	X
Swamp woodland/Swamp grassland	Wsw/Gsw	67.20	0.96	X	X	X

Table 7.10 – Vegetation Types Within the Study Area and Each Project Component Area (cont'd)

Broad Vegetation Group/ Vegetation Type	FIMS Code	Study Area		Project Component Area		
		Area (km²)	Cover (%)	PRL-15*	Export Pipeline Corridor	Riverways
Freshwater swamp vegetation BVG		1,792.43	25.60			
Swamp woodland/Herbaceous swamp	Wsw/Hsw	77.83	1.11	X	–	–
Swamp grassland/Swamp forest	Gsw/Fsw	3.38	0.05	–	–	X
Swamp grassland/Swamp woodland	Gsw/Wsw	3.82	0.06	X	X	–
Riverine successional grassland	Gri	2.05	0.03	X	–	X
Herbaceous swamp	Hsw	47.67	0.68	X	X	X
Herbaceous swamp/Swamp grassland	Hsw/Gsw	0.75	0.01	X	–	–
Herbaceous swamp/Swamp forest	Hsw/Fsw	0.53	0.01	–	X	–
Herbaceous swamp/Swamp woodland	Hsw/Wsw	16.95	0.24	–	–	–
Mangroves BVG		603.63	8.62			
Mangrove	M	603.63	8.62	–	X	X
Littoral forest BVG		1.78	0.03			
Littoral forest	B	1.78	0.03		X	
Converted lands		32.17	0.46			
Land use	O	30.07	0.43	–	X	X
Urban areas	U	2.10	0.03			
Other losses[#]	<i>n/a</i>	44.23	0.63			
Total Land Area		7,001.74	100.00			
Total Natural Vegetation Cover		6,924.99	98.90			

* PRL-15 is used here to represent the area of production, processing and related facilities.

[#] Areas of non-vegetation mapped as roads and bare ground under the Upstream Deforestation Baseline Report (Part 7 of Volume 2). Mapped separately from the vegetation mapping, they are subtracted independently from the total natural vegetation cover, but not the total land area, to calculate the proportion of the study area supporting natural vegetation.

7.7.5.3 Anthropogenic Disturbance

Habitat Loss

Mapped areas of habitat loss amount to approximately 1.1% of the study area land surface. Approximately 32 km² of converted lands are identified as Land use (O) and Urban areas (U) (see Table 7.10) and primarily occur along the relatively settled coastal strip of the Southeast Coast ecological zone, with some additional areas around villages along the coast in the Mangroves ecological zone and along major waterways on the Delta Swamps and Plains ecological zone. An additional 44.2 km² of cleared land was recorded under the deforestation study (Part 7 of Volume 2) and 96% is attributed to clearance for logging roads and associated infrastructure, with additional minor contributions associated with subsistence agriculture (1.9%) and petroleum sector activities (1.5%), the latter mostly within PRL-15.

Between 2000 and 2014, approximately 3,139 ha (0.72%) of forest area were lost from the deforestation study area, which is within the eastern 63% of the study area. Rates of forest loss were faster between 2000 and 2007 than between 2007 and 2014 (Table 7.11). The greater forest

losses between 2000 and 2007 were shown to relate to the development of logging tracks and infrastructure in the lower and more accessible terrains of Vailala Block (Blk) 3 at the south and east ends of the export pipeline corridor. Fewer roads and less infrastructure appeared to be developed in the northeast portion of the block between 2007 and 2014.

Table 7.11 – 2000 to 2014 Land Use and Change

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

Degradation Through Commercial Forestry

Commercial forestry is the largest industrial land use activity to have operated within the study area. Seven logging concessions overlap more than 75% of the study area (Figure 7.24), of which percentage approximately 70% is considered commercially viable production forest. Four concessions are currently licensed, two of which are presently active (i.e., Vailala Blk 3 and East Kikori). To date, approximately 1,300 km² of forest have been logged in the study area, nearly one quarter of the total area under concession.

Hill forest and alluvial forest are the main production forest types. Approximately 1,125 km² of these forest types have been logged, including most of the forest in the Southeast Hills ecological zone and parts of the Middle Purari Hills and Delta Swamps and Plains ecological zones (see Figure 7.24). In Project component areas, around 50 km² of forest have been harvested in the southeast corner of PRL-15 and approximately 116 km² along nearly the entire length of the export pipeline corridor (see Figure 7.24 and Plate 7.19). The regenerating forest is variable in age, with some logging occurring prior to 2002 (e.g., areas within the export pipeline corridor north of the active Evara logging camp) and other areas logged within the last two to three years (e.g., in the northeast, between Poroi 1 and Poroi 2 villages (see Figure 7.19), and in the southeast between Kilavi and Arehava 2 villages (see Figure 7.20)).

The majority of the unlogged hill and alluvial forest occurs within the Middle Purari Hills or in the Delta Swamps and Plains ecological zones, respectively.

Plate 7.19 – Commercial Logging Activities in the Export Pipeline Corridor

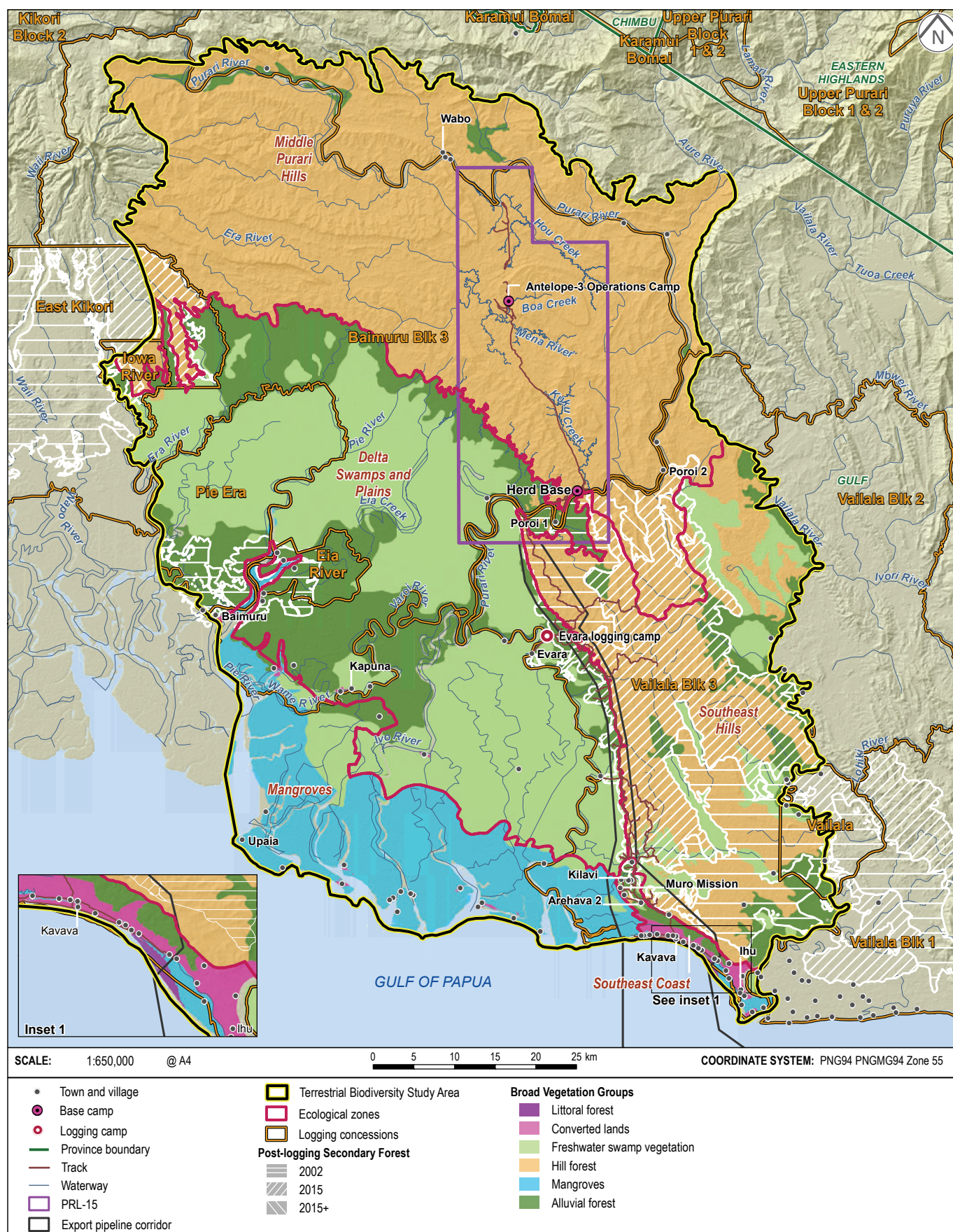


Photo: ERIAS Group.

LOGGING CONCESSIONS AND POST-LOGGING SECONDARY FOREST WITHIN BROAD VEGETATION GROUPS

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FIGURE 7.24



Communities outside of the Project area of influence have not been verified. Only government administrative centers and notable locations have been labeled for context.

In addition to forestry concessions, Special Agricultural and Business Leases (SABLS) provide a mechanism for converting forest to agricultural land use. See also Section 9.8.3 for a discussion on SABLS under land tenure.

Local Resource Extraction

Small-scale timber harvesting is practiced throughout Papua New Guinea to meet local community requirements, including raw material for houses, fencing, canoes and firewood. Of the forests observed during biodiversity baseline surveys, those most affected by local timber extraction are the alluvial forests in the settled Southeast Coast ecological zone. Amid widespread land conversion in this area, patches of remnant alluvial forest are retained by local landowners, sometimes to the exclusion of industrial logging interests, to provide a continuing supply of natural resources.

The commercially valuable non-timber forest product eaglewood (*Gyrinops caudata* and *Aquilaria filaria*) is present in the study area and was recorded in logged hill forest at terrestrial biodiversity Site 3), although, there is no evidence of local harvesting of this product.

7.7.5.4 Vegetation Condition in the Project Component Areas

The total calculated area of habitat loss is an underestimate of the actual amount of natural vegetation that has been removed from within the study area. In many instances this is because converted land occurs in mosaic form with areas of natural vegetation or because of the deficiencies in remote sensing methods. In these areas, the presence of habitat loss is registered in a numeric disturbance code²⁰ (see Figures 7.19 and 7.20).

For the study area, disturbance codes were revised where the existing FIMS codes under-represented the percentage of canopy disturbance visible from LIDAR imagery and aerial survey. This was mostly applied to areas subjected to logging, particularly in hill forest areas throughout the export pipeline corridor, and to areas of increased subsistence agriculture activities toward the coast. The disturbance codes that were applied to logging areas were based on observations of canopy disturbance from the LIDAR imagery and aerial survey, but the same codes were applied to forest where roads were present in otherwise intact forest such as PRL-15. Thus, the disturbance codes do not necessarily reflect the level of disturbance to the internal forest structure and ground, which are likely to show higher levels of disturbance compared to canopy disturbance because of the relatively rapid canopy closure that occurs within 10 years after logging. The information in Figures 7.19 and 7.20 exemplifies this situation; both show a disturbance code of 9 for the undisturbed forest in PRL-15 and also for heavily logged forest south of the Purari River in Vailala Blk 3. This is because the logged forests in Vailala Blk 3 retain a reasonably intact canopy that conceals the heavily disturbed understory. Table 7.10 describes the vegetation types shown in Figures 7.19 and 7.20.

Production, Processing and Related Facilities

Most of the Hill forest (Hm) in PRL-15 remains in its natural state (Plate 7.20). The forests north of the Purari River have not been commercially logged; and while Pawaian residents pass through

²⁰ Forest condition is inherent in the FIMS disturbance codes, which reflect the overall level of forest canopy disturbance for a polygon. Where forest remains but has been subjected to anthropogenic disturbance, a disturbance code is provided from 1 to 9 where 9 indicates 90% of the canopy is intact. The degree of disturbance is defined in four categories:

- Slight disturbance 8 to 9 (for this study, it includes the presence of roads through otherwise intact forest).
- Moderate disturbance 6 to 7.
- Heavy disturbance 4 to 5.
- Very heavy disturbance greater than 4.

the area, anthropogenic disturbance is low and the forests do not support villages. Most forest loss or degradation in the area is attributable to earlier Project exploration phases through the construction and operation of roads or tracks, wellpads and isolated camp facilities. As a result (as explained earlier), the disturbance code 9 is applied to the vegetation type (i.e., Hm9) (see Figure 7.19 and Plate 7.20).

In the southwest portion of PRL-15, south of the large areas of Hill forest (Hm), is a northwest to southeast complex of Open alluvial forest/Swamp forest/Hill forest (Po/Fsw/Hm) that covers the central parts of the CPF, logistics base and airstrip area. Further southwest, freshwater swamp vegetation and associated complexes occur, including around the PRL-15 oxbow wetlands north of the Purari River (Plate 7.21). These extend north to meet the Po/Fsw/Hm complex and cover the western half of the CPF, logistics base and airstrip area (see Figure 7.19).

Plate 7.20 – Well-structured Hill Forest (Hm) on Aure Bed Sediments of the Mena Basin in PRL-15



Photo: Iain Woxvold.

Plate 7.21 – Freshwater Swamp Vegetation Around the PRL-15 Oxbow Wetlands



Photo: Iain Woxvold.

A small area of unlogged Alluvial forest (PI) is present in PRL-15 on the northern bank of the Purari River around Poroi 1 village. While the canopy is largely intact, some conversion and resource harvesting is expected from the local residents.

In contrast, south of the Purari River in the Vailala Blk 3 logging concession, almost all of the Alluvial forest/Swamp forest (PI/Fsw) complex and most of the Hill forest (Hm) has been intensively logged.

Onshore Export Pipeline Corridor

Lying within the Vailala Blk 3 concession, much of the Hill forest (Hm) and Alluvial forest (PI) in the export pipeline corridor and surrounding areas to the east have been subjected to intensive logging (see Figures 7.19 and 7.20).

In the areas of Hill forest (Hm) in the export pipeline corridor, secondary forest dominates with only small areas of primary forest remaining along some drainage lines and in areas of steep terrain unsuitable for logging (Plate 7.22). In addition, almost all of the Small crowned hill forest (Hs) has been intensively logged, including most of that in the export pipeline corridor (see Figures 7.19 and 7.20), with only remnant pockets of primary forest remaining (Plate 7.23).

Plate 7.22 – Logged Hill Forest (Hm)

Photo: Iain Woxvold.

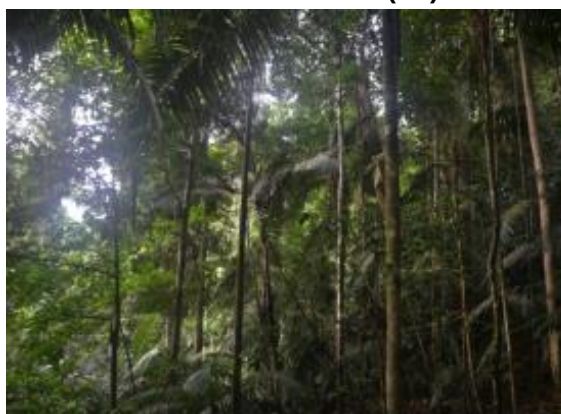
Plate 7.23 – Remnant Primary Small Crowned Hill Forest (Hs)

Photo: Iain Woxvold.

Open alluvial forest (Po) occurs in the northern half of the export pipeline corridor, along approximately 30 km of the eastern rim of the Delta Swamps and Plains ecological zone. All accessible areas of merchantable forest appear to have been logged; however, examples of primary Open alluvial forest (Po) were present away from logging roads (Plate 7.24).

