# PAPUA LNG PROJECT

## UPSTREAM ENVIRONMENTAL IMPACT STATEMENT

## VOLUME 2: ENVIRONMENTAL AND SOCIAL BASELINE STUDIES

## Part 6: Upstream Terrestrial Biodiversity Baseline Report
## Annex 3: Upstream Bats (Chiroptera) Baseline Study Report

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TOTAL E&P PNG LIMITED

December 2019
(Report No. 01215B_1-2_v5)

# Upstream Bats (Chiroptera) Baseline Study Report

## Papua LNG Project

## Total E&P PNG Limited

**August 2017**

**01215B_25-1-2_v5**

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Report Reference Number: 01215B_25-1-2_v4

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# Acronyms and abbreviations

| Term | Definition |
|---|---|
| ABTC | Australian Biological Tissue Collection, South Australian Museum |
| AMS | Australian Museum, Sydney |
| ANS | Academy of Natural Sciences, Philadelphia |
| asl | above sea level |
| BC-UPNG | Biology Department Collection, University of Papua New Guinea |
| BST | Body Sub Type (part of the bat echolocation call type nomenclature) |
| c. | *circa* (meaning approximately) |
| CEPA | Conservation and Environment Protection Authority |
| CITES | Convention on International Trade in Endangered Species of Wild Fauna and Flora |
| CPF | Central Processing Facility |
| CR | Critically Endangered (IUCN threat category) |
| DD | Data Deficient (IUCN threat category) |
| EN | Endangered (IUCN threat category) |
| EIS | Environmental Impact Statement |
| ESBS | Environmental and Social Baseline Survey |
| FIMS | Forest Inventory Mapping System |
| GPS | Global Positioning System |
| IFS | Initial Frequency Sweep (part of the bat echolocation call type nomenclature) |
| IUCN | International Union for Conservation of Nature |
| kHz | kiloHertz (unit of frequency; used to characterize bat echolocation calls) |
| km | kilometers |
| LC | Least Concern (IUCN threat category) |
| m | meters |

| Term | Definition |
|---|---|
| mCF | Million cubic feet |
| mm | millimeters |
| NA | not applicable, or not available |
| NT | Near Threatened (IUCN threat category) |
| P | Species protected under the Papua New Guinea *Fauna (Protection and Control) Act 1966* |
| PNG | Papua New Guinea |
| PNG-NMAG | Papua New Guinea National Museum and Art Gallery |
| SAM | South Australian Museum, Adelaide |
| sp. | species (singular) |
| spp. | species (plural) |
| TFS | Terminating Frequency Sweep (part of the bat echolocation call type nomenclature) |
| Upstream PAOI | Upstream Project Area of Influence |
| VU | Vulnerable (IUCN threat category) |
| WMA | Wildlife Management Area |

# Glossary

| Term | Definition |
|---|---|
| anonymous calls | Bat echolocation calls from an unattended overnight recording session that need to be identified to species or call type. |
| bat detector | A digital recording device that has a microphone sensitive to ultrasonic signals, and which can record these ultrasonic signals to flash memory media. |
| central cordillera | The central mountainous spine of New Guinea that runs from the eastern edge of the Bird's Head Peninsula in Indonesian New Guinea to the eastern tip of mainland Papua New Guinea. |
| cryptic species | Species that appear very similar or identical but are genetically distinct. |
| Ecological vicars | Two or more species that perform effectively the same ecological role, but in different areas or communities. |
| endemic | Belonging exclusively, or confined to, a particular locality or defined geographic area. |
| exotic | Not native or occurring naturally in the study area, introduced from elsewhere by direct or indirect human action. |
| karst | A landscape formed from the dissolution of soluble rocks, typically limestone, to form a variety of surface and underground features including karren, cavities and caves, and cave formations (speleothems). |
| mangal | Mangrove community. |
| species new to science | A species or taxon that has not been encountered previously, and is effectively 'undiscovered' by western science. Differs from an 'undescribed species' as defined here. |
| reference calls | Bat echolocation calls that are obtained from an individual bat that is then taken as a whole specimen voucher, so that the identification can be verified later if required. Anonymous calls (*see above*) are identified based on the information from reference calls. |
| study area | The study area (abbrev. upstream terrestrial biodiversity study area) is a general reference for the area to be characterized under the terrestrial biodiversity study. |
| sympatry/sympatric | Populations occurring together within the one locality or habitat. Often used as the basis for validating closely-related species. |
| taxa | Plural of taxon. |
| taxon | A general reference to a species or subspecies—whether it is described formally, or is suspected of being a distinct species or subspecies that has not yet been examined in a taxonomic study and described formally. |
| taxonomy | The science of naming, classifying and identifying organisms. |

| Term | Definition |
|---|---|
| undescribed species | A taxon that has been encountered previously (prior to the present study), and is thought to be a unique species, but has not yet been formally described (scientifically 'named'). Differs from a 'new to science species' as defined here. |
| Upstream Project Area of Influence | Located within the broader study area, the Upstream PAOI includes the area within which the Project may potentially and measurably impact biodiversity through direct, indirect and/or cumulative impact processes. |

# Executive summary

Joint venture partners, Total E&P PNG Limited (TEP PNG) (40.13%), ExxonMobil (XOM) (37.03%) and Oil Search Limited (Oil Search) (22.84%), are currently planning the development of the Elk-Antelope gas field, which is located in the Gulf Province, Papua New Guinea.

The Elk-Antelope gas field is located within Petroleum Retention License 15 (PRL-15) in Baimuru District in the interior lowlands of Gulf Province approximately 120 km northwest of Kerema and 360 km northwest of Port Moresby. The purpose of this technical study report is to present results of the baseline assessment of bat (Chiroptera) communities present in the upstream terrestrial biodiversity study area (study area).

Bats were surveyed at 11 main sites through a comprehensive approach that incorporated trapping (mist nets: 71 positions, 38,304 net-meter-hours; and harp traps: 42 positions, 111 trapping nights), observation, examination of owl pellet bone accumulations, and acoustic recordings using 'bat detectors' (199 recording nights). Captured bats were identified from external morphology. Echolocation calls in the acoustic recordings were recognized and organized with a custom semi-automated data analysis pipeline, and then attributed to species based on information in published and unpublished sources.

A list of 47 bat species that potentially occur in the study area was compiled from various published and unpublished sources prior to the survey. At least 39 species of bat were recorded over 11 survey sites, including 25 species that were trapped (21 species in harp traps; 16 species in mist nets) and at least 24 species that were detected via acoustic recordings. Of the 39 species recorded, 34 had been predicted to occur in the study area.

The IUCN Critically Endangered (CR) Bulmer's Fruit Bat *Aproteles bulmerae* was confirmed for the study area based on recently deposited skeletal remains in the Wi'i Creek cave owl roost deposit. The presence of isolated teeth of juveniles suggests that the site is, or was recently, a maternity site for this species. This occurrence is consistent with other recent records of Bulmer's Fruit Bat from owl roost deposits at low elevation karst in southern Papua New Guinea. These findings dispel previous notions (based on captures of living animals at two sites) of this species as a montane forest specialist, but while they extend both its geographic and ecological range, and point to new areas where extant populations might be sought, they do not necessarily mean that the species is widespread or anywhere abundant.

Three bat species listed as Data Deficient (DD) by the IUCN were also recorded (or thought to be present based on the most likely attribution of echolocation calls; New Guinea Sheath-tailed Bat *Emballonura furax*, Papuan Sheath-tailed Bat *Saccolaimus mixtus*, and New Guinea Free-tailed Bat *Otomops papuensis*), with the possibility of one other DD species, Semon's Leaf-nosed Bat *Hipposideros semoni*.

At least one undescribed species was captured, and one more potentially undescribed species was recorded acoustically. The capture was of an undescribed relative of the Papuan Long-eared Bat *Nyctophilus microtis.* Call type *75 mCF* may represent an unknown species of leaf-nosed bat, designated in this report as *Hipposideros* sp. 1.