In the southern half of the export pipeline corridor (see Figure 7.20), Swamp forest/Swamp woodland (Fsw/Wsw) (Plate 7.25) extends south from near Aivai village for approximately 16 km to the northern part of the populated Southeast Coast ecological zone, along with areas extending further east of Hepere village. Much of this area is mapped as logged; and although Swamp forest (Fsw) is not considered a commercial production forest type, typical communities do include desirable timber species. In addition, sago, in the Swamp woodland (Wsw) component of the complex, has no commercial value as a timber species; and any extensive stands are likely to remain intact.

Plate 7.24 – Interior of Unlogged Open Alluvial Forest (Po)

Photo: Iain Woxvold.

Plate 7.25 – Interior of Sago Swamp Woodland (Wsw)

Photo: Iain Woxvold.

At the local scale, sago present near villages is often harvested by landowners; and coastal areas mapped as Land use (O) in the export pipeline corridor support linear, subparallel sago swamps occupying the poorly drained swales between relict parallel beach ridges behind the populated coastal front.

Where accessible, Alluvial forest (PI) is among the first forest types to be harvested by commercial logging operations. The largest local occurrences in the lower Vailala River catchment (Southeast Hills ecological zone) east of the export pipeline corridor have mostly been

logged (see Figure 7.20). In settled areas of the southern section of the export pipeline corridor (interior plains of the Southeast Coast ecological zone), much of the loss or degradation of the Alluvial forest (PI) is associated with conversion for shifting agriculture, agroforestry or village developments, which is reflected in a high disturbance code of 5 applied to the vegetation type (i.e., PI5) (Plate 7.26; see Figure 7.20). Conversions are most prevalent north of this area between Hepere and Paevera villages, with some of the remaining forest heavily logged in recent years. Some forest patches in this area have been retained by local landowners to provide a continuing supply of forest resources; however, remnant forest canopies are fragmented, uneven and varied in height.

Southeast of Paevera village, in the eastern half of the export pipeline corridor coastal approach, the Alluvial forest (PI) is in better condition, despite the presence of garden developments and resource harvesting. The mapped occurrences of Littoral forest (B) are also in the southeast (Plate 7.27).

Plate 7.26 – Garden Development in Alluvial Forest (PI) in Hinterland of Orokolo Bay



Photo: Iain Woxvold.

Plate 7.27 – Littoral Beach Vegetation on Accreting Sand Dunes (Foreground)



Photo: Iain Woxvold.

Largely undisturbed Mangrove (M) vegetation is present in the southwestern section of the export pipeline corridor (Plate 7.28 and Plate 7.29). Although areas of Land use (O) associated with permanent settlements are mapped along the coast, natural resources are harvested from adjacent forest areas, and gardens are planted in some areas of mangrove forest, the vast scale of the mangrove ecosystem in this deltaic zone means that these disturbances do not register as a FIMS disturbance code. The smaller areas of Mangroves (M) that line the creeks in the heavily settled Southeast Coast ecological zone are more disturbed (M7), as in these areas' settlements are more widespread and the mangrove vegetation more limited. To the far southeast of the corridor, the larger Mangrove (M) areas are in better condition and have been assigned a disturbance code of 9 (M9) (see Figure 7.20).

**Plate 7.28 – Mangrove (M) Zonation Patterns:
Parallel to Estuary Front at Right
Foreground, Mosaic Interior in the
Background**



Photo: Iain Woxvold.

**Plate 7.29 – Fringing Mangrove
Backed by Nipa Palm**



Photo: Iain Woxvold.

Riverways

Along the riverways, including the river transport corridor, downstream of PRL-15, alluvial and freshwater swamp vegetation types (including complexes) (Plate 7.30 and Plate 7.31) line much of the Purari River and its distributaries upstream of the Mangroves ecological zone (see Figure 7.20). These areas are sparsely populated; and apart from a few localized sites where logging of Open alluvial forest (Po) is mapped along the eastern banks of the Purari River distributary channel between Evara and Aivai villages, the vegetation types present remain effectively intact and no disturbance codes are applied.

**Plate 7.30 – Swamp Woodland/Swamp
Grassland (Wsw/Gsw) Complex**



Photo: Iain Woxvold.

**Plate 7.31 – Swamp Forest (Fsw), West
of the Purari River Distributary Channel**



Photo: Iain Woxvold.

7.7.6 Flora and Fauna

7.7.6.1 Overview

A total of 1,272 terrestrial plant and animal species was recorded (Table 7.12) during the 2016 biodiversity baseline surveys. This section provides an overview of surveyed faunal communities.

Table 7.12 – Number of Species Recorded in the Study Area

	Taxonomic Group						
	Flora	Non-volant mammals	Bats	Birds	Reptiles	Frogs	Odonates
Site 1	348	12	26	90	19	32	46
Site 2	282	7	23	81	22	26	27
Site 3	200	10	25	102	22	26	30
Site 4	318	16	23	106	21	25	31
Site 5	323	12	23	109	18	18	44
Site 6A	179	5	11	62	4	3	21
Site 6B	163	–	–	39	4	0	4
Site 6C	–	–	–	11	1	–	–
Site 6D	146	–	–	32	5	3	6
Site 7	301	13	24	113	18	24	44
Site 8	267	14	25	96	21	17	28
Site 8M	21	3	15	39	1	0	0
Site 9	294	14	21	92	15	13	30
Wi'i Ck Cave	–	23	2	–	–	–	–
Totals*	812	42	39	183 (214)	57(70)	42(49)	97

* Totals for all taxa show the number of species recorded during the 2016 Project surveys. In addition to species recorded at survey sites, information from informal records included: five species of non-volant mammals confirmed present from Middle Purari Hills based on local landowner information, plus one invasive rodent species observed only at Herd Base; three additional bird species seen only at Herd Base or the Purari airstrip. Totals shown in brackets for birds, reptiles and frogs include combined data from the Project and prior surveys. Prior surveys yielded no additional species for other taxonomic groups.

Non-volant Mammals

The study area supports populations of at least 42 non-volant mammal species representing three major taxonomic groups: monotremes (1 species), marsupials (19 species) and placental mammals (22 species). The marsupial fauna is dominated by herbivores from six families: bandicoots (Paramelidae), tree kangaroos and wallabies (Macropodidae), and possums, gliders and cuscuses (Acrobatidae, Petauridae, Pseudocheiridae and Phalangeridae). Four marsupial carnivores (Dasyuridae) were also confirmed present. Placental mammals include 20 species of rodent (Muridae), the dog (*Canis familiaris*) and pig (*Sus scrofa*). All terrestrial non-volant mammals are breeding residents (non-migratory), and six are invasive alien species (see Section 7.7.6.6) either not native to New Guinea (five species) or introduced from other parts of New Guinea (one species).

Forest environments support the highest non-volant mammal diversity, providing habitat for all native terrestrial species. Two habitat-specialist aquatic rodents rely on watercourses, often within forest environments: the water rat (*Hydromys cf. chrysogaster*) and the new-to-science small water rat (*Hydromys* sp. 1).

Bats

Thirty-nine bat species were recorded in the study area. The bat community is divisible into two major groups based on feeding strategy; fruit bats (family Pteropodidae, 11 species) and insectivorous bats (6 families, 28 species). The latter group use ultrasonic echolocation calls to detect their prey. The food resources of most bat species are distributed widely across the study area, both in intact forest environments and, for a variety of species, in open and disturbed habitats. Roosting behaviours vary; some species roost singly or in small groups while others form aggregations of hundreds or even thousands of individuals. Some species shelter beneath foliage or in tree hollows, while others rely on caves and other rocky habitats. Compared to arboreal roost sites, cave roosts are a relatively restricted resource in the study area landscape.

Birds

A total of 214 bird species has been recorded in the study area, including 183 species recorded during Project surveys.

The study area's forest environments support the highest diversity of bird species. Species richness is highest in hill and alluvial forest, and mangrove forest is notable for supporting a suite of habitat-specialist and near specialist avian taxa. Resident frugivores make up a high proportion of the study area's forest bird community. Compared to other tropical regions, New Guinea's avifauna includes a high proportion of frugivorous species (Pearson, 1977; Mack & Dumbacher, 2007), such as cassowaries (Casuariidae), pigeons and doves (Columbidae), a variety of parrots (Psittacidae), Blyth's hornbill (*Rhyticeros plicatus*) (Bucerotidae), flowerpeckers (Dicaeidae), starlings and mynas (Sturnidae) and most birds-of-paradise (Paradisaeidae) (Coates, 1985, 1990). Other important forest-dwelling guilds include nectarivores and insectivores. Most forest bird species reside permanently in New Guinea.

Birds of open and disturbed terrestrial environments comprise mostly resident species that also occupy intact forest, non-breeding migrants from Australia and the invasive alien Eurasian tree sparrow (*Passer montanus*). New Guinea includes relatively few resident land birds that are exclusively associated with open and disturbed habitats (Bowman et al., 1990).

Wetland bird species occurring in the study area include a variety of resident and migratory taxa. Focal habitat for these species includes tidal wetlands (e.g., tidal flats, lagoons and estuaries) in coastal and subcoastal zones and off-river waterbodies (including oxbow lakes) in freshwater environments.

Herpetofauna

Ninety-nine herpetofauna species were recorded during Project surveys, including 42 frogs and 57 reptiles.

Native frogs represent four taxonomic families, the most diverse being the Microhylidae with 22 recorded species. A fifth family, the Bufonidae, is represented by the invasive alien cane toad (*Rhinella marina*). New Guinean microhylids have a reproductive cycle that is independent of free-standing water; they lay eggs in trees or on or under the ground where their embryos develop directly into small frogs, bypassing the tadpole stage. All other frog groups occurring in southern mainland Papua New Guinea require free-standing water (e.g., watercourses or forest pools) to breed.

The reptile fauna includes 35 lizard species (4 families), 16 snakes (5 families), 2 crocodiles (Crocodylidae) and 4 turtles (3 families). Skinks (Scincidae, 21 species) were the most species-rich family, with geckos (Gekkonidae, 9 species) and colubrid snakes (Colubridae, 8 species) the next most diverse. Forest environments support most lizard and snake species, including two

dangerously venomous snakes: the death adder (*Acanthophis laevis*) and the New Guinea small-eyed snake (*Micropechis ikaheka*). All crocodile and turtle species depend on marine or freshwater environments.

Seven additional frog species and 13 additional reptiles were recorded during prior surveys conducted in the study area.

Odonates

Ninety-seven species of odonates were recorded in the study area, including 46 species of damselfly (suborder Zygoptera) and 51 species of dragonfly (suborder Anisoptera). The families Coenagrionidae (18 species) and Platycnemididae (13 species) dominated the damselfly fauna, while the Libellulidae (38 species) was the most diverse dragonfly family.

With an aquatic larval stage and free-flying adult stage, all odonates rely on both freshwater and terrestrial environments. Compared to damselflies, most dragonflies are relatively strong fliers, exhibit a broader habitat tolerance and have broader geographic ranges. Limited range endemism is more prevalent among damselflies, many of which are closely associated with shaded forest environments.

7.7.6.2 Conservation-listed Species

Ninety-two IUCN listed and nationally Protected species have been recorded within the study area (61 species) or may occur based on known distribution and habitat preferences (31 species).²¹

For each major taxonomic group, Table 7.13 lists the number of species from each conservation category recorded or potentially occurring in the study area. A selection of these species is shown in Plates 7.32 to 7.37. Of greatest significance are those species listed under an IUCN Threatened category. They include:

- ♦ Three IUCN Critically Endangered species, three of which are confirmed present: the timber tree *Diospyros lolinopsis*, and Bulmer's fruit bat (*Aproteles bulmerae*) (Plate 7.37).
- ♦ Nine IUCN Endangered species, eight of which are confirmed present: the timber trees *Diospyros insularis*, *Pterocarpus indicus* and *Flindersia pimenteliana* (Plate 7.34), two tree kangaroo species (*Dendrolagus* spp.), the giant bandicoot (*Peroryctes broadbenti*) (Plate 7.35), the migratory far eastern curlew (*Numenius madagascariensis*) and the pig-nosed turtle (*Carettochelys insculpta*).
- ♦ Seventeen (17) IUCN Vulnerable species, 13 of which are confirmed present (Table 7.14): four tree species (e.g., *Archidendron forbesii* (Plate 7.32)), five non-volant mammals (e.g., grey dorcopsis (*Dorcopsis luctuosa*) (Plate 7.36)), three resident forest bird species and one freshwater turtle species.

21 The following changes have been made to the IUCN rankings of recorded or potentially occurring species since undertaking the terrestrial biodiversity baseline study (based on the 2018 IUCN Red List). Among previously Threatened species: Two have had their status downgraded to Least Concern: the tree *Gluta Papuana* and the southern cassowary (*Casuarius casuarius*); the butterfly *Ornithoptera meridionalis* has been downgraded to Near Threatened; and two previously Vulnerable taxa have had their status upgraded to Endangered: the timber tree *Pterocarpus indicus* and the pig-nosed turtle (*Carettochelys insculpta*). Two previously Data Deficient species and one Least Concern species are now categorised as Near Threatened: the Papuan sheath-tailed bat (*Saccolaimus mixtus*), the blue-black kingfisher (*Todirhamphus nigrocyaneus*) and the butterfly *Ornithoptera paradisea*. The New Guinea flightless rail (*Megacrex inepta*) has been downgraded from Near Threatened to Least Concern, and four previously Data Deficient species are now categorised as Least Concern (two bats and two birds). Three previously Least Concern or Not Evaluated species are now categorised as Data Deficient (one plant, one bat and one frog). There are no changes to nationally Protected status.

Figure 7.25 shows the number of IUCN listed and nationally Protected species potentially occurring in each ecological zone, and in each of 10 major natural environments identified in the study area. Most species occupy hill forest, alluvial forest and/or wooded swamp (swamp forest/woodland) environments. Diversity is highest in hill and alluvial forest, where most conservation-listed species are permanent residents. Wetlands, watercourses, and marine tidal flats and beaches each support multiple conservation-listed species, many of which are migratory or transient non-breeding visitors.

Plate 7.32 – *Archidendron forbesii* (VU)



Photo: Fanie Venter.

Plate 7.33 – Scheepmaker's Crowned Pigeons (*Goura scheepmakeri*) (VU)



Photo: Iain Woxvold.

Plate 7.34 – Seed Pods of the Timber Tree Maple Silkwood (*Flindersia pimenteliana*) (EN)



Photo: Fanie Venter.

Plate 7.35 – Giant Bandicoot *Peroryctes broadbenti* (EN) at Site 7



Photo: Iain Woxvold

Plate 7.36 – Grey Dorcopsis (*Dorcopsis luctuosa*) (VU) at Site 5



Photo: Iain Woxvold

Plate 7.37 – Teeth of Juvenile Bulmer's Fruit Bat (*Aproteles bulmerae*) (the Six Teeth at Right; Unerupted Teeth of Juvenile Dobsonia Shown at Left for Comparison) Collected from Owl Pellet Deposit at the Wi'i Creek Cave Site



Photo: Ken Aplin.

Table 7.13 – Number of Species From Each Conservation Category Recorded and Potentially Occurring in the Study Area

Taxonomic Group	IUCN*					PNG*
	CR	EN	VU	NT	DD	P
Flora	2/3	3/3	4/7	6/8	6/6	–
Non-volant mammals	–	3/3	5/5	1/1	1/2	4/4
Bats	1/1	–	–	–	1/3	1/1
Birds	–	1/2	3/4	3/15	1/3	14/18
Reptiles	–	1/1	1/1	–	–	–
Frogs	–	–	–	–	2/2	–
Odonates	–	–	–	–	4/4	–
Butterflies [#]	–	–	–	0/2	–	_/3
Total[†]	3/4	8/9	13/17	10/26	15/20	19/26

* Numbers indicate: recorded/potentially occurring; CR - Critically Endangered, EN - Endangered, VU - Vulnerable, NT - Near Threatened, DD - Data Deficient, and P - Protected.