Identification of some captured bats and recorded call types to species was problematic because of unresolved issues with taxonomy. Among 16 taxa where names are qualified by the term 'cf.' (applied where there is insufficient information for confident species determination), there are likely to be several additional 'cryptic' species that require further attention by taxonomists. Selected examples include: unstriped tube-nosed fruit bats *Paranyctimene* spp. which may be represented by both *P. raptor* and *P. tenax*; striped tube-nosed fruit bats *Nyctimene* cf. *'albiventer'*, which includes at least two undescribed forms known to be present and widespread within Papua New Guinea; Papuan Long-eared Bat *Nyctophilus microtis* with captures of two morphological forms; and several call types of the Vespertilionidae that are suspected to contain cryptic species based on differences in

morphology noted from captures on the present survey, and elsewhere. No taxon with recognized taxonomic issues encountered on the survey is thought to be restricted to the study area.

Calculations of relative abundance (the proportional representation of each call type among recording positions in each site) and community level analyses showed that the mangrove community of echolocating bats was distinct from communities in the remainder of the study area. The mangroves support a subset of bat species present in the alluvial and hill forest habitats, with an absence of hipposiderids and high relative abundance of some common species (*Miniopterus* cf*. medius, Nyctophilus* cf. *microtis, Pipistrellus angulatus*) that might roost in adjacent forest habitats and forage in the mangal. This finding implies that the persistence of mangrove bat communities (and of the wider mangrove ecosystem) depends to a significant degree on the existence of a substantial buffer zone in surrounding habitats in which many species of bats that forage in the mangroves spend their daylight hours.

No species of bat is likely to be endemic or restricted only to the study area, but three can be considered as ‘range-restricted’ (Bulmer’s Fruit Bat *Aproteles bulmerae*; the Papuan Free-tailed Bat *Otomops papuensis* and Watts’s Pipistrelle *Pipistrellus wattsi*). Most of the species found in the study area are known to be distributed widely throughout mainland New Guinea, and also extend to island groups to the east or west, or south to Australia (encompassing endemism categories 1–3; Table 1). Three taxa are distributed widely on New Guinea but do not occur elsewhere (category 4; Wollaston’s Leaf-nosed Bat *Hipposideros wollastoni*; the Fly River Leaf-nosed Bat *Hipposideros muscinus*; and the Fly River Woolly Bat *Kerivoula muscina*).

# 1 Introduction

## 1.1 Background

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

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

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

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

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

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

As part of the Project environmental, social and health impact assessment (ESHIA), a Terrestrial Biodiversity Baseline Study has been commissioned to provide a baseline characterization of terrestrial biodiversity and conservation values present in the vicinity of the Upstream Project area. This report presents the results of the technical study on odonata conducted as part of the Terrestrial Biodiversity Baseline Study.

## 1.2 Upstream Terrestrial Biodiversity Study Area and Ecological Zones

The upstream terrestrial biodiversity baseline study area (hereafter 'study area') covers approximately 7,290 $km^2$ of the Gulf Province lowlands (to c. 600 m above sea level (asl)). The study area is divided into five ecological zones, each of which is expected to support a distinct assemblage of terrestrial biota—the Middle Purari Hills, Southeast Hills, Delta Swamps and Plains, Mangroves, and Southeast Coast.

The study area encompasses the upstream project area of influence (upstream PAOI), the area within which the Project may potentially and measurably impact biodiversity. The terrestrial biodiversity field surveys were focused at representative sites within the upstream PAOI, hereafter referred to in this report as survey sites. Further description of the PAOI is provided in the main Upstream ESBS report and is no longer referred to in this report.[1]

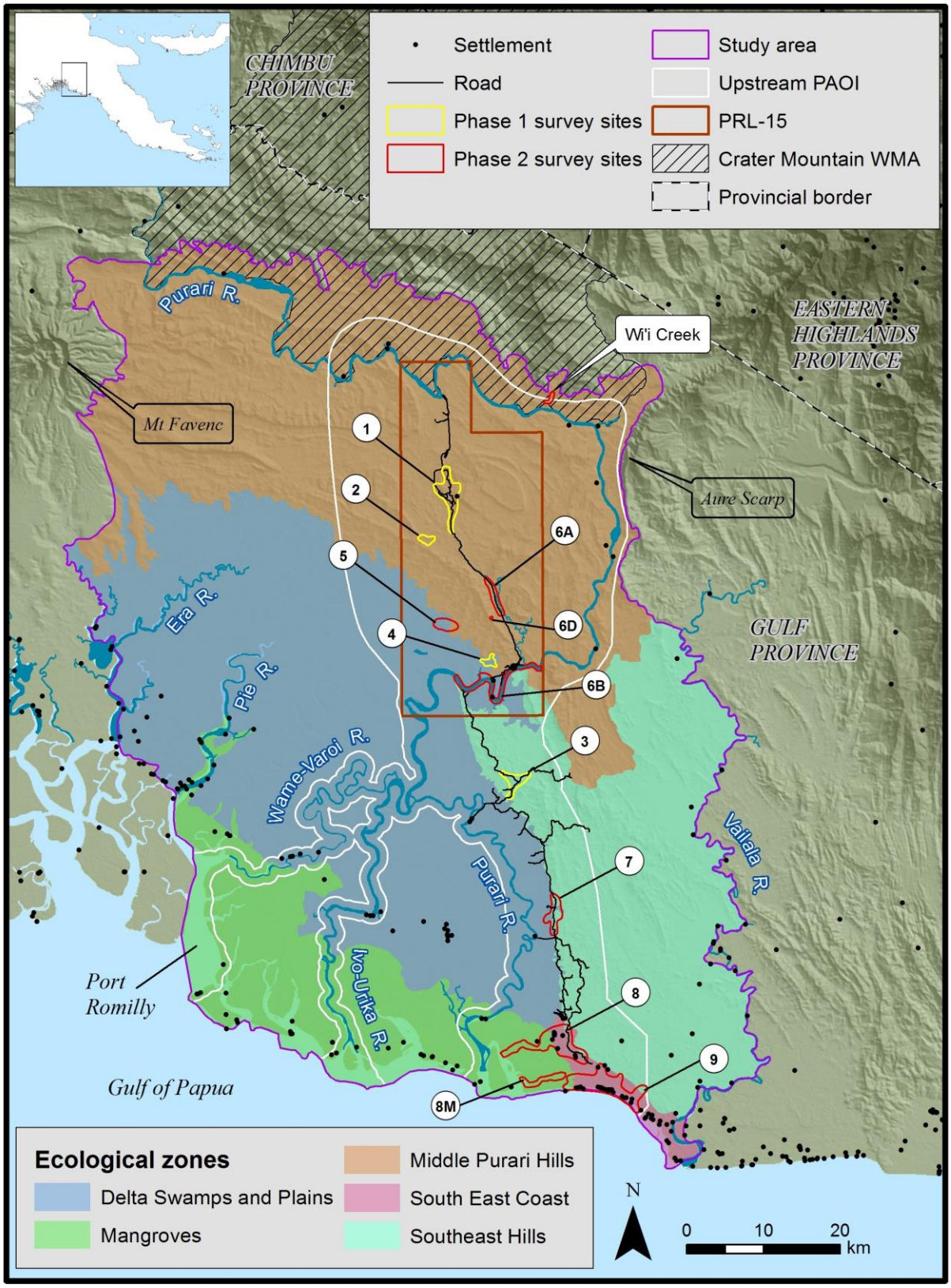
The study area and its component ecological zones are shown in Figure 1. They are described in more detail in the Upstream Terrestrial Biodiversity Baseline Report.

## 1.3 Technical study objectives

The objectives of this technical study are:

- To collate and assess existing information relevant to bat communities in the vicinity of the study area.
- To survey bat communities present in the study area.
- To describe and discuss the composition, condition and conservation significance of bat communities present within the study area, including:
  - The presence and status of species of conservation significance recorded or potentially present.
  - Habitats and other landscape features important to bat communities.
- To summarize knowledge gaps in relation to bat communities present within the study area.

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




Note: Not all sites were surveyed under the bat technical study. Information on the sites surveyed is presented in Section 3.1.

**Figure 1 – The study area and its component ecological zones, the Upstream PAOI and the location of Phase 1 and 2 terrestrial biodiversity study survey sites (numbered 1–9)**

# 2 Existing information

This section summarizes existing knowledge relevant to understanding the distribution and status of bats within the study area. The first part of this section summarizes existing knowledge from within the study area, and the second part from areas surrounding it.

## 2.1 Existing knowledge for the study area

The lower reaches of the Purari River catchment are among the least studied parts of Papua New Guinea for bats. The earliest confirmed records date from as recently as the mid-1970s, and even now there are almost no publicly available data for the study area.

### 2.1.1 PNG Fisheries and Wildlife Division Surveys 1974–1977

The objective of surveys by the PNG Fisheries and Wildlife Division was to inventory wildlife resources with special reference to those used by local communities, and to assess the potential effects that large-scale development might have on these resources (Liem 1983). Surveys were conducted between Wabo and the Orokolo Bay coast, with a strong focus on riverine habitats and included the use of mist nets and selective shooting. Specimens collected during the surveys were originally held at the Wildlife Division facility at Moitaka and some at least were later transferred to the PNG National Museum (PNG-NMAG) in Port Moresby. There appears to be no published list of bat species recorded and only two of the larger species that are hunted received later mention—*Pteropus macrotis* and *P. neohibernicus*.

### 2.1.2 Wabo Hydroelectric Scheme Environmental Studies 1977–1982

Environmental studies were carried out in 1977–1982 to support the potential development of a hydro-electric project with a proposed dam site near Wabo, and reported in 21 technical report volumes. No new mammal surveys were carried out during these studies but selected data from the Wildlife Division surveys were presented, albeit usually in summary form. Volume 3 by Liem and Haines (1977) contains a review of the ecology of the mangrove and estuarine communities, and includes mention of flying-foxes (*Pteropus* spp.) as part of this community.

The Wabo Hydroelectric Scheme studies were later edited into a publicly available monograph (Petr 1983) that included summaries by Pernetta (1983) of wildlife (including mammals) known from the area and by Liem (1983) of wildlife known to be used by local communities. Bats receive brief mention in both accounts.

### 2.1.3 2011–2012 Purari Hydropower surveys

In 2011, new environmental studies were commissioned as part of renewed interest in developing a hydro-electric dam in the northern part of the study area upstream of Wabo (Middle Purari Hills). Three multi-disciplinary biodiversity surveys were undertaken in 2011–2012. A detailed bat survey, including the extensive use of acoustic recording methods, was carried out by Ken Aplin (field work) and Kyle Armstrong (analysis), and the resulting dataset ranks among the most detailed for any region of Papua New Guinea. An EIS was not submitted to government authorities and the data are not available publicly for use in this study.

### 2.1.4 Studies commissioned for development of the Elk-Antelope gas field

Environmental studies within PRL-15 were commissioned by the previous operator (InterOil) in support of approvals for several petroleum development proposals. These studies cover areas within and southeast of PRL-15, and were variously carried out by DES (2008, 2010) and included other unpublished reports. Bats were assessed to some extent by all of these studies, which are reviewed briefly below.

**Douglas Environmental Services**

Douglas Environmental Services (DES) conducted two site-based flora and fauna studies and one preconstruction survey within PRL-15 during the period 2008–2010. Their fauna survey programs comprised:

- Survey at six sites over 11 days in June 2008, with additional incidental observations made at points along the Purari River including Staging, Wabo and various unidentified villages (DES 2008).
- Surveys conducted at 25 sites over 11 days in July 2010 (DES 2010).

Mist nets were deployed for bats during the 2008 survey but the survey effort is not indicated. The netting resulted in captures of two species that were identified as *Nyctimene albiventer* and *Syconycteris australis*. Figure 45 in DES (2008) shows a small *Nyctimene* that would be identified as '*albiventer*' using current literature. A pipistrelle (*Pipistrellus* sp.) was reported (DES 2008: 79) as common around lights at Staging Camp, but this was not supported by capture. The survey carried out in 2010 did not employ mist netting but two species of bats were recorded—*Pteropus neohibernicus* and *Aselliscus tricuspidatus*.

**Unpublished Reports**

A series of rapid assessment vertebrate fauna surveys were coordinated along a proposed pipeline route south of PRL-15, through the lower Purari River and Vailala River catchments. Bats were surveyed by deployment of a single 'AnaBat' bat detector unit, which was carried during evening spotlighting surveys and then positioned in camp for the remainder of the night. No mist netting was carried out.

Surveys were conducted at six sites over 18 days during November–December 2008: three sites each in the Purari River and Vailala River catchments, including five sites within the present study area (Middle Purari Hills ecological zone, three sites; Southeast Hills ecological zone, two sites).

A total of 25 distinctive call types was recognized, which was thought to represent "somewhere between 16 and 30 different species". Illustrations of each call types were included which allows for reassessment in the light of reference calls that have accumulated since that time. This reassessment is presented in Appendix 1.

A preconstruction survey was carried out along a proposed right of way (ROW) over five days in March 2011 that included use of an 'AnaBat' bat detector over an unspecified number of nights. No mist netting activity was reported.

The AnaBat survey is reported to have detected 21 microbat species, although only 11 call types are listed. The call types are listed by structure and characteristic frequency with tentative identification of some to family but the call types were not illustrated. The lack of precise taxonomic assignment was appropriate in view of the absence of a reference call library for Papua New Guinea bats. However, later in the report two species of *Otomops* are listed as present in the study area with the statement: "The AnaBat recordings detected a call sequence very close to this species and it is being treated as if it is present within the Project Area". These species were not indicated in the earlier summary of AnaBat results and it is not possible to verify the records as *Otomops* spp. because no calls were illustrated.

In 2012, an impact assessment was completed for an entire upstream project proposal; no additional fauna data were provided.

## 2.2 Existing knowledge from surrounding areas

Three areas are of direct relevance to the study area: 1) the Purari River catchment uplands to the immediate north; 2) the Vailala and Lakekamu River basins to the east; and 3) the Kikori River basin to the west.

### 2.2.1 Purari River catchment uplands

The Purari River drains more than 25,000 $km^2$ of New Guinea's central cordillera. To the immediate north of the study area, the landscape of the Purari River catchment is dominated by two extinct volcanoes, Mount Karimui in the west and Crater Mountain in the east (Löffler 1977). Both rise to elevations above 2,500 m asl. Wherever the limestone strata are exposed they are heavily karstic and contain innumerable caves and sinkholes.

Each of Mount Karimui and Crater Mountain has attracted considerable attention from biologists. The earliest records from Mount Karimui are of blossom bats (species of *Syconycteris* and *Macroglossus*) collected by J. H. Sedlacek in 1963 and in the BPBM, Hawai'i (reported by Hide et al. 1984). Between 1980 and 1982, anthropologist Robin Hide documented patterns of land use including wildlife exploitation in the area (Hide et al. 1984). During this period, Mount Karimui was also visited by a team from the PNG Wildlife Division who recorded several additional bat species. Drawing on all of these sources, Hide et al. (1984) was able to list only eight bat species occurring between 800 m and 1,300 m asl on and around Mount Karimui. All specimens collected by Hide are present in the Biology Collection of the Biology Department, University of Papua New Guinea (BC-UPNG). In 1984, a joint expedition from the South Australian Museum (SAM) and University of New South Wales (led by Ken Aplin) spent two months surveying vertebrates (including mammals) in the Mount Karimui area. A total of 21 bat species was recorded, including all but one of those reported by Hide et al. (1984). The voucher collections are present in the Australian Museum, Sydney (AMS) and associated tissue samples in the Australian Biological Tissue Collection (ABTC) of the South Australian Museum.

The earliest bat sampling in the Crater Mountain area was carried out by Aplin during a 10-day visit to Haia Mission at 600 m asl in 1984. Only three species were recorded, with specimens lodged as per the remainder of the Karimui collection. Intensive ecological work in this area commenced following establishment of the Crater Mountain Wildlife Management Area (WMA) in 1994. Two studies have focused on the ecology of bats—an unpublished Honours thesis by Ms Kore Tau on cave-roosting fruit bats (during which a population of the IUCN Critically Endangered Bulmer's Fruit Bat *Aproteles bulmerae* was discovered) and unpublished studies by Nancy Irwin on tube-nosed fruit bats (*Nyctimene* spp. and *Paranyctimene* spp.). No general inventory of the bat fauna of the Crater Mountain WMA has been produced, though small numbers of voucher specimens have been lodged in the PNG-NTMAG) and at the University of Kansas Natural History Museum (KU), Lawrence, Kansas.