[#] Butterflies were not the subject of any field survey.

[†] This does not total 92 species as some are listed under both the IUCN and PNG categories.

Note: Least Concern species are not considered to be of conservation priority and are therefore not included in this table.

Table 7.14 – IUCN Vulnerable Species Confirmed Present in the Study Area

Species	Common Name
Trees	
<i>Mammea grandifolia</i>	-
<i>Ceratopetalum succirubrum</i>	-
<i>Archidendron forbesii</i>	-
<i>Intsia bijuga</i>	Kwilia/merbau
Non-volant Mammals	
<i>Zaglossus bartoni</i>	Eastern long-beaked echidna
<i>Dendrolagus spadix</i>	Lowland tree kangaroo
<i>Dorcopsis luctuosa</i>	Grey dorcopsis

Table 7.14 – IUCN Vulnerable Species Confirmed Present in the Study Area (cont'd)

Species	Common Name
Non-volant Mammals (cont'd)	
<i>Thylogale brunii</i>	Dusky pademelon
<i>Xeromys myoides</i>	False water rat
Resident Forest Birds	
<i>Harpyopsis novaeguineae</i>	Papuan eagle
<i>Goura scheepmakeri</i>	Scheepmaker's crowned pigeon
<i>Psitttrichas fulgidus</i>	Pesquet's parrot
Freshwater Turtles	
<i>Pelochelys bibroni</i>	Striped New Guinea soft-shelled turtle

7.7.6.3 New-to-science and Scientifically Undescribed Species

Sixty-three species recorded in the study area are scientifically undescribed, 48 of which are new-to-science, being discovered for the first time during Project surveys, and 15 of which were previously discovered but remain scientifically undescribed (Table 7.15).²² Fifty-one species are so far known only from within the study area (see Table 7.15). A selection of new-to-science species is shown in Plates 7.38 to 7.43.

Table 7.15 – Number of New-to-science and Scientifically Undescribed Species from Each Surveyed Taxonomic Group

Taxonomic Group	New-to-science	Undescribed	Study Area Only
Flora	34	1	34
Non-volant mammals	2	0	2
Bats	0	1	0
Birds	0	0	0
Reptiles	2	1	2
Frogs	3	11	5
Odonates	7	1	8
Total	48	15	51

More than half (34 of 48) of all new-to-science species are plants, reflecting the higher species richness of this taxonomic group and the generally low prior survey effort conducted by taxonomic botanists in the interior lowlands of Gulf Province. Odonates yielded the next highest number of new discoveries (eight species, one now described), this being attributable to a relatively low historical survey effort into this insect group in New Guinea and a tendency toward limited-range endemism among damselflies. Limited-range endemism is also frequently observed in New Guinean frogs; five frog species are known only from the study area.

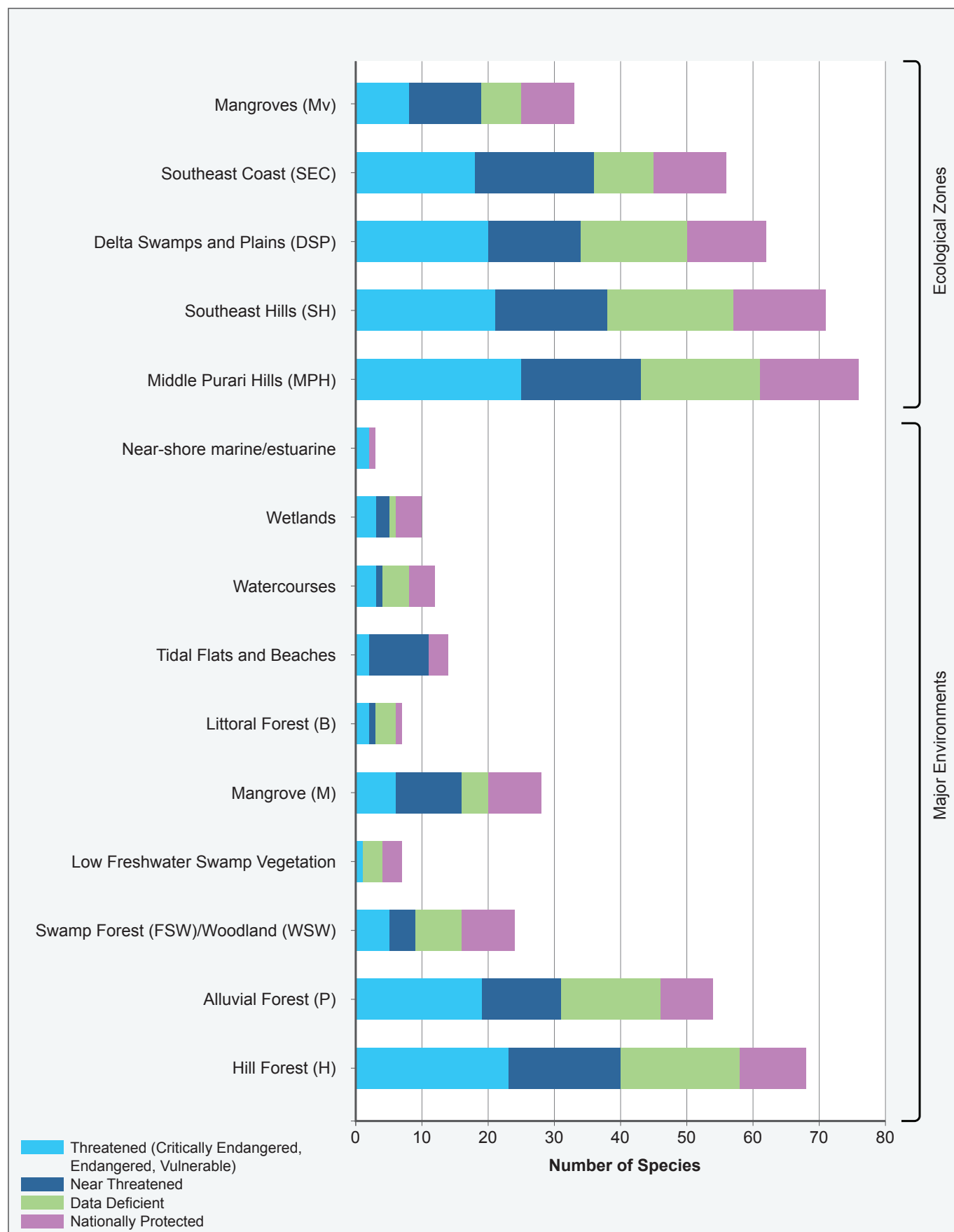
Among reptiles, one new gecko (*Gehyra* sp. 1; Plate 7.40) was discovered in logged hill forest, and a distinctive new snake species (*Stegonotus* sp. 1; Plate 7.43) is at present known only from alluvial forest in the study area. Among non-volant mammals, two new-to-science species of small rodent were identified among skeletal remains from an owl pellet deposit collected at the Wi'i Creek cave site.

²² Two species have been formally described and named since the terrestrial biodiversity baseline study: the frog *Choerophryne crucifer* (previously *Choerophryne* sp. 1) and the damselfly *Bironides ypsilon* (previously *Bironides* sp. 1).

IUCN LISTED AND NATIONALLY PROTECTED SPECIES POTENTIALLY OCCURRING IN ECOLOGICAL ZONES AND MAJOR NATURAL ENVIRONMENTS

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FIGURE 7.25



Discovery patterns throughout ecological zones and major environments are shown in Figure 7.26. Discovery rates were highest in hill forest in the Middle Purari Hills ecological zone, followed by alluvial forest on the Delta Swamps and Plains. Fewer discoveries in mangroves (two species), freshwater swamp vegetation types (five species) and littoral forest (zero species) reflect lower species richness, higher previous survey efforts and more widespread distributions of these lowland community components.

7.7.6.4 Regional Endemism and Restricted-range Species

New Guinea is among the most endemically rich regions on Earth (Mittermeier et al., 1997; Wikramanayake et al., 2002). While the biota of southern New Guinea share a strong affinity with Australian flora and fauna (Gressitt, 1982; Allison, 2007), the lowland rainforests of the study area support a high proportion of regionally endemic (i.e., those occurring only in New Guinea) and restricted-range species. The tendency toward regional endemism and limited-range distributions varies among major taxonomic groups.

Plate 7.38 – *Begonia* sp. 5



Photo: Fanie Venter.

Plate 7.39 – *Medinilla* sp. 1



Photo: Fanie Venter.

Plate 7.40 – *Gehyra* sp. 1



Photo: Steve Richards.

Plate 7.41 – *Oreophryne* sp. 1



Photo: Steve Richards.

Plate 7.42 – *Nyctophilus* sp. 1

Photo: Steve Richards.

Plate 7.43 – *Stegonotus* sp. 1

Photo: Steve Richards.

Among endemic taxa, the most sensitive species are those with the smallest geographic ranges. For this report and in accordance with International Finance Corporation (IFC) principles, these 'restricted-range' species include terrestrial fauna with a global distribution of less than 50,000 km². Among the species-rich plant dataset, screening for restricted-range flora focused on species known only from Gulf Province or from adjacent provinces in areas below 500 m asl in catchments that overlap the study area.

A total of 119 restricted-range species has been recorded or may occur in the study area (Table 7.16; Figure 7.27). A selection of restricted-range species is shown in Plates 7.44 to 7.49.

Table 7.16 – Restricted-range Species Recorded or Potentially Occurring in the Study Area

Taxonomic Group	IUCN*					PNG	New-to-science	Undescribed	Other Named RR	Total
	CR	EN	VU	NT	DD	P				
Flora	–	–	2	–	–	–	34	1	9	46
Non-volant mammals	–	1	1	–	1	1 [#]	2	–	3	8
Bats	1	–	–	–	1	1 [#]	–	1	1	4
Birds	–	–	1	1	1	1 [#]	–	–	–	3
Reptiles	–	–	–	–	–	–	2	1	7	10
Frogs	–	–	–	–	2	–	3	11	9	25
Odonates	–	–	–	–	1	–	7	1	14	23
Total	1	1	4	1	6	3[#]	48	15	43	119

* CR - Critically Endangered, EN - Endangered, VU - Vulnerable, NT - Near Threatened, DD - Data Deficient, and P - Protected.

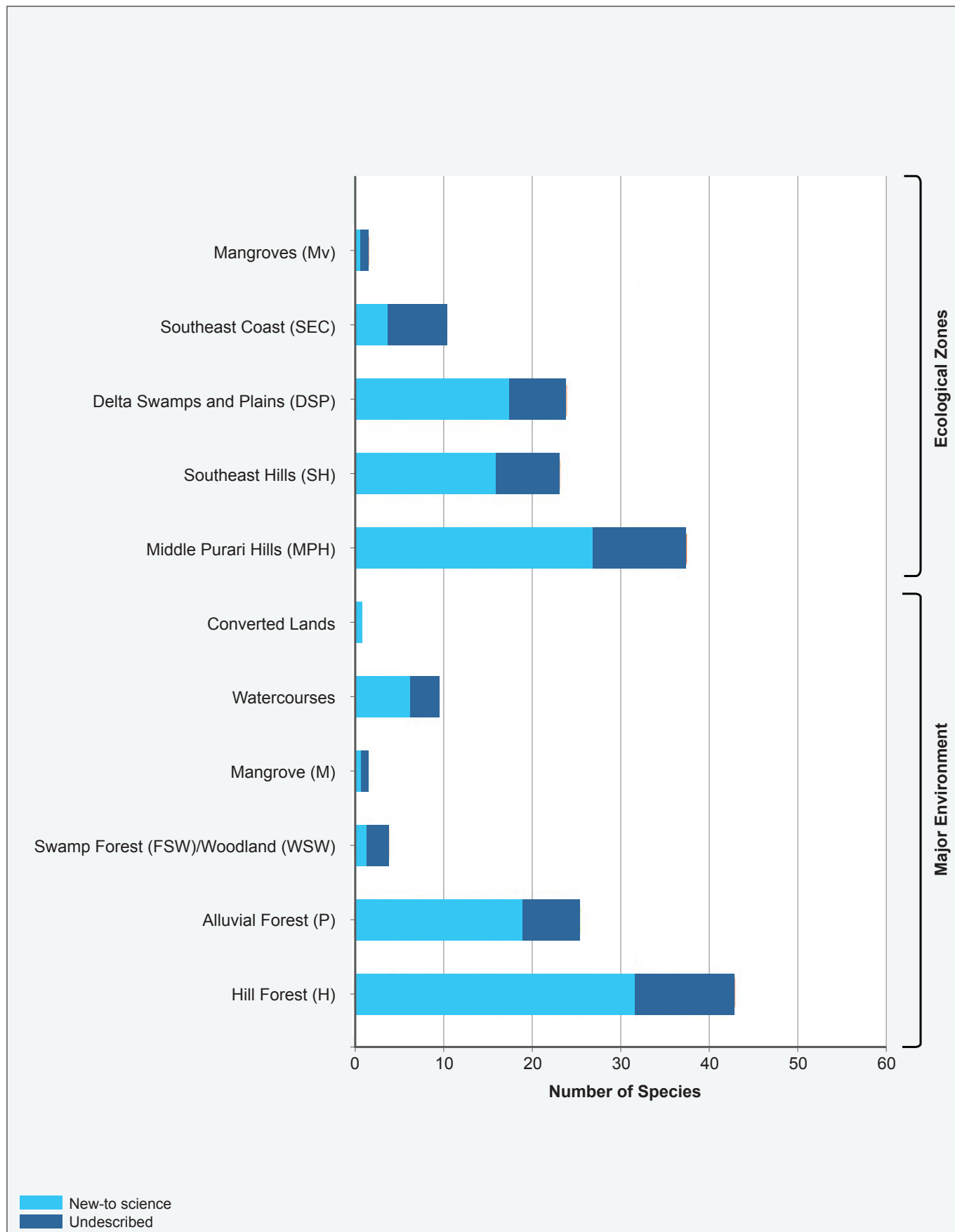
[#] Some restricted-range (RR) species Protected under PNG law are also listed under an IUCN listed category; as such, Totals do not count these species twice.

Note: Least Concern species are not considered to be of conservation priority and are therefore not included in this table.