### 2.2.2 Vailala and Lakekamu River basins

The only recent information on bats of the Vailala River basin, to the immediate east of the Purari River catchment, comes from the November-December 2008 surveys reviewed above. *Otomops papuensis* was described in 1948 from a specimen from "Vailala River" (Lawrence 1948).

The Lakekamu basin is a small catchment which spans the border between Gulf and Central provinces in the southern foothills of the Owen Stanley Range. The Lakekamu River meets the coast immediately east of Kerema, and its middle and upper reaches remain heavily forested (Mack 1998).

The coastal portion of the Lakekamu River basin was surveyed in the early to mid-1960s as part of a Commonwealth Scientific and Industrial Research Organisation (CSIRO) Land Systems Research survey that included the Kerema district of eastern Gulf Province (Mabbutt et al. 1965). In 1966, this survey work extended to the coastal lowlands of eastern Gulf Province, overlapping with the southeast corner of the study area, including the Southeast Coast and parts of the Southeast Hills, Mangroves and Delta Swamps and Plains ecological zones (Ruxton et al. 1969). Bats were not

surveyed in these habitats but a side visit to a region of lowland karst habitat (elevations 165–260 m asl) in the vicinity of Putei Mission in March 1966 resulted in records of 17 species of bats (McKean 1972).

Biological survey of the forested inland habitats of the Lakekamu River basin commenced in 1979. Bats were first surveyed during a two-month period in 1996 under the Rapid Assessment Program (RAP) of Conservation International (Mack 1998). The bat survey employed mist nets and harps traps. Netting effort is stated as:

"39 mist-nets from 1-3 nights on 4 netlanes, all in alluvial forest" and the total effort as 12,965 net-meter-hours (Wright et al. 1998: 68). Two harp traps were deployed for a total of 88 harp-trap-nights. The results are summarized as follows: "*Syconycteris australis* was captured four times more frequently than any other bat species (33 individuals). Next plentiful were *Nyctimene albiventer* (9), *Aselliscus tricuspidatus* (8) and *Paranyctimene raptor* (6). Low numbers were found of *Hipposideros cervinus* (4), *Hipposideros muscinus* (3) and *Rhinolophus euryotis* (3). Only one *Hipposideros diadema* and one *Pipistrellus watt*si were found".

Voucher specimens were deposited in the PNG-NTMAG in Port Moresby and the Academy of Natural Sciences (ANS) in Philadelphia, USA. Tissues samples were deposited in the ANS.

### 2.2.3 The Kikori Basin Conservation Program

The Kikori River basin west of the study area is the most intensively biologically surveyed region of Papua New Guinea. Much of this information has accumulated since the late 1980s when commercial reserves of oil and gas were discovered in Southern Highlands Province. In partnership with industry leaders[2], in 1994 the World Wildlife Fund (WWF; now called the World Wide Fund for Nature) initiated the Kikori Integrated Conservation and Development Project, which continues under the title of the Kikori Basin Conservation Program[3] (Leary *et al.* 1995; McCall and Flemming 2000). Throughout this extended period of study, WWF and its partners have carried out multiple biodiversity surveys covering a broad range of taxa at elevations from sea-level to over 2,500 m asl. Bats were captured in mist nets and harp traps on the majority of these surveys. Acoustic recordings were made of some bat calls (as reference calls; Leary and Pennay 2011) but acoustic detection was not used comprehensively as a survey tool.

Leary et al. (1995) and Leary and Seri (1997) reviewed the available data for the Kikori River basin up to 1996. More recent work is detailed in Leary (2004). The combined list across all sites totals 24 species.

Mammal survey work was carried out on the southern flanks of Mount Sisa by Peter Dwyer in 1979–1980 (Dwyer 1990) and then in 1985 by a SAM team lead by Ken Aplin. The voucher collections were lodged in the AMS and associated tissue samples are in the Australian Biological Tissue Collection (ABTC) of the SAM. Although the results of these surveys are often included in reviews of the mammals of the Kikori basin (e.g. by Leary and Seri 1997; Namo 2004), most of the sampling localities (e.g. Magidobo, Bobole, Namosado) actually lie within the headwaters of the Strickland River to the west of the Kikori basin. Exceptions are two lowland localities sampled by the South Australian Museum team in 1985—Waro and Fogomai'iu, which lie within the Hegigio catchment of the Kikori basin.

A second publicly available body of work on the Kikori Basin derives from acoustic surveys carried out by Richards (2005, 2009) for the PNG Liquid Natural Gas Project. This was the first systematic survey of bats in Papua New Guinea to rely heavily on acoustic detection and it generated a large volume of data. Unfortunately, only some of the identifications given by Richards are useful as context, since no

[2] A joint venture currently led by Esso Highlands Limited as operator of the PNG LNG Project.

[3] http://wwf.panda.org/who_we_are/wwf_offices/papua_new_guinea/index.cfm?uProjectID=PG0013.

example call types were provided for each identification to allow for independent verification, and the approach used to identify calls in the absence of a comprehensive reference call set (given the pioneering nature of the work) was flawed. Thus, comparisons between the present study and that of Richards (2005, 2008) would be unreliable.

## 2.3 Summary of existing knowledge for bats

The foregoing review of existing knowledge leads to the following conclusions:

- Bats are poorly surveyed across most of the study area, with the only notable exception being the sites along a formerly proposed pipeline route in the southeast of the study area surveyed in 2008.
- Bat inventories for surrounding areas to the west, north and east are the most complete for sites at elevations above 600 m asl in the Purari and Kikori Basins, and less complete for lower elevations in all catchments.
- Three of the major ecological zones represented within the study area are effectively unsurveyed for bats on a regional scale, namely the Delta Swamps and Plains, the Mangroves, and the Southeast Coast (beach ridges and plains) ecological zones.
- A lack of confidence in taxonomic determinations, variably a product of unreliable or unsubstantiated identifications or a genuine lack of taxonomic resolution, effectively precludes comparisons for the majority of the bat species.

Given these limitations, it is useful to extend consideration of the potential bat fauna of the study area based on wider patterns of distribution and habitat use. Relevant information is contained in the distribution maps and accounts in Flannery (1995) and Bonaccorso (1998), tempered with more recent reports and personal knowledge of museum holdings in various institutions around the world.

Based on these sources and using a combination of local records and more general sources, a list was compiled of species that are either: confirmed present (C); or are likely to occur (L), in each of the major ecological zones in the study area (Table 1).

**Table 1 – List of 47 bat taxa that are known to be or that might be present in the study area**

Note: IUCN Status categories are: DD—Data Deficient; LC—Least Concern. Presence in the study area: C—*confirmed* present (from sources described in *Section 2.1*); L—considered *likely* to occur. Endemism category is described in *Section 3.3.5*.