NEW-TO-SCIENCE AND UNDESCRIBED SPECIES RECORDED IN ECOLOGICAL ZONES AND MAJOR ENVIRONMENTS

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FIGURE 7.26



RESTRICTED-RANGE SPECIES RECORDED OR POTENTIALLY OCCURRING IN ECOLOGICAL ZONES AND MAJOR ENVIRONMENTS

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FIGURE 7.27

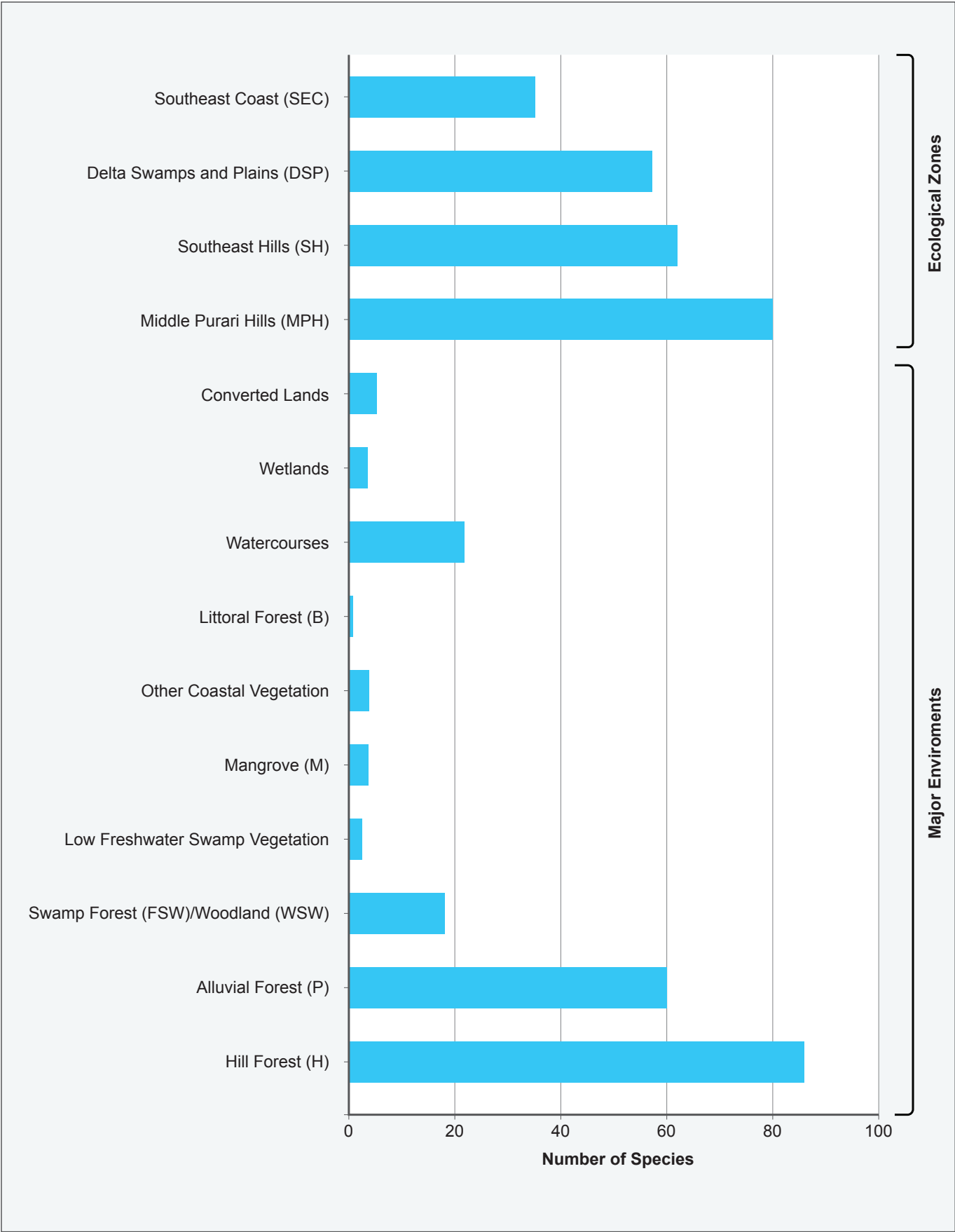


Plate 7.44 – *Litoria exophthalmia*

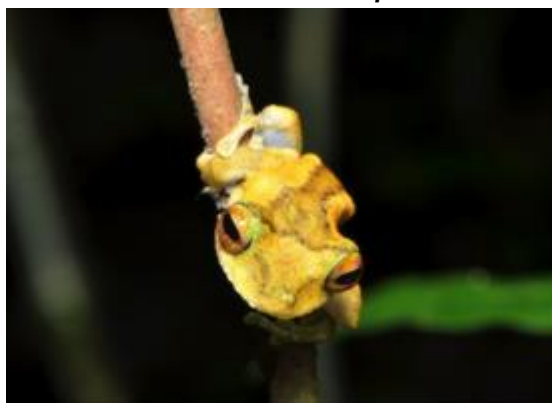


Photo: Steve Richards.

Plate 7.45 – *Nososticta chrismulleri*



Photo: Steve Richards.

Plate 7.46 – *Psychotria purariensis*



Photo: Fanie Venter.

Plate 7.47 – *Pseuduvaria filipes*



Photo: Fanie Venter.

Plate 7.48 – Oriomo Bandicoot (*Echymipera oriomo*) at Site 5



Photo: Iain Woxvold.

Plate 7.49 – *Curtodactylus serratus*



Photo: Steve Richards.

The highest diversity of restricted-range taxa occurs among plants (46 species), frogs (25 species) and odonates (23 species) (see Table 7.16). Among plants, nearly half (48%) of the identified restricted-range species belong to three families—Rubiaceae (12 species), Begoniaceae (5 species) and Myrtaceae (5 species). Among odonates, more than 82% (19/23) of restricted-range species are damselflies (suborder Zygoptera). Flight-capable vertebrates are generally more wide ranging; the study area's bat and bird communities each include fewer than five restricted-range species.

Figure 7.27 shows the number of restricted-range species recorded or potentially occurring in each ecological zone and in various major environments. Hill and alluvial forest support the highest diversity of restricted-range species. Watercourses in forest environments provide important habitat for a suite of restricted-range odonates (18 species), frogs (4 species) and the new-to-science small water rat *Hydromys* sp. 1.

Species with the smallest recorded distributions include those known only from the study area. They include 48 new-to-science species discovered during Project surveys, two additional scientifically undescribed frogs previously known only from the Wabo area, and six restricted-range plant species. In most cases, the habitats known to support these species extend beyond the study area into the adjacent Kikori, Vailala and Lakekamu river catchments without apparent geographic barrier. Accordingly, most or all species presently known only from the study area are expected to occur more widely in Gulf Province, at least in other sectors of the local biogeographic regions of which the study area forms a part (see Section 7.7.4.2). Until it is possible to confidently predict that a species does occur in adjacent areas of suitable habitat, the possibility that one or more species is restricted to the study area cannot be ruled out.

7.7.6.5 Migratory and Congregatory Species

Overview

No terrestrial mammals or herpetofauna occurring in the study area engage in long-distance migration, and no terrestrial non-volant mammals or herpetofauna are known to congregate in large groups. More significant congregatory behaviors and localized landscape-level movements are observed among bats, birds and two large freshwater turtle species.

Bats

The seasonal and daily movements of New Guinean bats are poorly documented; however, many species are probably capable of long-distance flights, and some may travel many kilometers between regular roosting and feeding sites. It is not possible to identify regular bat movement corridors in the study area. They may be numerous and widespread and are expected to vary between taxa and potentially across seasons within taxa. The most permanent and well-defined flight corridors with the greatest number of individuals travelling through the narrowest aerial channel are expected to occur on approaches to caves that support large colonies of one or more bat species.

Many New Guinean bat species roost together in large groups, either habitually or seasonally for breeding. Flying-foxes of the genus *Pteropus* congregate seasonally in large 'maternity camps' in forest canopies, often located in mangroves, riparian forest or freshwater swamp vegetation. No flying-fox camps were observed during Project surveys, although their occurrence was reliably reported by local residents; reported locations include the PRL-15 oxbow wetlands.

A variety of bats roost in caves, including several large fruit bats (Pteropodidae) and small insectivorous bats belonging to the families Emballonuridae, Hipposideridae, Rhinolophidae, Miniopteridae and Vespertilionidae. Cave-roosting species recorded in the study area include the

IUCN-listed Bulmer's fruit bat (*Aproteles bulmerae*) (Critically Endangered), New Guinea sheath-tailed bat (*Emballonura furax*) (Data Deficient), Papuan sheath-tailed bat (*Saccolaimus mixtus*) (Data Deficient) and Semon's leaf-nosed bat (*Hipposideros semoni*) (Data Deficient). Aggregate numbers of animals depend on the species present and cave's chamber size; sizeable caves often include bats of multiple species. Cave habitats are discussed further in Section 7.7.7.

Birds

The study area includes habitats that support trans-oceanic migrant birds, both from the northern hemisphere and from Australia, and migratory and resident taxa that congregate together at various sites in the study area landscape.

At least 31 migratory shorebird species may occur in the study area. Of these, 23 species congregate on or near the coast, and more than one third of them (8 of 23) are listed by the IUCN as Threatened or Near Threatened with extinction. Additional migratory and resident bird taxa may join these coastal aggregations. In the study area, the largest aggregations of coastal bird species are expected to occur along the tidal flats, lagoons and estuaries of the Mangroves ecological zone and, to a lesser degree, of the Southeast Coast ecological zone.

Based on numbers of migratory shorebirds recorded previously in the nearby Kikori River delta (Jaensch & Watkins, undated; Bamford et al., 2008), the tidal wetlands of the Purari River delta may qualify as an internationally important wetland site under Criterion 6 of the Ramsar Convention for the greater sand plover (*Charadrius leschenaultia*) and Terek sandpiper (*Xenus cinereus*) and as an internationally important staging site for the IUCN Endangered far eastern curlew (*Numenius madagascariensis*).

In addition to coastal species, at least 36 migratory and congregatory bird species may occur in freshwater environments in the study area. The largest aggregations are expected to occur in off-river freshwater wetlands, such as the oxbow lakes and swamps of the Purari and Vailala river catchments, respectively, and in the Delta Swamps and Plains and Southeast Hills ecological zones. The potential importance of these coastal and freshwater habitats is discussed further in Section 7.7.7.

At least two and possibly as many as five swiftlet species (*Aerodramus* spp., *Collocalia esculenta*) occur locally, all of which nest and roost colonially in caves. Colonies range from a few individuals to hundreds of birds, depending on the dimensions of the shelter site. The importance of caves is discussed in Section 7.7.7.

No habitat for terrestrial (non-waterbird) migratory species requiring specific conservation action is found in the study area. Additionally, suitable trees used for lekking and colonial nesting by species such as birds-of-paradise and starlings, respectively, are widespread within and beyond the study area's forest environments.

Large Freshwater Turtles

The IUCN Endangered pig-nosed turtle (*Carettochelys insculpta*) (Plate 7.50) and the IUCN Vulnerable striped New Guinea soft-shelled turtle (*Pelochelys bibroni*) are recorded in the study area. These species nest on sandy river banks, and the pig-nosed turtle additionally (at least in the Kikori River delta) at the mouths of major rivers, on islands in river deltas and on coastal beaches. Both of these species nest along the Purari River or its tributaries in the southern part of PRL-15 and probably more widely in the study area. The nesting sites are used year after year, and each is visited by multiple laying females. The location and significance of the PRL-15 nesting sites is discussed in Section 7.7.7.

Plate 7.50 – Pig-nosed Turtle (*Carettochelys insculpta*) (EN)

Photo: Steve Richards.

Movement patterns in the Gulf Province drainages are poorly known; but in the Kikori River delta, movements may involve 'migrations' between nesting and feeding areas (Eisemberg et al., 2014, 2015); e.g., in the Purari and Kikori river catchments, hatchlings move to the lower delta to feed on mangrove fruit and other vegetation.

7.7.6.6 Invasive Alien Species

Weeds

Weeds are classified into three groups based on their potential to cause ecological harm:

- ♦ Priority 1 species – those species that can persist in unmodified native ecosystems, have the potential to cause ecosystem degradation by displacing native species or negatively impact on regeneration or rehabilitation measures.
- ♦ Priority 2 species – those species that can persist in disturbed areas and are unlikely to persist without some anthropogenic influence.
- ♦ Priority 3 species – those species that require ongoing disturbance and are unable to out-compete native species without regular human interference. These species are not considered an ecological threat.

Ninety-seven alien plant species were identified in the study area, of which seven are Priority 1 weeds and 34 are Priority 2 weeds. Nearly 60% of alien plants are Priority 3 weed species. The Priority 1 weeds and their occurrences in the study area are described in Table 7.17, and a selection is shown in Plates 7.51 to 7.56.

Table 7.17 – Priority 1 Alien Weeds Recorded from the Study Area

Species	Description and Occurrence in Study Area
Angelonia/monkey face (<i>Angelonia angustifolia</i>)	Erect herb to 1 m high. Forms dense stands on poorly drained sites. Widespread: in PRL-15 infesting wellpads and associated landslips, Antelope-3 Operations Camp, the Herd Base—Gas Field Road, the Purari Airstrip and nearby logging roads; in the export pipeline corridor present at Paevera village and coastal villages.
Water hyacinth (<i>Eichhornia crassipes</i>)	An erect perennial aquatic herb, free-floating or occasionally rooted in shallow water. Noted in Nea Creek, the PRL-15 oxbow wetlands in the southwest part of PRL-15 and at the Purari Airstrip.

Table 7.17 – Priority 1 Alien Weeds Recorded from the Study Area (cont'd)

Species	Description and Occurrence in Study Area
Anglestem willow (<i>Ludwigia leptocarpa</i>)	Annual herb. Infests wet sites where topsoil is exposed. Infestations reported: In PRL-15 at the Elk-2 wellpad and the Purari Airstrip and in the export pipeline corridor in waterlogged sites adjacent to logging roads.
Mile-a-minute vine (<i>Mikania micrantha</i>)	Fast-growing vine that tolerates partially shaded environments, commonly invading minimally to moderately disturbed, poorly drained sites. Highly invasive and can smother the canopy of large trees. Widespread in disturbed and open sites: In PRL-15 it is present at Herd Base, along the Herd Base—Gas Field Road, at the Purari Airstrip and nearby logging roads; in the export pipeline corridor it is present along logging roads, in undisturbed swamp grassland and in coastal villages.
Bamboo daka (<i>Piper aduncum</i>)	Shrub/small tree to 6 m. Tolerates a range of climatic conditions and will grow in shade and full sun. Highly invasive; establishes in natural gaps and on stream banks in primary forest. Widespread, particularly along roads: In PRL-15 it is present at Herd Base, along the Herd Base—Gas Field Road, at the Purari Airstrip and nearby logging roads, and along watercourses; in the export pipeline corridor it is present along logging roads; also in Pawaian villages and along the banks of the Purari River.
African tulip tree (<i>Spathodea campanulate</i>)	The only Priority 1 large tree (to 20 m tall) identified in the study area. Along with <i>Piper aduncum</i> , this is the most successful woody invader of disturbed forest environments in New Guinea. It invades post-logging secondary forest and out-competes regenerating native species. Recorded at Muro Mission, southern export pipeline corridor.
Coconut palm (<i>Cocos nucifera</i>)	A tall palm to 20 m. Forms localized infestations on areas of raised ground in Mangrove (M). Causes structural change in mangrove forest and has the potential to out-compete native species. A naturally occurring species, but with a commercial cultivar planted extensively in the Southeast Coast ecological zone since the early 1900s. Recorded in mangrove forest in the southwest export pipeline corridor (see Figure 7.21).

**Plate 7.51 – Monkey Face
(*Angelonia angustifolia*)**

Photo: Howard Rogers.

**Plate 7.52 – Water Hyacinth
(*Eichhornia crassipes*)**

Photo: Howard Rogers.

**Plate 7.53 – Anglestem Willow
(*Ludwigia leptocarpa*)**



Photo: Howard Rogers.

**Plate 7.54 – Bamboo Daka
(*Piper aduncum*)**



Photo: Howard Rogers.

**Plate 7.55 – African Tulip Tree
(*Spathodea campanulate*)**



Photo: Howard Rogers.

**Plate 7.56 – Coconut Palm
(*Cocos nucifera*)**



Photo: Iain Woxvold.

Invasive alien plant species were recorded at widespread infestation sites at heavily disturbed locations or converted lands, including in village and garden areas, particularly in the populated Southeast Coast ecological zone, at the Purari Airstrip, in logging camps, along the extensive network of logging roads and in an associated dieback area, and at Project facility and infrastructure sites, including Herd Base, Antelope-3 Operations Camp, wellpads, and along the Herd Base—Gas Field Road.

In contrast, few weeds were observed in intact natural environments; as such, expansive areas of natural forest habitat are essentially weed free. The lack of weeds in these environments reflects the relatively undisturbed quality of the forests that cover much of the PAOI and broader study area (see Section 7.7.5.3).

Animals

Invasive alien feral or domestic mammals present in the study area include rodents (Plate 7.57), cats, dogs and pigs (Plate 7.58). No invasive alien bats were recorded or are likely to occur in the study area. One bird species (Eurasian tree sparrow (*Passer montanus*)) and one amphibian

(cane toad (*Rhinella marina*)) (Plate 7.59) were also recorded. The species' occurrences in the study area are described in Table 7.18.

Among invertebrates, an infestation of the giant East African snail (*Lissachatina fulica*) was recorded at Site 8 in the Southeast Coast ecological zone.

Plate 7.57 – Black Rat (*Ratus rattus*)



Photo: Ken Aplin.

Plate 7.58 – Feral Pig (*Sus scrofa*) Sow and Piglets



Photo: Iain Woxvold.

Plate 7.59 – Cane Toad (*Rhinella marina*)



Photo: Steve Richards.

Table 7.18 – Invasive Alien Animals Recorded from the Study Area

Species	Occurrence in Study Area
Mammals	
Rodents (Muridae) – Pacific rat (<i>Rattus exulans</i>), black rat (<i>R. rattus</i>), small spiny rat (<i>R. steini</i>) and house mouse (<i>Mus musculus</i>)	Currently restricted to anthropogenic habitats, including active Project facility sites, active logging roads and villages. The black and Pacific rats are the most widespread alien rodents; the small spiny rat and house mouse were recorded at single sites. A long-term resident black rat population (pre-1970s) is reported for the populated Southeast Coast ecological zone. By contrast, recent infestations are reported by local landowners residing near transport infrastructure sites: black and Pacific rats in Evara village appeared shortly after the construction of a nearby logging camp in 2000, and black rats at Wabo village in the last 1 to 2 years. Native rodent populations are presumed thus far to have kept alien species from invading natural habitats; and trapping results suggest that disturbance-tolerant native species are out-competing alien rodents, in at least some post-disturbance regrowth habitats. Alien rodent populations are, therefore, likely to be currently patchily distributed in heavily disturbed sites in the study area.
Pig (<i>Sus scrofa</i>)	Introduced into New Guinea approximately 2,500 years ago. Feral populations are now widespread and occupy a variety of habitats. Widespread in the study area; recorded at all flora and fauna survey sites except in mangroves. Highest densities were recorded in undisturbed alluvial forest; camera trapping rates suggest they are less abundant in hill forest and wherever they are subject to hunting by local communities.
Dog (<i>Canis familiaris</i>)	Present in New Guinea since prehistoric times. Occur both as domestic and feral populations, with a regular interchange of individuals in some areas. Where present, feral dogs are the apex predator in New Guinea's terrestrial ecosystems. Domestic dogs are kept by local residents throughout the study area. The status of local feral populations is uncertain. At least one feral population is likely to be present north of the Purari River in PRL-15; unaccompanied dog prints seen at Site 6A were attributed to feral dogs by local residents who stated they were common in the area.
Cat (<i>Felis catus</i>)	Populations are rarely reported in New Guinea's rainforest environments and may be largely restricted to human settlements and nearby disturbed areas (Flannery, 1995). In the study area, cats are kept as pets in most villages and at some Project facility sites; no evidence of a feral population was obtained.
Birds	
Eurasian tree sparrow (<i>Passer montanus</i>)	Established colonies present at Herd Base, at the Antelope-3 Operations Camp and in coastal villages of Oroko Bay. Strongly commensal in New Guinea. Restricted to open and disturbed habitats around human settlements.
Herpetofauna	
Cane toad (<i>Rhinella marina</i>)	Highly toxic introduced species. Patchy distribution in Papua New Guinea, restricted predominantly to open savanna habitats, urban areas, and disturbed forest environments; rare in closed canopy rainforest. Widespread but patchily distributed in anthropogenic habitats across the study area. Present in: ♦ PRL-15, at the Antelope-3 Operations Camp and at Herd Base. ♦ The export pipeline corridor, common in settled areas of the Southeast Coast ecological zone and were present along the logging road at Site 3, but not found in adjacent logged forest habitats. Easily introduced to novel, isolated disturbed sites via human transport vectors (road or air).

Table 7.18 – Invasive Alien Animals Recorded from the Study Area (cont'd)

Species	Occurrence in Study Area
Invertebrates	
Giant East African snail (<i>Lissachatina fulica</i>)	A severe infestation observed at Site 8. A serious agricultural pest, present in gardens, disturbed sites and adjacent alluvial forest south of the Muro River. Local residents indicated that this species had arrived in the last few years and that the Muro River was acting as a dispersal barrier with snails yet to be found north of there.

7.7.7 Protected Areas, Priority Ecosystems and Focal Sites

7.7.7.1 Protected Areas

Approximately 445 km² of the Crater Mountain Wildlife Management Area (WMA) overlaps the northern margin of the study area north of the Purari River (see Figures 7.17 and 7.18). The northern extremity of PRL-15 lies within this WMA. No current or proposed Project facilities are present in this area.

7.7.7.2 Priority Ecosystems

The study area includes a diverse array of major environments, including five BVGs (see Section 7.7.5), anthropogenic converted lands, tidal wetlands and freshwater aquatic environments.

The major environments are divided into 20 ecosystems to which a baseline sensitivity value has been assigned (see Section 7.7.8). The baseline sensitivity ranking of the various ecosystems is shown in Table 7.19, with features underpinning the assignments for those ecosystems considered to be Moderately Sensitive or higher. Examples of these ecosystems are shown in Plates 7.60 to 7.65. Further information on each ecosystem can be found in Part 6 of Volume 2.

Table 7.19 – Baseline Sensitivity of Ecosystems in the Study Area

Feature	Sensitivity*	Characteristics#
Terrestrial Ecosystems		
Hill forest (H) - primary	MS	◆ Expansive areas of primary hill forest remain in the northern study area, spanning most of the sparsely populated Middle Purari Hills ecological zone and most of PRL-15. ◆ Hill forest is the most common vegetation type across Papua New Guinea. It is widespread locally and regionally, and is well connected to comparable environments outside the Project area. ◆ The species composition and primary ecological functions are intact and succession processes occur following most natural disturbances. ◆ Supports a high diversity of IUCN Threatened and other Very Sensitive species. ◆ Middle Purari Hills landscape lies within multiple areas of biological importance recognized under the PNG Conservation Needs Assessment (Beehler 1993), including an area of biological importance to herpetofauna (Allison 1993) and major wilderness areas† (Allison, 1993; Beehler, 1993).
Hill forest (H) - logged	LS	Not applicable.

Table 7.19 – Baseline Sensitivity of Ecosystems in the Study Area (cont'd)

Feature	Sensitivity*	Characteristics#
Terrestrial Ecosystems (cont'd)		
Hill forest (H) on limestone (MPH)	VS	◆ Discrete occurrences in the Middle Purari Hills: in the west along the Kereru Range, in the extreme northwest where it contacts the Purari River at Hathor Gorge and around Mua Creek, and at the Wi'i Creek site in the northeast Middle Purari Hills. ◆ Supports a high diversity of Very Sensitive (including IUCN Threatened) and habitat-specialist species. ◆ Largely unmodified by human activity and is located in an area that is remote with recognized wilderness values.
Alluvial forest (P) - primary	VS	◆ Predominantly in discrete areas at the northern, southern and eastern margins of the Delta Swamps and Plains ecological zone, with more minor occurrences often too small to be mapped along major watercourses in the Middle Purari Hills and the Southeast Hills ecological zones, and at the base of the foothills in the Southeast Coast ecological zone. ◆ Supports the IUCN Critically Endangered tree <i>Diospyros lalinopsis</i> and relatively high densities compared to hill forest of a variety of IUCN Threatened fauna species. ◆ May be critical to the survival of a suite of new-to-science species not recorded in other forest environments. ◆ Elsewhere, regional equivalents have been extensively harvested and are under continuing pressure from logging operations.
Alluvial forest (P) – logged	MS	◆ Discrete areas at the southern and eastern margins of the Delta Swamps and Plains ecological zone, along major watercourses in the Southeast Hills ecological zone and at the base of the foothills in the Southeast Coast ecological zone. ◆ Connectivity remains with relatively undisturbed exemplars. ◆ Has potential to regenerate and support a variety of conservation significant species.
Riverine seral forest (Fri)	MS	◆ Minor occurrences on aggrading scroll arches along major watercourses in the Delta Swamps and Plains ecological zone. ◆ Part of the alluvial forest BVG; however, as a pioneer successional vegetation type it is prone to regular flooding disturbance, it has a high regenerative capacity and its occurrences are too small to support regionally important concentrations of conservation significant species.
Swamp forest (Fsw)	MS	◆ Covers extensive areas of the Delta Swamps and Plains ecological zone, with lesser occurrences in the Mangroves and the Southeast Hills ecological zones. ◆ Intact natural system that supports some conservation significant species.
Swamp woodland (Wsw)	MS	◆ Covers extensive areas of the Delta Swamps and Plains ecological zone, with lesser occurrences in all other ecological zones. ◆ Intact natural system that supports some conservation significant species.
Low freshwater swamp vegetation (Hsw, Gsw, Gri)	MS	◆ Discrete occurrences in flood prone areas, predominantly in the Delta Swamps and Plains ecological zone. ◆ Intact natural system that supports some conservation significant species.

Table 7.19 – Baseline Sensitivity of Ecosystems in the Study Area (cont'd)

Feature	Sensitivity*	Characteristics#
Terrestrial Ecosystems (cont'd)		
Mangrove (M)	VS	♦ Swamp forest under tidal influence, predominantly in the Mangroves ecological zone, additional discrete occurrences in the Southeast Coast ecological zone. ♦ Supports the IUCN Critically Endangered tree <i>Bruguiera hainesii</i>. ♦ May be critical to the survival of several plant species known only from single sites. ♦ Provides important physical and chemical regulating services necessary for supporting nearshore environments that act as nurseries for a range of fish and aquatic invertebrate species. ♦ Sensitive to disturbance.
Littoral forest (B)	LS	Not applicable
Converted land	NS	Not applicable
Freshwater Aquatic Ecosystems		
Forest streams	MS	♦ In hill forest and well drained alluvial forest. ♦ Important habitat for a variety of new-to-science and other restricted-range habitat-specialist species, predominantly frogs and odonates, but also including the new-to-science small water rat <i>Hydromys</i> sp. 1.
Open-canopy watercourses	MS	♦ Essentially unmodified systems that provide important habitat for two IUCN Vulnerable freshwater turtle species and for two crocodile species.
Oxbow lakes	VS	♦ Essentially unmodified systems that support a wide variety of habitat-specialist taxa, provide important breeding habitat for a variety of birds and herpetofauna. ♦ Sensitive to establishment and spread of aquatic plant invasive alien species.
PRL-15 oxbow wetlands	VS	♦ Approximately 25 km² of wetlands in the southwest of PRL-15 on the Delta Swamps and Plains. ♦ Comprises six open-water oxbow lakes, including the largest off-river waterbodies in the study area, and a surrounding area of integrated wetlands including permanently inundated swamp vegetation and two minor watercourses. ♦ Essentially an unmodified system that supports a wide variety of habitat-specialist taxa, provides important breeding habitat for a variety of birds and herpetofauna, and is sensitive to a variety of impacts, notably including the establishment and spread of aquatic plant invasive alien species.
Coastal freshwater lakes	MS	♦ 12 small freshwater lakes behind primary dune systems on recently aggraded shorefront in the Southeast Coast ecological zone. ♦ Support a variety of resident and migratory habitat-specialist species. ♦ Restricted local availability. ♦ May not recover easily from disturbance.
Near-shore marine/estuarine waters	LS	Not applicable.

Table 7.19 – Baseline Sensitivity of Ecosystems in the Study Area (cont'd)

Feature	Sensitivity*	Characteristics#
Coastal and Estuarine Aquatic Ecosystems		
Tidal wetlands - Purari River delta	VS	♦ Known to support congregations of migratory shorebirds, although the number of birds supported is unknown. Based on shorebird counts conducted immediately west of the study area, the Kikori River delta is recognized as an internationally important wetland site for three migratory shorebird species under Ramsar Convention threshold criteria (Bamford et al., 2008). The Purari River delta includes a similar area of tidal habitats.
Tidal wetlands - export pipeline corridor	LS	♦ Similar to the tidal wetlands of the Purari River delta, but are located in a settled shoreline, are more limited in extent and are more frequently visited by local landowners.

* Sensitivity: VS - Very Sensitive; MS - Moderately Sensitive; LS - Low Sensitivity; NS - Not Sensitive (see Section 7.7.8.1).

Only provided for ecosystems considered to be Moderately Sensitive or higher.

† Areas with low human population density and a natural environment with little disturbance.

Plate 7.60 – Forest Stream in PRL-15

Photo: Steve Richards.

Plate 7.61 – Mid-reach of an Open-canopy Watercourse, PRL-15

Photo: TEP PNG.

Plate 7.62 – A Smaller Oxbow Lake in the PRL-15 Oxbow Wetlands

Photo: Iain Woxvold.

Plate 7.63 – Coastal Freshwater Lake, Southeast Export Pipeline Corridor

Photo: Iain Woxvold.

Plate 7.64 – Coastal Freshwater Lake, Southeast Export Pipeline Corridor



Photo: Iain Woxvold.

Plate 7.65 – Tidal Habitats, Western Export Pipeline Corridor



Photo: Iain Woxvold.

Terrestrial Ecosystems

Twenty terrestrial ecosystems are identified based on vegetation type, with hill and alluvial forest further divided according to condition (logged or primary) and substrate (limestone).

Among terrestrial ecosystems, hill and alluvial forests support the highest species richness, including the highest diversity and abundance of conservation significant species. Of these forest types, primary alluvial forest is of the highest conservation value due to: 1) its more restricted local and regional availability; 2) relatively limited connectivity with similar habitat outside of the study area; and 3) its high commercial value to the logging industry. The study area supports the largest primary formations of Alluvial forest (PI) and Open alluvial forest (Po) remaining anywhere within the Kikori-Purari biogeographic region.

At the southern end of the export pipeline corridor, areas of Alluvial forest (PI) that have not been commercially logged have been heavily disturbed by local residents, essentially comprising a patchwork of remnant natural forest and converted habitats in varying stages of regeneration (see Section 7.7.5.3).

Among other forest types, Hill forest (H) on limestone and Mangrove (M) are both considered to be of high conservation value due to their intact condition and their support for a variety of habitat-specialist species and conservation-listed species.

Freshwater Aquatic Ecosystems

Five freshwater aquatic ecosystems are identified, including forest streams, open canopy watercourses and three types of off-river waterbody ecosystem. Off-river waterbody ecosystems include oxbow lakes, coastal freshwater wetlands and the PRL-15 oxbow wetlands: a series of six oxbow lakes and surrounding swamp vegetation located in the southwest part of PRL-15 and including the largest off-river waterbodies in the study area.

Oxbow lakes and the PRL-15 oxbow wetlands are of the highest conservation value owing to their unmodified condition and their support for a variety of habitat-specialist flora and fauna. The importance of oxbow wetlands for aquatic fauna is further discussed in Section 7.6.

Coastal and Estuarine Aquatic Ecosystems

Three coastal and estuarine aquatic ecosystems are recognized in the study area: nearshore marine/estuarine waters, tidal wetlands of the Purari River delta and tidal wetlands in the export

pipeline corridor. In terms of terrestrial flora and fauna, tidal wetlands of the Purari River delta are of the highest conservation significance, as they provide extensive areas of suitable foraging and roosting habitat for a variety of migratory shorebird species.