| Scientific name | Common name | IUCN Status | Presence in the study area | Endemism category |
|---|---|---|---|---|
| PTEROPODIDAE | | | | |
| Dobsonia minor | Lesser Naked-backed Fruit Bat | LC | L | 3 |
| Dobsonia moluccensis | Moluccan Naked-backed Fruit Bat | LC | L | 2 |
| Macroglossus minimus | Dagger-toothed Long-nosed Fruit Bat | LC | L | 1 |
| Nyctimene aello | Greater Tube-nosed Fruit Bat | LC | L | 3 |
| Nyctimene albiventer | Common Tube-nosed Fruit Bat | LC | C | 2 |
| Nyctimene certans | Mountain Tube-nosed Fruit Bat | LC | L | 2 |
| Paranyctimene raptor | Green Tube-nosed Fruit Bat | LC | L | 3 |
| Paranyctimene tenax | Steadfast Tube-nosed Fruit Bat | LC | L | 3 |

| Scientific name | Common name | IUCN Status | Presence in the study area | Endemism category |
|---|---|---|---|---|
| Pteropus macrotis | Large-eared Flying-fox | LC | C | 2 |
| Pteropus neohibernicus | Great Flying-fox | LC | C | 3 |
| Rousettus amplexicaudatus | Common Rousette | LC | L | 1 |
| Syconycteris australis | Common Blossom Bat | LC | C | 1 |
| EMBALLONURIDAE | | | | |
| Emballonura beccarii | Beccari's Sheath-tailed Bat | LC | L | 2 |
| Emballonura furax | New Guinea Sheath-tailed Bat | DD | C | 3 |
| Emballonura raffrayana | Raffray's Sheath-tailed Bat | LC | C | 1 |
| Mosia nigrescens | Lesser Sheath-tailed Bat | LC | C | 1 |
| Saccolaimus saccolaimus | Bare-rumped Sheath-tailed Bat | LC | C | 1 |
| HIPPOSIDERIDAE | | | | |
| Aselliscus tricuspidatus | Trident Leaf-nosed Bat | LC | C | 1 |
| Hipposideros ater | Dusky Leaf-nosed Bat | LC | L | 1 |
| Hipposideros calcaratus | Spurred Leaf-nosed Bat | LC | L | 1 |
| Hipposideros cervinus | Fawn-colored Leaf-nosed Bat | LC | L | 1 |
| Hipposideros diadema | Diadem Leaf-nosed Bat | LC | C | 1 |
| Hipposideros maggietaylorae | Maggie Taylor's Leaf-nosed Bat | LC | L | 2 |
| Hipposideros muscinus | Fly River Leaf-nosed Bat | DD | L | 4 |
| Hipposideros semoni | Semon's Leaf-nosed Bat | DD | L | 1 |
| Hipposideros wollastoni | Wollaston's Leaf-nosed Bat | LC | C | 4 |
| RHINOLOPHIDAE | | LC | | |
| Rhinolophus arcuatus | Arcuate Horseshoe Bat | LC | L | 1 |
| Rhinolophus euryotis | New Guinea Horseshoe Bat | LC | L | 1 |
| Rhinolophus megaphyllus | Eastern Horseshoe Bat | LC | L | 1 |
| Rhinolophus philippinensis | Large-eared Horseshoe Bat | LC | C | 1 |
| MINIOPTERIDAE | | | | |
| Miniopterus australis | Little Bent-winged Bat | LC | C | 1 |

| Scientific name | Common name | IUCN Status | Presence in the study area | Endemism category |
|---|---|---|---|---|
| Miniopterus macrocneme | Small Melanesian Bent-winged Bat | DD | L | 1 |
| Miniopterus magnater | Large Bent-winged Bat | LC | L | 1 |
| Miniopterus medius | Medium Bent-winged Bat | LC | C | 1 |
| Miniopterus tristis | Greater Bent-winged Bat | LC | C | 1 |
| VESPERTILIONIDAE | | | | |
| Kerivoula muscina | Fly River Woolly Bat | LC | C | 4 |
| Myotis moluccarum | Maluku Myotis | LC | L | 1 |
| Nyctophilus microtis | Papuan Long-eared Bat | LC | L | 2 |
| Philetor brachypterus | Short-winged Pipistrelle | LC | L | 1 |
| Phoniscus papuensis | Golden-tipped Bat | LC | L | 1 |
| Pipistrellus angulatus | New Guinea Pipistrelle | LC | L | 1 |
| Pipistrellus papuanus | Papuan Pipistrelle | LC | L | 2 |
| Pipistrellus wattsi | Watts's Pipistrelle | LC | L | 6 |
| Murina florium | Flute-nosed Bat | LC | L | 1 |
| MOLOSSIDAE | | | | |
| Chaerephon jobensis | Northern Mastiff Bat | LC | L | 1 |
| Mormopterus beccarii | Beccari's Mastiff Bat | LC | L | 1 |
| Otomops papuensis | Papuan Free-tailed Bat | DD | C | 6 |

# 3 Methods

## 3.1 Survey sites and timing

### 3.1.1 Survey sites overview

The survey was conducted at 11 main sites in the study area between 19 January and 16 February 2016, and between 21 June and 20 July 2016 (Figures 2–7; Table 2). An additional brief visit was made to check a cave on Wi'i Creek.

**Table 2 – Geographic location of the study sites within the study area (coordinates of base camp), survey timing and trail elevations covered**

| Base location | PNG94 | | Alt (m asl) | Arrival | Departure | Trail elevations | |
|---|---|---|---|---|---|---|---|
| | Easting | Northing | | | | Min | Max |
| Phase 1 | | | | | | | |
| Site 1 | 294689 | 9209644 | 110 | 19 January 14:30 | 27 January 11:00 | 70 | 200 |
| Site 2 | 291894 | 9202769 | 100 | 27 January 11:15 | 2 February 10:30 | 75 | 200 |
| Site 3 | 303459 | 9171560 | 150 | 2 February 10:45 | 8 February 16:00 | 100 | 190 |
| Site 4 | 300251 | 9186944 | 50 | 9 February 14:20 | 16 February 09:30 | 45 | 55 |
| Phase 2 | | | | | | | |
| Site 5 | 294432 | 9191260 | 20 | 21 June 17:00 | 2 July 10:45 | 20 | 45 |
| Site 6A | 300655 | 9195465 | n/a | 27 June 09:20 | 28 June 16:10 | 30 | 75 |
| Site 6D | 300280 | 9192765 | n/a | 26 June 10:15 | 26 June 16:00 | 185 | 310 |
| Site 7 | 308305 | 9153930 | 15 | 2 July 11:00 | 9 July 12:25 | 5 | 30 |
| Site 8 | 308835 | 9138610 | 5 | 9 Jul, 12:40 | 15 July 09:20 | 0 | 30 |
| Site 8M | M1 309575<br>M2 309180<br>M3 308595 | 9133025<br>9132980<br>9132770 | n/a | various 11-13 July | various 11-13 July | 0 | 5 |
| Site 9 | 315970 | 9131180 | 2 | 15 July 09:30 | 20 July 13:45 | 0 | 30 |
| Wi'i Creek owl | 308184 | 9221948 | 319 | 30 June | 30 June | — | — |

| Base location | PNG94 | | Alt (m asl) | Arrival | Departure | Trail elevations | |
|---|---|---|---|---|---|---|---|
| | Easting | Northing | | | | Min | Max |
| roost cave | | | | 13:30 | 13:55 | | |

### 3.1.2 Site 1

Site 1 is located in PRL-15 in the upper Era River catchment, Middle Purari Hills ecological zone (**Figure 2**). All natural habitat in this area is mapped as Hill forest (Hm) but there are patches of alluvial forest along Boa Creek. Accommodation was at the Antelope-3 Operations Camp. Bat survey effort at this site focused on areas that represented contrasting habitats for bats:

1) The heavily modified environs of the Antelope-3 Operations Camp, sampled with harp traps, mist nets and bat detectors set under lights.

2) A tributary of Boa Creek where nets and harp traps were set across and beside the creek, which varied from 5–15 m in width and comprised a series of riffles and pools, all with gravel bed-load. Water depths ranged from 20–150 cm and flanking vegetation was mainly dense regrowth in the areas worked. Bat detectors were set along the same stretches of stream.

3) A small creek crossing the road between the ANT-2 and ANT-5 drilling pads. Nets, harp traps and bat detectors were set in a deeply incised gully. Bat detectors were also set along the road verge and along a degraded watercourse beside the road where forest cover had been removed.

### 3.1.3 Site 2

Site 2 is located in the Middle Purari Hills ecological zone near the proposed trunkline west route option (Figure 2). It is in the Mena basin headwaters, upper Era River catchment near the divide between the Era River and Pie River catchments. All natural habitat in this area is mapped as Hill forest (Hm) but there are patches of alluvial forest on alluvial terraces of an unnamed creek running past the camp.

The substrate at this site is weakly consolidated mudstone, and the hill forest community displays an exceptionally high level of natural disturbance due to a combination of tree fall and small scale landslides and slumps. The result is a mosaic of vegetation types at various successional stages, including many dense stands of climbing palm that inhibited movement around the camp.

Bat survey effort at this site focused on three areas that represented contrasting habitats for bats:

1) The clearings around the fly camp and helipad, sampled with bat detectors.

2) An unnamed creek where mist nets and harp traps were set across and beside the creek, which varied from 3–10 m in width and comprised a series of riffles and pools, all with gravel bed-load. Water depths ranged from 20–50 cm and most of the creek was shaded by tree cover or choked with tree fall. Bat detectors were set along the same stretches of stream.

3) A ridge with a less disturbed patch of hill forest. Nets and bat detectors were set in this area.

### 3.1.4 Site 3

Site 3 is located in the northern section of the proposed export pipeline corridor (Figure 3). The fly camp was located c. 5 km northeast of a logging camp and c. 8 km northeast of Evara village, both on the Purari River. The camp is situated in the Southeast Hills ecological zone, but is c. 2.5 km from a boundary with the Delta Swamps and Plains ecological zone. All natural habitat within the Southeast Hills ecological zone around Site 3 is mapped as Hill forest (Hm). Habitat in the Delta Swamps and Plains ecological zone is mapped as Open alluvial forest (Po).

Much of the forest habitat around Site 3 is heavily disturbed by logging activity.

Bat survey effort at this site focused on areas of hill forest of contrasting degrees of disturbance in the hill zone, including the most heavily disturbed areas:

1) The clearings around the fly camp and along the forestry roads between the camp and helipad and running northwest from the camp. These habitats were sampled extensively with bat detectors, and the road provided access to steep flanking slopes where detectors could sample flight spaces in and above the canopy of more intact patches of forest.

2) An unnamed creek where mist nets and harp traps were set across and beside the creek, which varied from 3–10 m in width and comprised a series of riffles and pools, most with coarse sand or gravel bed-load. Water depths ranged from 20–100 cm and most of the creek was shaded by tree cover or choked with tree fall. Bat detectors were set along the same stretches of stream.

3) Areas of forest that had been subject to logging at varying levels of intensity. These areas were sampled using all methods.

### 3.1.5 Site 4

Site 4 is located in the south of PRL-15 in the southeast of the proposed 'CPF logistics base and airstrip area' (Figure 4). The fly camp was located in the Delta Swamps and Plains ecological zone, near a border with the Middle Purari Hills ecological zone. Apart from the localized disturbance associated with various geotest pads and access foot tracks running between them, this area supports a mosaic of Open alluvial forest (Po), Swamp forest (Fsw) and Hill forest (Hm). Streams within the terrace complex are deeply incised, with overhanging forest cover.

Bat survey effort at this site focused on areas that represented contrasting habitats:

1) Mature alluvial forest on a low terrace, sampled by all methods.

2) The clearings within alluvial forest around the fly camp and helipad, and the nearby geotest pads which were overgrown with dense scrub. These habitats were sampled extensively with bat detectors.

3) An unnamed stream (tributary of Oyomo Creek) within alluvial forest where mist nets and harp traps were set across and beside the creek, which varied from 10–20 m in width.

4) Deeply incised narrow streams within alluvial forest, sampled by all methods.

5) Mature hill forest on low hills, sampled by all methods.

### 3.1.6 Site 5

Site 5 is located in the central-west of PRL-15 (Figure 5). The fly camp was located in the north of the proposed 'CPF, logistics base and airstrip area' near the boundary between the Middle Purari Hills and Delta Swamps and Plains ecological zones. Elevated country to the east of the camp supports mature and essentially undisturbed Hill forest (Hm), while the low-lying areas to the south and west support a mosaic of Open alluvial forest (Po) and Swamp forest (Fsw). Stands of alluvial forest close to the camp had suffered dieback and contained numerous dead tree boles, the majority still standing but clothed in climbing vines. A prolonged flooding event in 2014 is the likely cause of the tree mortality. In the absence of an effective canopy, the understorey in these areas consists of a dense, and in many areas, virtually impenetrable tangle of vines, chiefly *Calamus* spp. Patches of similarly impacted alluvial forest were observed during helicopter travel around the site, interspersed with patches of unaffected alluvial forest and swamp communities dominated by sago-palms.

Bat survey effort at this site focused on areas that represented contrasting habitats:

1) The clearings in alluvial forest habitat around the fly camp and helipad, and a 10 m wide flowing stream on the margin of the helipad clearing, all sampled with bat detectors.

2) A mosaic of alluvial forest and swamp forest habitats, much of it impacted by tree die-off, to the east of the fly camp and sampled with bat detectors.

3) Hill forest habitats further to the east of the camp, sampled with bat detectors.

4) Alluvial forest on a low terrace with interspersed patches of sago palm in depressions, sampled by all methods on tracks running north and west of the camp.

#### 3.1.7 Site 6A

Site 6A is located in PRL-15 and is within the catchment of Kuku Creek in the Middle Purari Hills ecological zone (Figure 5). Survey was carried out along and beside a segment of the road between Herd Base and Hou Creek Base.

Apart from the localized disturbance associated with the road and some small roadside gardens, this area supports a mature hill forest community growing on the valley slopes, and patches of alluvial forest growing on low-lying alluvial terraces. Side-streams are deeply incised within the terrace complex and have overhanging forest cover.

Bat survey effort at this site was restricted to bat detector deployment. They were placed to sample two accessible habitats:

1) The roadside habitat, which is overgrown with dense scrub.

2) A major side stream (Wara Djo'oua) that crosses the road.

#### 3.1.8 Site 6D

Site 6D is located in the PRL-15 in an area of rugged terrain to the west of Kuku Creek (Figure 5). It falls within the Middle Purari Hills ecological zone and supports mature Hill forest (Hm) with areas of natural disturbance associated with landslides. The area was visited to assess the potential occurrence of caverns or fissures in this landform.

#### 3.1.9 Site 7

Site 7 is located to the south of PRL-15 in the proposed export pipeline corridor (Figure 6). The camp was located on a former logging road that extends along the boundary between the Delta Swamps and Plains ecological zone (to the west) and the Southeast Hills ecological zone (to the east). Logging activity in both ecological zones ceased more than 10 years ago and the area now supports advanced secondary forests. The road has been kept clear of regrowth and varies in width from 10–20 m. It supports a carpet of vines and is fringed by a zone of dense shrubs and palms.

Small crowned hill forest (Hs) on the low hills to the east of the road was heavily logged and has a broken canopy and dense understorey. The Open alluvial forest (Po) to the west of the road is more variable in condition, with some patches heavily disturbed and others seemingly intact. Small muddy-bottomed streams emerge from the low hills, but the drainage rapidly becomes disorganized with no major channels encountered on the alluvial plain. Low-lying areas support patches of swamp woodland (Wsw) and swamp grassland (Gsw) habitat.

Bat survey effort at this site focused on the following habitats:

1) Stream-side habitats to the east of camp, sampled with mist nets, harp traps and bat detectors.

2) The open flyway along the road and the cluttered roadside habitat, sampled by bat detectors.

3) The Open alluvial forest (Po), sampled by all methods.

4) The Swamp woodland (Wsw) and Swamp grassland (Gsw) habitats, sampled by bat detectors.

### 3.1.10 Site 8

Site 8 is south of the proposed export pipeline corridor (Figure 7). The camp was established c. 0.5 km east of Avavu village on a broad alluvial plain that supports a mosaic of active gardens, palm plantations and regrowth forest. The site provided access to two ecological zones—Southeast Hills to the east, Southeast Coast to the south (and around the fly camp).

A 2 km-wide belt of Alluvial forest (Pl) to the east of the camp was logged intensively in 2012. This area now supports a remnant scatter of original trees interspersed with dense sapling regrowth. In many areas, the ground is strewn with decaying timber off-cuts and the surface is visibly disturbed by heavy machinery. The logging road has been kept clear of regrowth and numerous gardens have been planted along its margins.