7.7.7.3 Focal Sites

Within the various ecosystems, focal sites occur as localized terrain and habitat features upon which multiple species or multiple individuals of one or more species are ecologically dependent. There is a heightened risk that the loss or degradation of such features, singly or otherwise, may disproportionately affect the activities or survivability of multiple individuals in a local population and, in some cases, may jeopardize the viability of local populations.

Nine types of focal site are recognized, including caves and rock shelters (three types), large trees (two types), nesting sites for IUCN Vulnerable freshwater turtles, crocodile nesting sites, hill forest pools and the site in which the IUCN Critically Endangered mangrove tree *Bruguiera hainesii* was recorded. Focal sites of highest conservation significance include:

- ♦ The Wi'i Creek cave and *Bruguiera hainesii* sites, both of which support IUCN Critically Endangered species.
- ♦ Other caves and nesting sites for crocodiles and two IUCN Vulnerable freshwater turtle species: the pig-nosed turtle (*Carettochelys insculpta*) and the striped New Guinea soft-shelled turtle (*Pelochelys bibroni*).

The baseline sensitivity ranking of important focal sites is shown in Table 7.20, with features underpinning the assignments for the sites considered to be Moderately Sensitive or higher. A map of off-river waterbodies is shown in Figure 7.28, while turtle and crocodile nesting site locations, documented in the southern PRL-15 area, are provided in Figure 7.29. The Wi'i Creek cave site area is shown in Figure 7.21.

Further information on each of these focal sites can be found in Part 6 of Volume 2.

Table 7.20 – Baseline Sensitivity of Focal Sites in the Study Area

Feature	Sensitivity*	Characteristics
Caves - general	VS	♦ Play a regionally significant and, in some cases, potentially globally significant (e.g., troglobitic fauna) role in supporting populations of multiple habitat-specialist species. ♦ Have a somewhat limited regional availability. ♦ Are sensitive to disturbance.
Caves - Wi'i Creek area	ES	♦ Potentially harbors a maternity roost of the IUCN Critically Endangered Bulmer's fruit bat (<i>Aproteles bulmerae</i>) (see Plate 7.37). ♦ Any other caves found to support this species would be considered to be similarly sensitive.
Other rock shelters (shallow rocky overhangs and fissures)	MS	♦ Often mentioned as secondary roost sites for cave-roosting bat species (Flannery, 1995; Bonaccorso, 1998). ♦ Likely to be localized but may occur anywhere in hilly terrain in the study area (Plate 7.66).

Table 7.20 – Baseline Sensitivity of Focal Sites in the Study Area (cont'd)

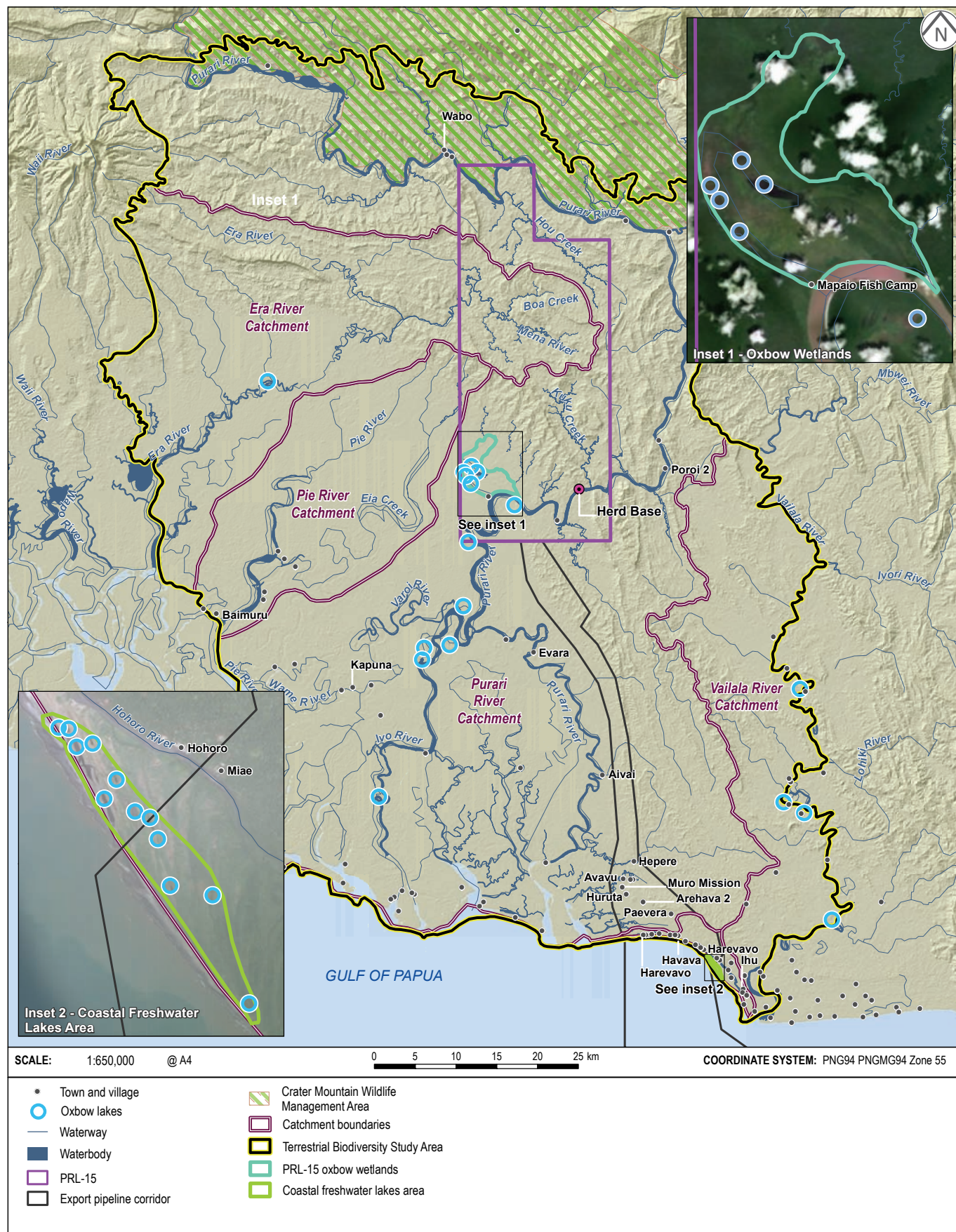
Feature	Sensitivity*	Characteristics
Large trees (general)	MS	♦ Defined as: – Greater than 1 m diameter at breast height (dbh) in areas of unlogged hill forest (all types), Alluvial forest (PI) and Open alluvial forest (Po). – Greater than 75 cm dbh in areas of logged hill and alluvial forest and in vegetation types other than those above. ♦ Provide a concentrated source of natural resources that are important for maintaining the diversity of local wildlife populations (e.g., tree hollows, breeding and lekking sites). ♦ Support heavier epiphyte loads, which provide additional habitat for fauna. ♦ Relatively rare in logged forest, where all accessible commercial species and greater than 50 cm dbh are typically removed.
Large trees (figs)	MS	♦ Defined as those with greater than 50 cm dbh. ♦ Among the most important food source for tropical frugivores in the world (O'Brien et al., 1998; Shanahan et al., 2001), including conservation significant species, some fig specialists and keystone species that play an important ecological role in dispersing seeds of rainforest trees.
<i>Bruguiera hainesii</i> site	ES	♦ A stand of the IUCN Critically Endangered mangrove tree, plus a 500-m radius (Plate 7.67).
Freshwater turtle nesting sites	VS	♦ Nesting sites for two large IUCN Vulnerable freshwater turtle species (Plate 7.68), the pig-nosed turtle (see Plate 7.50) and the striped New Guinea soft-shelled turtle.
Crocodile nesting sites	VS	♦ Nesting sites for the estuarine crocodile (<i>Crocodylus porosus</i>) and the New Guinea freshwater crocodile (<i>Crocodylus novaeguineae</i>).
Hill forest pools	MS	♦ Small pools in hill forest provide important breeding habitat for a variety of frogs and odonates, including two undescribed species of tree frog and a new-to-science damselfly. ♦ Widespread but sparsely distributed in steep terrain of the Middle Purari Hills and Southeast Hills ecological zones.

* Sensitivity: MS – Moderately Sensitive; VS – Very Sensitive; ES – Extremely Sensitive (see Section 7.7.8.1).

LOCATION OF OFF-RIVER WATERBODIES AND THE PRL-15 OXBOW WETLANDS WITHIN THE STUDY AREA

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FIGURE 7.28



Communities outside of the Project area of influence have not been verified. Only government administrative centers and notable locations have been labeled for context.

LOCATION OF TURTLE AND CROCODILE NESTING SITES DOCUMENTED IN SOUTHERN PRL-15

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FIGURE 7.29

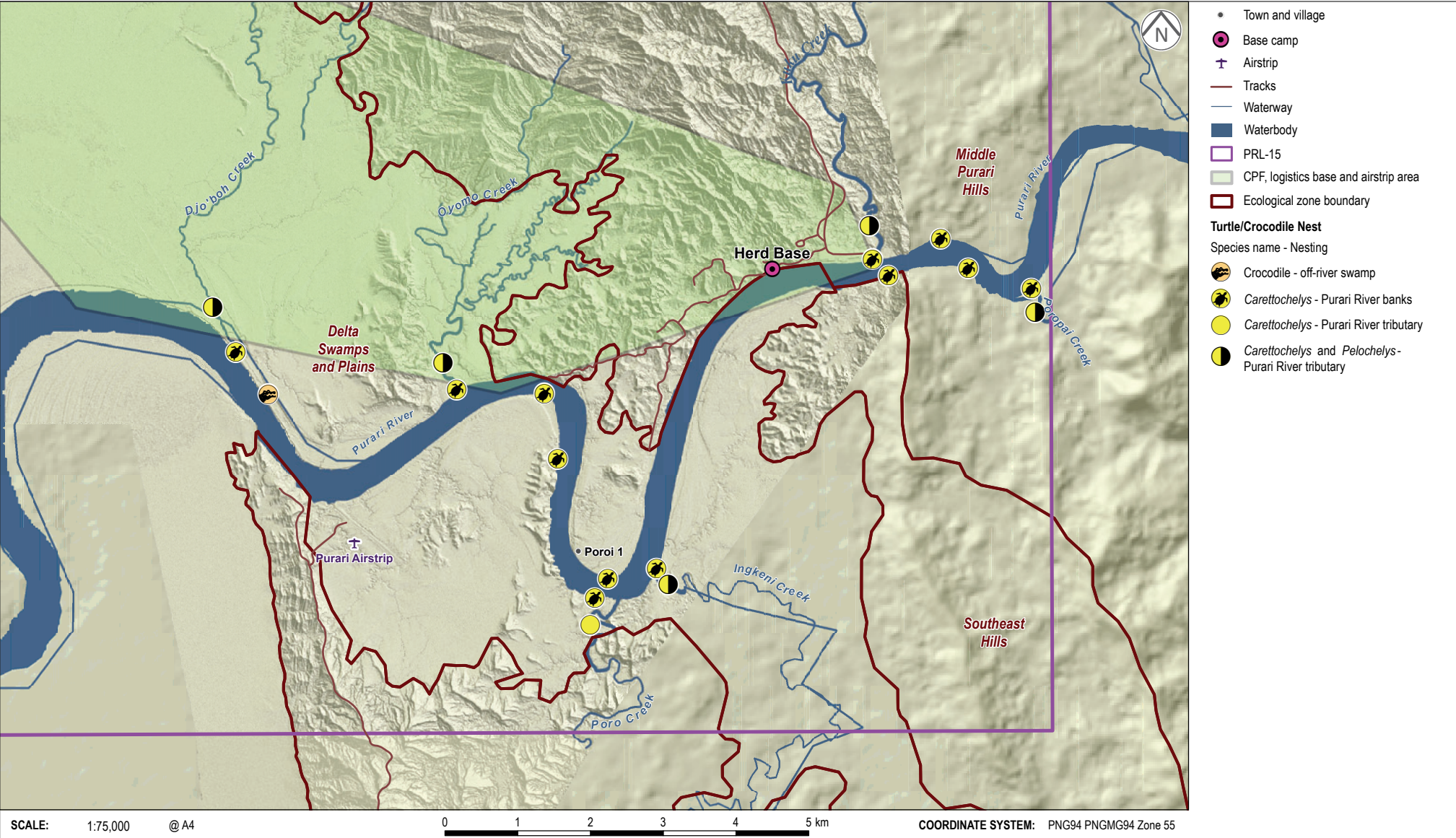


Plate 7.66 – Sheer Cliffs of the Mena Basin Aure Beds Formation near the Antelope-3 Operations Camp



Photo: Iain Woxvold.

Plate 7.67 – Transitional Mangrove Forest Showing *Bruguiera hainesii* Trees on Left



Photo: Fanie Venter.

Plate 7.68 – Pig-nosed Turtle Nesting Bank, Purari River Downstream from Herd Base



Photo: Iain Woxvold.

7.7.8 Baseline Sensitivity

7.7.8.1 Assigning Sensitivity

The baseline sensitivity of biodiversity values is determined to facilitate the assessment of potential Project-related impacts and the development of appropriate management measures, including avoidance and mitigation, which are described in Part III of the EIS. The sensitivity of biodiversity values is evaluated at the species, ecosystem and focal site scales. Based on its inherent value and sensitivity to change, each biodiversity value is assigned one of the following five sensitivity rankings²³:

- ♦ Not Sensitive.
- ♦ Low Sensitivity.
- ♦ Moderately Sensitive.
- ♦ Very Sensitive.
- ♦ Extremely Sensitive.

For this study, conservation significant species are defined as those species assigned a sensitivity ranking of Moderately Sensitive or higher.

²³ These equate to sensitivity rankings of minimal, low, medium, high and very high, respectively, in Chapter 11.

More detailed information on the concepts underpinning sensitivity assignment is provided in Part 6 of Volume 2.

7.7.8.2 Flora and Fauna

A total of 164 conservation significant species was recorded or may occur in the study area, including 97 Moderately Sensitive, 62 Very Sensitive and 5 Extremely Sensitive species (Table 7.21).

Table 7.21 – Conservation Significant Species Recorded or Potentially Occurring in the Study Area

Taxonomic Group	Sensitivity*			Total Number of Species
	MS	VS	ES	
Flora	9/20/18/(30)	10/24/15/(31)	3/1/1/(4)	65
Non-volant mammals	2/3/–/(4)	8/4/2/(10)	–/–/–/(0)	14
Bats	2/1/–/(2)	–/–/–/(0)	1/1/–/(1)	3
Birds	29/1/–/1 [#]	7/2/–/(7)	–/–/–/(0)	37
Reptiles	–/–/–/2/(2) [#]	2/2/2/(4)	–/–/–/(0)	6
Frogs	1/11/8/(11)	–/2/2/(2)	–/–/–/(0)	13
Odonates	2/14/4/(15)	–/8/4/(8)	–/–/–/(0)	23
Butterflies	3/–/–/(3)	–/–/–/(0)	–/–/–/(0)	3
Total	97	62	5	164

* Sensitivity: MS - Moderately Sensitive; VS - Very Sensitive; ES - Extremely Sensitive (see Section 7.7.8.1). Numbers indicate: conservation-listed/restricted-range/new-to-science and undescribed/(total). Within each cell, the total is not a sum of all figures, since many species occur in more than one category (e.g., conservation-listed and restricted-range).

[#] The fourth category refers to the southern cassowary (*Casuarius casuarius*) and two locally occurring crocodile species, species of importance to local communities but that are not conservation-listed, restricted-range or scientifically undescribed.

Of greatest significance are those species assigned Extremely Sensitive or Very Sensitive status:

- ♦ Extremely Sensitive: five species comprising four plants and one bat, including:
 - Four IUCN Critically Endangered species, three of which are confirmed present (see Section 7.7.6.2). The plant *Guioa hospita* may also occur.
 - One new-to-science species, the plant *Begonia* sp. 5 (see Plate 7.38), currently known only from a few individuals in or near the proposed CPF area.
- ♦ Very Sensitive: 62 species comprising 31 plants, 10 non-volant mammals, 7 birds, 6 herpetofauna species, and 8 odonate species, including:
 - Nine IUCN Endangered species, eight of which are confirmed present (see Section 7.7.6.2).
 - Seventeen IUCN Vulnerable species, 13 of which are confirmed present (see Section 7.7.6.2).
 - One IUCN Data Deficient species: starry owlet-nightjar (*Aegotheles tatei*).
 - Twenty-six restricted-range new-to-science and undescribed species.
 - Six restricted-range plants known only from the type material collected previously from the southeast sector of the study area; none are known from PRL-15, and all but *Cyrtandra externata* are expected to have been found outside of the export pipeline corridor. None were rediscovered during Project surveys.

- Four restricted-range damselflies, all habitat specialists of clear-flowing primary forest streams, previously known only from the type localities either north or west of the study area. Each of these species was recorded during Project surveys.

Further information on these significant species can be found in Part 6 of Volume 2.

7.7.8.3 Protected Areas, Priority Ecosystems and Focal Sites

The number of priority ecosystems and focal sites assigned sensitivity status of Moderately or higher is shown in Table 7.22. Sensitivity assignments for each ecosystem and focal site are shown in Tables 7.19 and 7.20. A sensitivity map of protected areas, terrestrial ecosystems and selected focal sites is provided in Figure 7.30.

Table 7.22 – The Number of Priority Ecosystems and Focal Sites Assigned Sensitivity Status of Moderately Sensitive or Higher

Feature	Sensitivity*		
	MS	VS	ES
Priority ecosystems	9	6	0
Focal sites	4	3	2

* Sensitivity: MS – Moderately Sensitive; VS – Very Sensitive; ES – Extremely Sensitive (see Section 7.7.8.1).

Protected Areas

The Crater Mountain WMA is considered to be Very Sensitive due to its ongoing recognition as part of the New Guinean protected areas network.

Priority Ecosystems

Sixteen priority ecosystems (see Section 7.7.7.2) are assigned Moderately Sensitive or Very Sensitive status. No Extremely Sensitive features are identified at the ecosystem scale.

Very Sensitive priority ecosystems include:

- ♦ Three terrestrial ecosystems: Hill forest (H) on limestone, unlogged Alluvial forest (P) and Mangrove (M).
- ♦ Two freshwater aquatic ecosystems: oxbow lakes and the PRL-15 oxbow wetlands.
- ♦ One coastal and estuarine aquatic ecosystem: tidal wetlands of the Purari River delta.

The features underpinning the assignments for those ecosystems considered to be Moderately Sensitive or higher are outlined in Table 7.19.

Sensitivity values assigned to freshwater aquatic and estuarine aquatic ecosystems are based on a terrestrial biodiversity perspective; additional information on these aquatic ecosystems is provided in Section 7.6.

Focal Sites

Nine focal sites (see Section 7.7.7.3) are assigned a sensitivity status of Moderately Sensitive or higher.

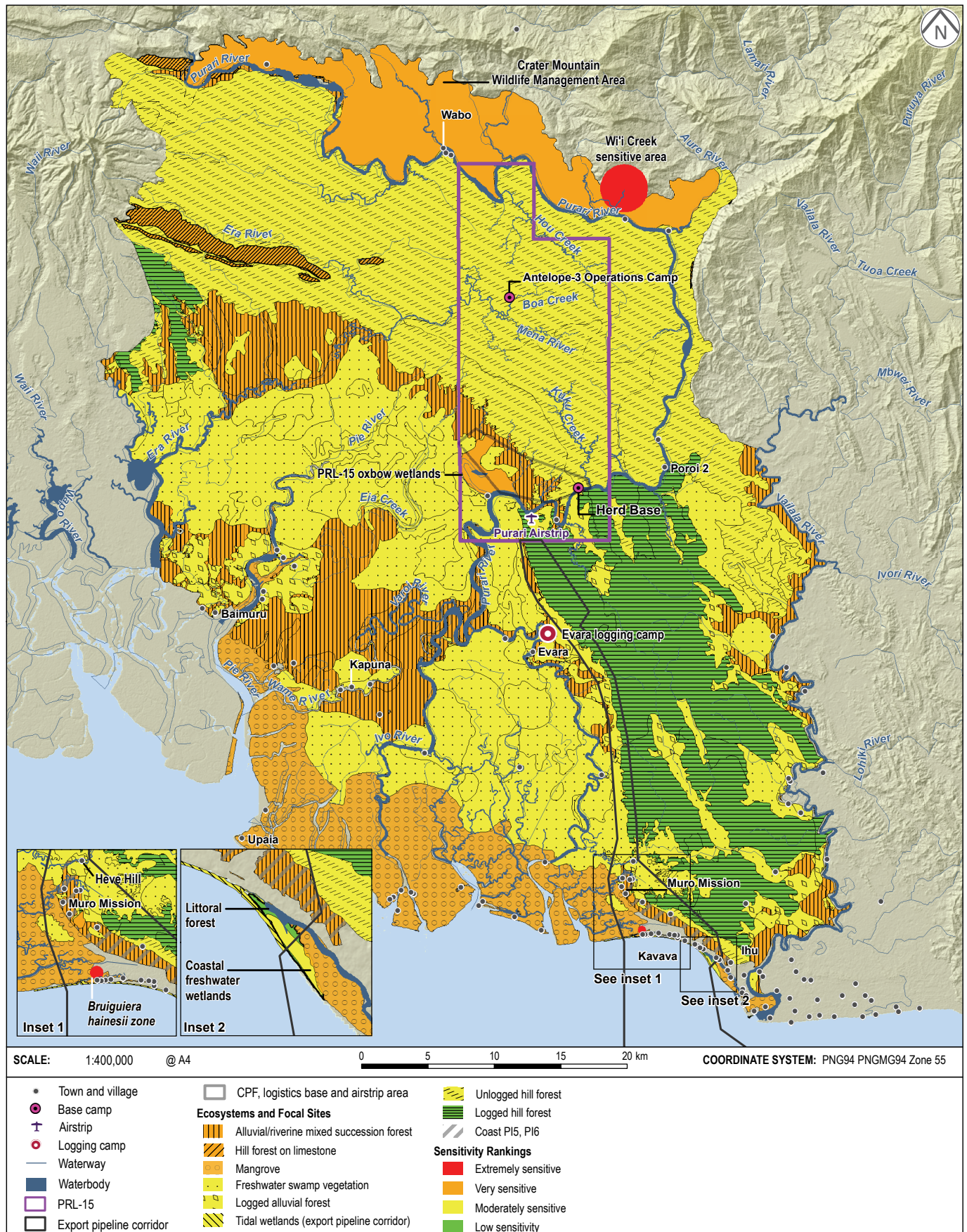
Two focal sites are considered to be Extremely Sensitive:

- ♦ The Wi'i Creek cave, in which remains of the IUCN Critically Endangered Bulmer's Fruit Bat were found (see Plate 7.37).
- ♦ The site supporting a population of the IUCN Critically Endangered mangrove tree *Bruguiera hainesii*.

SENSITIVITY MAP OF ECOSYSTEMS AND SELECT FOCAL SITES

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FIGURE 7.30



Communities outside of the Project area of influence have not been verified. Only government administrative centers and notable locations have been labeled for context.

Three focal sites are considered to be Very Sensitive:

- ♦ Caves: in general (i.e., other than the Wi'i Creek cave), for their potential to play a regionally significant role in supporting populations of multiple habitat-specialist species, for their somewhat limited regional availability and for their sensitivity to disturbance.
- ♦ Nesting sites for two crocodile species occurring in the study area.
- ♦ Nesting sites for two IUCN Vulnerable freshwater turtle species.

The features underpinning the assignments for those focal sites considered to be Moderately Sensitive or higher are outlined in Table 7.20.

7.8 Vegetation Regeneration

The information in this section has been summarized from the Upstream Vegetation Regeneration Baseline Report (Part 8 of Volume 2). Further, more detailed information is contained in that report.

7.8.1 Study Overview

The Upstream Vegetation Regeneration Baseline Report characterizes natural regeneration of different vegetation types on various landforms and substrates to identify the factors that will influence the assessment of rehabilitation requirements for areas that may be disturbed by Project construction activities. The regeneration requirements were investigated through assessment of:

- ♦ Passive rehabilitation by natural regeneration of a range of disturbed and constructed surfaces.
- ♦ Active rehabilitation requirements in potentially sensitive vegetation communities and poorly represented vegetation types (if present).
- ♦ Regeneration response/impacts in potential spoil sidelaying areas.
- ♦ Sensitive vegetation type resilience to potential impacts from (e.g., construction-related) earthworks.
- ♦ Potential effects of plant pathogens, in terms of rehabilitation success.

This baseline study was completed through a literature and spatial data review and by field surveys in June/July and September 2016 involving aerial survey, ground observation and vegetation sampling (regeneration assessment), and soil collection in a representative range of disturbed sites. Sites assessed included natural forest gaps, slumps and landslips, road alignments and associated cut and fill slopes, disturbed sites where vegetation has been cleared but topsoil remained intact, disturbed sites where topsoil has been cleared or eroded, and sensitive vegetation types where present and accessible.

Rehabilitation was assessed contextually in the terrestrial biodiversity study area, as outlined in Section 7.7.2 (see Figure 7.17), while the field-based assessment was undertaken in the area in which the proposed Project-related disturbance will occur, including PRL-15 and the export pipeline corridor.

7.8.2 Tropical Forest Rehabilitation

Influencing Factors

Broad approaches to and factors influencing tropical rainforest rehabilitation that are likely to be important for rehabilitation in the study area include soil type, water infiltration rates, soil modification, natural regeneration and active rehabilitation.

The five major soil-forming factors are climate, parent material, vegetation, relief and time. Differences in the combination of these factors result in soil types varying over relatively short distances, such as between ridge, slope, toe slope and valley features. The different soil types are characterized by differences in chemical and physical properties (Bleeker, 1983), which may affect their response to disturbance and their ability to act as a successful rehabilitation substrate once they are disturbed. Study area soils have been described in Section 7.2.

Rainfall infiltration into tropical soils is essential for ecosystem function and natural recovery processes and is dominated by two systems: 1) rapid drainage with short residence time through macropores created by soil fauna, and 2) slow drainage with longer residence in micropores where the moisture is retained by capillarity (Nortcliff & Thornes, 1989). If infiltration is inadequate, then accelerated runoff is likely to lead to an increased erosion risk.

Soil quality typically declines on modified (e.g., disturbed or constructed) surfaces due to degradation of the soil nutrient status and physical properties. Changes to soil physical properties include changes to soil texture (the proportion of sand, silt and clay), an increase in the proportion of rock fragments and an increase in the bulk density with an associated decrease in infiltration due to compaction (Ahirwal & Kumar, 2016). In addition, soil fertility is typically lower due to a loss of topsoil exposing less fertile subsoil or the leaching of nutrients from loss of the protective vegetation cover. In some circumstances, soils are completely lost leaving bare rock, which may have a 1 to 2 cm bryophyte crust on flat surfaces that eventually facilitates soil development and the establishment of pioneer plants in the thinnest of new soils.

Depending on the degree of disturbance, many plant species from tropical forests have the potential to rapidly regenerate or re-establish without intervention. Natural regeneration is highly successful for re-establishing native species to restore forest along flat terrain or even gently sloping terrain, provided that topsoil remains, erosion is not excessive and fire is excluded (Rogers, 2005). Relying entirely on natural regeneration; however, can be slow and ineffective, depending on the landscape and ecological conditions. Key aspects in natural regeneration that have been identified by both Parrotta (2002) and Holl and Cairns (2002) include:

- ♦ Seed availability.
- ♦ Seed germination.
- ♦ Competition with existing vegetation.
- ♦ Microclimate.
- ♦ Microhabitats.
- ♦ Fire.
- ♦ Soil nutrients.
- ♦ Soil microbial communities.
- ♦ Herbivores and predation.
- ♦ Social factors.
- ♦ Time.

Limitations or constraints may occur in each of the identified aspects of the rehabilitation process, which may limit the overall development rate of a forest ecosystem. Consequently, prior identification of constraining rehabilitation factors is important in assessing the likely success of natural forest re-establishment.

Active tropical forest rehabilitation, as distinct from relying entirely on natural regeneration processes, is an important approach to restore forest ecosystems, particularly on previously cleared lands (ITTO, 2002) where natural regeneration is unlikely to have the desired success. Typical strategies are built on understanding the establishment ecology of tropical forest species and may include:

- ♦ Defining any potential soil constraints to plant establishment and growth.
- ♦ Introducing topsoil where appropriate and when available.
- ♦ Planting seedlings of appropriate early colonizing tree species.
- ♦ Controlling grasses and groundcovers to prevent smothering and competition for resources.
- ♦ Enrichment planting as an appropriate microclimate develops, including using shade-tolerant tree species; incorporating the longer-lived largest forest trees that will eventually form the forest canopy; or indirectly encouraging the establishment of these species by attracting seed-dispersing fauna, such as through fruit-bearing pioneer tree species (Jasper & Tongway, 2005), which typically grow fast, reach sexual maturity quickly and produce prolific quantities of fruit. The seed-dispersing fauna subsequently introduce other species through seed in their droppings.

Where topsoil remains intact, rehabilitation by natural regeneration is considered to be the best approach to rehabilitate the range of vegetation types that occur in the study area. Where topsoil has been lost, active rehabilitation is likely to be required, involving dispersing cleared vegetation across disturbed and reformed surfaces, and planting fast-growing pioneer species. At very sensitive sites, further action (e.g., hydromulching) may warrant consideration.

Constraints to Successful Rehabilitation

In addition to the broad approaches to and factors influencing rehabilitation as described above, erosion, weeds and dieback have the potential to constrain successful rehabilitation in the study area.

Erosion

Erosion causes soil to be moved or worn away from an area, primarily leading to the loss of nutrient-rich topsoil and its associated viable seed bank. The soil seed bank is essential for providing rapid regeneration across disturbed surfaces; and most of the seeds (99%) are pioneer species with fast growth rates, and short life cycles that quickly reproduce to replenish the soil seed bank. The seeds of pioneer species remain viable in the soil for several years, from which forest regeneration occurs.

Disturbance from construction activities (e.g., roads or a pipeline right of way) will expose the landscape to modified levels of erosional forces from rain, flowing water and gravity (mass movement), the effects of which will vary according to the soil type (including stability or erodibility of the exposed surface soils or subsoils), terrain and position in the landscape (e.g., ridge, slope or valley), and the construction drainage techniques.

Consequently, construction activities result in different erosion risks throughout the Project footprint, especially activities in areas with unstable dispersive soils on steep slopes. High rates of

erosion on Project construction surfaces without prompt mitigation will create challenges for rehabilitation.

Weeds

Weed infestations, especially if severe, can reduce the rehabilitation success by out-competing native species. While some weed species already exist in the Project area (see Section 7.7.6.6), construction activities can provide a migration pathway for these weeds (e.g., through transport of equipment and machinery) into areas that were previously weed free or can bring additional invasive species into an area where they were previously not present. Further information on weeds that typically invade construction surfaces can be found in the Upstream Terrestrial Biodiversity Baseline Report (Part 6 of Volume 2) and its annexes.

Dieback

Forest dieback has the potential to prevent successful rehabilitation and can be spread through Project-related activities. The two main natural causes of forest dieback in Papua New Guinea are:

- ♦ Root rot associated with the fungal pathogen *Phytophthora* sp.
- ♦ Prolonged inundation from severe flood events, particularly across the lowlands of Papua New Guinea.