Two discrete ranges of hills are present in the southeast sector of the site—Heve Hill, which has rounded topography and rises to c. 55 m asl, and the Paevera Hills with more angular topography and local peaks at 80 m asl. Both are mapped as non-calcareous sedimentary substrates, but this is erroneous for Heve Hill (see below). The habitat on Heve Hill is mapped as Hill forest (Hm) while that on the Paevera Hills is mapped as Small crowned hill forest (Hs).

Bat survey effort at this site focused on areas that represented contrasting habitats:

1) Gardens and palm plantations around the camp and helipad, sampled with bat detectors and mist nets.

2) Patches of regrowth forest interspersed between gardens and plantations, sampled with bat detectors, mist nets and harp traps.

3) The 20–30 m wide logging road.

4) Regrowth habitats in the logged alluvial forest, including shallow pools created by heavy machinery traffic.

5) Heve Hill was visited to investigate reports of sinkholes and subterranean caverns, but no other survey method was employed.

Heve Hill was visited on 14 July 2016 with landowners from Huruta village. The landscape features localized outcrops of calcareous siltstone and shows a variety of typical karst landforms such as dry valleys below stream sinks and small sinkholes on ridges. One cluster of sinkholes that formerly opened into a subterranean stream passage was choked with treefall and leaf litter at the time of the visit. This landscape very likely conceals a network of subterranean caverns. If these are accessible by small sinkholes and fissures they will almost certainly be used by cave roosting bats.

### 3.1.11 Site 8M

Site 8M is situated within the Mangroves ecological zone (Figure 7). The site comprises three sampling localities along Oeha Creek, a major tidal tributary of the Purari River. The main channel is variably fringed with stands of *Nypa* palms or pandanus in areas of deltaic accretion, or Mangrove (M) communities in areas of erosion. Access to each locality was by boat and movement within the sites was limited by the terrain, which comprised patches of deep mud along tidal drainages, interspersed with slightly elevated areas supporting mangrove forest. The area is visited for fishing, gathering of shellfish and collecting of forest products but shows minimal disturbance away from the few semi-permanent camps.

This site was sampled by deployment of bat detectors and harp traps at each of the three localities. In addition, the river frontage was monitored for flying-fox activity during travel to and from the site.

### 3.1.12 Site 9

Site 9 is located near the coast, midway along Orokolo Bay, and in proximity to several potential routes for the terminal segment of the export pipeline corridor (Figure 7). The topography in this area features a broad coastal plain (1–2 km wide), which is part of the Southeast Coast ecological zone, and a low coastal range, the Paevera Hills, which is part of the Southeast Hills ecological zone. The Paevara Hills rise to local peaks of 80 m asl and slightly higher elevations further to the east.

The coastal plain comprises a series of subparallel dune ridges with intervening shallow swales, each running approximately parallel to the coast. The foredunes support a series of villages, gardens and palm plantations, with patches of coastal scrub and small freshwater wetlands present at the eastern end of the bay. Inland of the villages are further plantations including coconut and betel nut palms on ridges and sago palms in low-lying areas. Further inland, this gives way to a 1 km wide belt of Alluvial forest (Pl) with localized areas of disturbance, and then to Small crowned hill forest (Hs) as the land begins to rise towards the Paevera Hills. Numerous small gardens are present along the ecotone between the coastal plain and the foothills.

Bat survey effort at this site focused on areas that represented contrasting habitats:

1) The clearings around the camp, and nearby patches of coastal scrub. These habitats were sampled with bat detectors and mist nets.

2) The plantation zone, including both coconut and sago palm stands, and low-lying areas with standing water after rain. These habitats were sampled with bat detectors, mist nets and harp traps.

3) The Alluvial forest (Pl) habitat, including clearings created by tree felling.

4) Gardens along the coastal plain/foothill ecotone.

### 3.1.13 Wi'i Creek owl and bat roost cave

The existence of large caves in an area of rugged terrain in the northeast corner of the study area was mentioned by residents of Wabo village, and confirmed by residents of Subu 2 Village who gave approval for Aplin to visit the area. The area was accessed via Wi'i Creek (a tributary of the Purari River) on 30 June 2016, and a large cave system was located at the base of a limestone bluff on a steep heavily forested slope (Table 2 for positional details).

Acoustic recordings were made at the cave entrance and a bone accumulation representing the prey remains of owls was sampled. The sample was taken from an area of the cave where bones were sitting on top of recently slumped sediment, thereby ensuring that the prey remains were also recently deposited. Further information on this site is presented in the Upstream Non-Volant Mammals Baseline Study Report by K.A. Aplin.