Phytophthora-related dieback in Papua New Guinea is confined to montane *Nothofagus* forests (southern beech) (Arentz, 1984, 1988), and therefore is irrelevant to the Project, as no *Nothofagus* forest is present in the study area.

Dieback related to plant pathogens (probably fungal) also occurs in Papua New Guinea's lowland zone (i.e., below 1,000 m asl), it but appears to be restricted to volcanic soils and is associated with roads and extensive pig activity.

Prolonged inundation occurs naturally, but changed hydrological conditions associated with construction earthworks can also cause flooding and therefore needs to be considered during the development of construction management plans at a later stage to reduce the risk of Project-induced dieback.

Localised patchy dieback, believed to be associated with land inundation due to changed surface hydrology from logging road construction, was recorded during the terrestrial biodiversity surveys along the export pipeline corridor, in an area of open alluvial forest (see Plate 7.69).

Plate 7.69 –Aerial View of Dieback with Dead Trees Adjacent to the River



Photo: Howard Rogers

7.8.3 Regeneration Response to Disturbance Across Different Surfaces

The regeneration characteristics of disturbed sites visited during the study are summarized in Table 7.23.

Table 7.23 – Regeneration Response to Different Disturbance Types

Disturbance Type	Substrate and Regeneration Response
Temporary clearance/cutting of woody vegetation	Vegetation is expected to rapidly regenerate where woody vegetation has been temporarily cleared, but soils and cut stumps remain relatively intact. Examples of good recovery from analogous natural disturbance events occur throughout the areas of hill forest where slumping has occurred. Based on forest recovery rates in logging gaps (Rogers, 2010), the rate of recovery from this type of disturbance is likely to be relatively fast with a closed canopy approximately 9 m tall being reached around five years after disturbance. Small clearings will regenerate, although typically regeneration is less abundant than in a large clearing. Raised microsites in these areas (e.g., a root mound) appear to be important for plant establishment. A raised microsite typically has better drainage and may receive more direct sun exposure to promote seedling/sapling growth. Summary: Excellent regeneration, particularly from cut stumps and previously suppressed saplings.
Complete removal of vegetation exposing topsoil	Where vegetation including stumps had been completely cleared, but topsoil remained, excellent regeneration was observed on gentle slopes around existing infrastructure sites. This capacity reflects moisture and temperature conditions that favor germination, a relative lack of competition from weed species, the application or dumping of salvaged topsoil with a viable soil seed bank, and/or relatively abundant seed rain from the adjacent forest. On sloping sites where the vegetation has been cleared, topsoil is particularly exposed to erosive rainfall events. Field observations suggest the topsoil and subsoil are rapidly lost in these high-rainfall events exposing unconsolidated sandstone or mudstone in areas of hill forest (Plate 7.70). These surfaces provide poor rehabilitation substrates and are mostly colonized by weeds or, on steeper slopes, vegetation may be absent.
Complete removal of vegetation exposing topsoil (cont'd)	Where surfaces are on gentle slopes with exposed unconsolidated sandstone substrate, several tree species will regenerate, particularly <i>Trichospermum</i>, <i>Alphitonia incana</i>, <i>Duabanga moluccana</i> and <i>Pipturus</i>. <i>Duabanga moluccana</i> was common along the ANT-3 access road and had a wide spreading crown that may assist with weed suppression. Summary: Poor regeneration on steep slopes due to high levels of topsoil erosion exposing subsoil; however, on gentle slopes in hill forest areas, regeneration on exposed topsoil was successful. On exposed sandstone substrate on gentle slopes, some tree species regenerate in the absence of topsoil.
Removal of vegetation and soil	Where complete removal of vegetation and topsoil occurs exposing subsoil and bedrock (e.g., during typical infrastructure construction), reinstatement may be required. In the study area, this is particularly applicable across hill forest where erosion will be at its highest, as this forest is underlain predominantly by siltstone and mudstone bedrock that forms part of the Southern Fold Mountains geomorphology region (see Section 7.2). Field observations suggest these substrates may be difficult to rehabilitate, as observed regeneration was poor and vegetation cover (apart from the occasional weed) was low across the representative sites (Plate 7.71). Poor regeneration is possibly reflecting the absence of topsoil and the associated soil seed bank, and a combination of poor rooting medium due to poor water-holding capacity, the blocky mudstone structure with little potential to form soil aggregates, and possibly low fertility. In particular, on slopes exposed to the sun, the mudstone is friable and dry and becomes hot with increasing sun exposure. Summary: Poor regeneration in areas of hill forest particularly across mudstone substrates, which become dry and friable. Sites often dominated by weeds.

Table 7.23 – Regeneration Response to Different Disturbance Types (cont'd)

Disturbance Type	Substrate and Regeneration Response
Sidecasting surfaces	In general, sidecast slopes are poor rehabilitation mediums because of a lack of topsoil and the small aggregate size of the upper slopes; better regeneration tends to occur at the base of sidecast slopes, as that is where large aggregates (e.g., large blocks of sidecast material) typically accumulate. Large aggregates are important for trapping organic matter (e.g., leaf litter and other plant debris) and plant propagules, and the organic matter decomposes providing a growing medium for seed germination. In PRL-15, sidecasting of excess spoil in hilly terrain was previously undertaken for exploration works associated with the construction of the existing Antelope and Elk wellpads. This sidecasting resulted in exposed surfaces; however, good regeneration was present on all the sidecast surfaces, except on a steep slope at ANT-3 where subsequent surface landslips had occurred (Plate 7.72). Where sidecast slopes are stable, the majority of them support good regeneration. The presence of regenerating forest reflects the sidecasting of topsoil, within which the first 10 cm supports the majority of the soil seed bank. Summary: Good regeneration where topsoil has been dispersed across the slope, but potential for landslips across steep slopes.
Wellpad surfaces	Wellpad surfaces are characterized by flat hardpack, normally made of crushed bedrock with variable drainage, possibly attributable to differing degrees of compaction. They often have steep side slopes. In the study area, where surfaces are waterlogged, little or no forest regeneration was present; however, weeds were abundant, including the Priority 1 weed <i>Angelonia angustifolia</i> at Elk-1 (see Section 7.7.6.6 and Plate 7.51). In contrast, well-drained hardpack surfaces lead to poor surfaces being present for any type of vegetation establishment other than occasional grasses and cryptogams, for example at ANT-1 (Plate 7.73). Bryophyte crusts were also present in the study area, particularly on the flat wellpad surface at ANT-1. Summary: Poor regeneration due to waterlogging across a surface, or poor regeneration caused by compacted well-drained hardpack. Poorly drained surfaces infested by weeds.

Plate 7.70 – Erosion of a Sandstone Substrate Leaving a Subsoil Pedestal

Photo: Howard Rogers.

Plate 7.71 – Regeneration Failure on a Convex Mudstone Substrate Surface

Photo: Howard Rogers.

**Plate 7.72 – Landslip on a Sidecast Slope
Showing Failed Regeneration**



Photo: Howard Rogers.

**Plate 7.73 – Bare Hardpack on a Wellpad
Surface**



Photo: Howard Rogers.

7.8.4 Rehabilitation of Vegetation Types and Landforms

Major differences in forest types in the study area are associated with varying landforms, also reflecting major differences in drainage and potentially in soil type. Construction works may impact vegetation and soil types associated with these different landforms in different ways, reflecting variation in natural regeneration capacity and associated soil properties such as stability (resistance to erosion) and fertility.

The proposed Project infrastructure will traverse a range of lowland vegetation types and associated landforms. Of these, some are poorly represented across the study area, while others are sensitive vegetation types that are likely to be difficult to rehabilitate, may be subject to regeneration failure if disturbed or are a particularly important resource of restricted distribution for local communities for ecosystem services. Disturbances that result in topsoil loss, drainage changes, soil compaction or substantial sedimentation may impact all the vegetation types. Consequently, where impacts are more severe, any vegetation type may be more difficult to rehabilitate (i.e., potentially sensitive) than at other locations.

Vegetation types and landforms often impacted by general construction activities, such as earthworks, are summarized in Table 7.24 with their rehabilitation requirements. Of these, three vegetation types are identified as potentially sensitive and may require additional rehabilitation measures if disturbance cannot be avoided.

Table 7.24 – Rehabilitation Constraints of Vegetation Types and Landforms

Vegetation Type (Hammermaster & Saunders, 1995a)	Landform (Field Observations and Löffler (1974))	Main Rock Type	Rehabilitation Constraints
Low Altitude Forest on Uplands – Below 1,000 m			
Hill forest (Hm)	Hilly terrain with weak or no structural control Homoclinal ridges and cuestas	Mixed or undifferentiated sedimentary Fine grained sedimentary	The hilly terrain and erosive soils of the hill forest BVG may present constraints to rehabilitation due to rapid topsoil loss in a high-rainfall environment where the vegetation cover has been removed. Rehabilitation of hill forest will be most challenging across steep slopes where erosion is likely to be high and particularly where mudstone is exposed, which quickly dries to a blocky friable structure in which plants appear not to regenerate (see Plate 7.71).
Small crowned hill forest (Hs)	Hilly terrain with weak or no structural control	Mixed or undifferentiated sedimentary	
Low Altitude Forest on Plains and Fans – Below 1,000 m			
Alluvial forest (PI)	Composite levee plain	Alluvial deposits	Rehabilitation of alluvial forest across the upstream study area may present constraints due to the potential for damage of poorly drained soils if disturbed (e.g., compaction or damage to soil structure and the associated soil seed bank). Forest dieback was identified at one location in the export pipeline corridor in an area of Open alluvial forest (Po) where canopy dieback and tree mortality was evident across low-lying areas in approximately 60 ha of forest (see Plate 7.69). While this area is likely to have been naturally swampy and subjected to prolonged inundation, the partial logging of the area and construction of a major logging truck haul road within 100 m of the area may have further impeded drainage.
Open alluvial forest (Po)	Composite levee plain	Alluvial deposits	
Freshwater Swamp Habitats			
Swamp forest (Fsw)	Composite levee plain	Alluvial deposits	Swamp forest (Fsw) is a very poorly drained forest type and is likely to be subjected to more prolonged inundation than other alluvial forest types. Consequently, a higher degree of water ponding and localized regeneration failure may occur. The soil structure of more poorly drained soils will also be more sensitive to damage from compaction by heavy machinery movements.
Swamp woodland (Wsw)	Composite levee plain	Alluvial deposits	Swamp woodland (Wsw) is a poorly represented vegetation type in the study area; and the waterlogged nature of the soil profile is potentially very susceptible to disturbance from construction damage, particularly from heavy machinery. Swamp woodland (Wsw) is usually dominated by sago palms (Metroxylon sagu), which have the capability to regenerate from seed and suckers. Consequently, Swamp woodland (Wsw) has good regeneration characteristics when only palms are cut back, as it can recover quickly from suckers. Additionally, sago seed is water transported and will float back into disturbed

Table 7.24 – Rehabilitation Constraints of Vegetation Types and Landforms (cont'd)

Vegetation Type (Hammermaster & Saunders, 1995a)	Landform (Field Observations and Löffler (1974))	Main Rock Type	Rehabilitation Constraints
Freshwater Swamp Habitats (cont'd)			
Swamp woodland (Wsw) (cont'd)			sites once construction has been completed. The main rehabilitation limitation is sedimentation, which can cause vegetation dieback. Sedimentation can cover the aerial roots and can impede drainage, resulting in fine root death caused by a lack of oxygen. <i>Pandanus</i> sp. also occasionally dominates Swamp woodland (Wsw). In the study area, this is a poorly represented vegetation type. <i>Pandanus</i> species regenerate from seed, but many <i>Pandanus</i> species also regenerate from branch cuttings. This vegetation type is restricted in occurrence and associated with heavily waterlogged soils; disturbance of this vegetation type can damage soils and interfere with water flows. <i>Pandanus</i>-dominated Swamp woodland (Wsw) has been identified as potentially sensitive and may require additional rehabilitation measures if disturbance cannot be avoided.
Herbaceous swamp (Hsw)	Composite levee plain	Alluvial deposits	Herbaceous swamp (Hsw) is often a thick mat of vegetation floating on relatively shallow water; it will not support heavy machinery. Herbaceous swamp (Hsw) is not a common vegetation type in the study area. Herbaceous swamp (Hsw) has been identified as potentially sensitive and may require additional rehabilitation measures if disturbance cannot be avoided.
Swamp grassland (Gsw)	Composite levee plain	Alluvial deposits	Swamp grassland (Gsw) often occurs along the river banks. Construction in this vegetation type can therefore cause river bank erosion. This vegetation type will not support heavy machinery. Swamp grassland (Gsw) has been identified as potentially sensitive and may require additional rehabilitation measures if disturbance cannot be avoided.
Estuarine Community			
Mangrove (M)	Mangrove swamps	Estuarine deposits	Mangroves are important for erosion protection, are an important resource for local communities for fishing and harvesting mud crabs, and present high-value ecosystem attributes (e.g., fish nurseries); therefore, mangrove rehabilitation is a priority. In the study area, mangroves dominated by the palm <i>Nypa fruticans</i> are lower lying than those dominated by forest. They are important for preventing coastal erosion (Ellison, 1997). Regeneration of palm-dominated mangroves is primarily from seed but also occurs from its rhizomatous stem when the plant is damaged (e.g., after severe disturbances such as

Table 7.24 – Rehabilitation Constraints of Vegetation Types and Landforms (cont'd)

Vegetation Type (Hammermaster & Saunders, 1995a)	Landform (Field Observations and Löffler (1974))	Main Rock Type	Rehabilitation Constraints
Estuarine Community (cont'd)			
Mangrove (M) (cont'd)			tsunamis). Rhizomatous-vegetative regeneration may allow palm-dominated mangroves to regenerate effectively without intervention (Dahdouh-Guebas et al., 2005), while regeneration from seed may not always be effective since most of the seed is likely to be washed away at high tide (Rozainah & Aslezaeim, 2010). Mangrove forest rehabilitation has been achieved through planting and through natural regeneration, with different degrees of success. Mangroves are mostly shade intolerant and can also suffer heavy seed predation by crabs, preventing seedling establishment (Barnuevo et al., 2017). When planted in high density, shade can prevent natural regeneration; and a planted mangrove forest can lack the stand structure and diversity of the original forest. Natural mangrove regeneration has been found to be more successful than planting; however, tidal flows strongly influence the initial species composition, which results in a wide dispersal (i.e., reduced retention) of lighter propagules and large clusters of species with heavier propagules, particularly in cleared areas. Overall, the level of tidal inundation a disturbed site is influenced by determines the suite of regenerating species due to the species-specific thresholds to flooding (Friess, 2016). Mangrove (M) has been identified as potentially sensitive and would likely require additional rehabilitation measures if disturbance cannot be avoided.
Littoral Forest			
Littoral forest (B)	Beach ridge complexes	Marine sands	Littoral vegetation is considered a sensitive vegetation type because of potential rehabilitation constraints. It consists of herbaceous beach vegetation (Plate 7.74), beach scrub, beach woodland and Littoral forest (B) communities. Littoral forest (B) is also a poorly represented vegetation type, reflecting its naturally restricted distribution on older marine sands in the Southeast Coast ecological zone (see Section 7.7.3). Most of the communities present have a relatively thin topsoil layer that would be difficult to salvage for rehabilitation and would be readily dispersed or easily eroded by heavy rainfall if the vegetation were cleared. Littoral vegetation has been identified as potentially sensitive and may require additional rehabilitation measures if disturbance cannot be avoided.

Plate 7.74 – Littoral Forest Herbaceous Beach Vegetation

Photo: Howard Rogers.

7.9 References

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