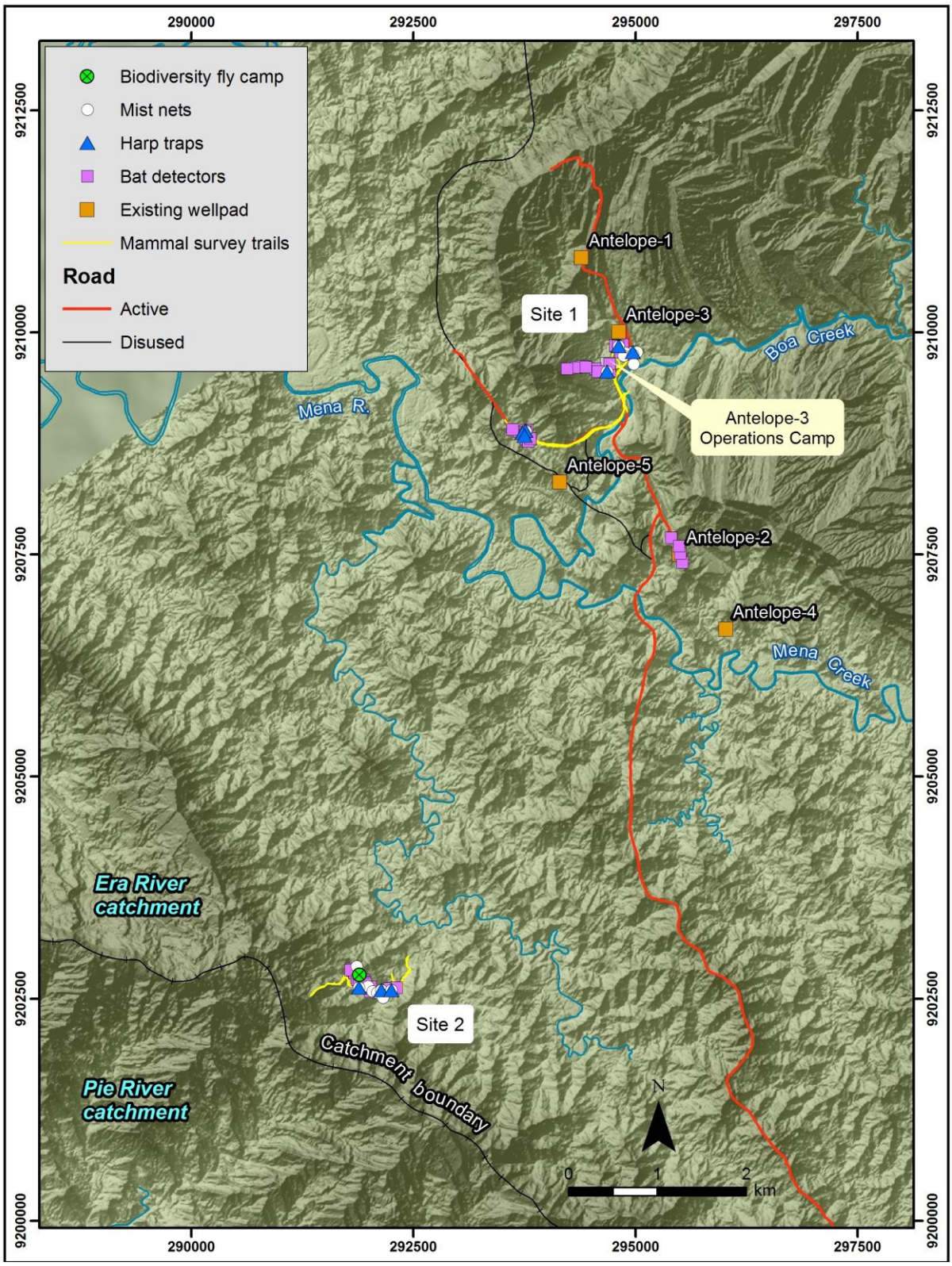



**Figure 2 – Bat survey coverage at Sites 1 and 2**

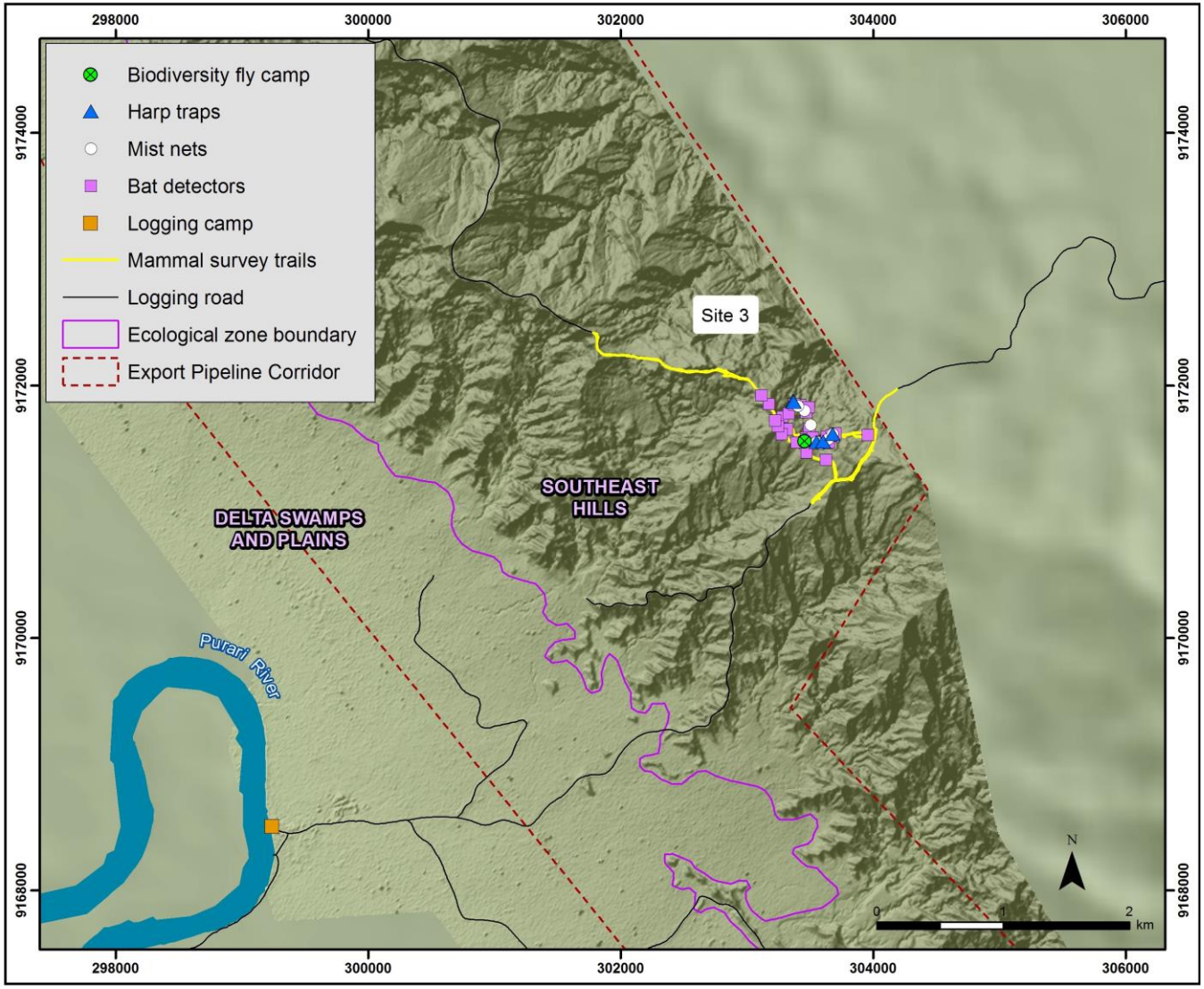



**Figure 3 – Bat survey coverage at Site 3**

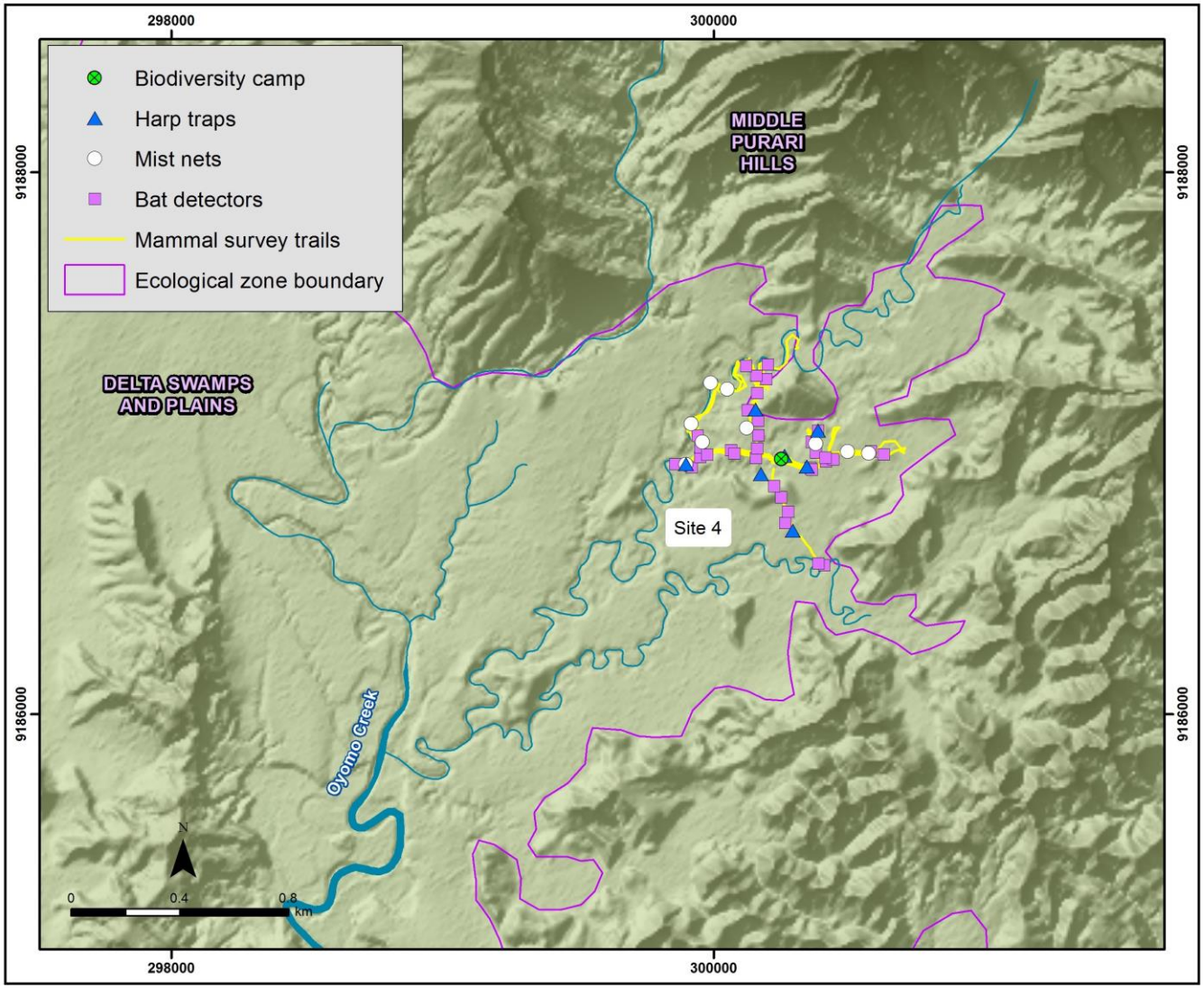



**Figure 4 – Bat survey coverage at Site 4**

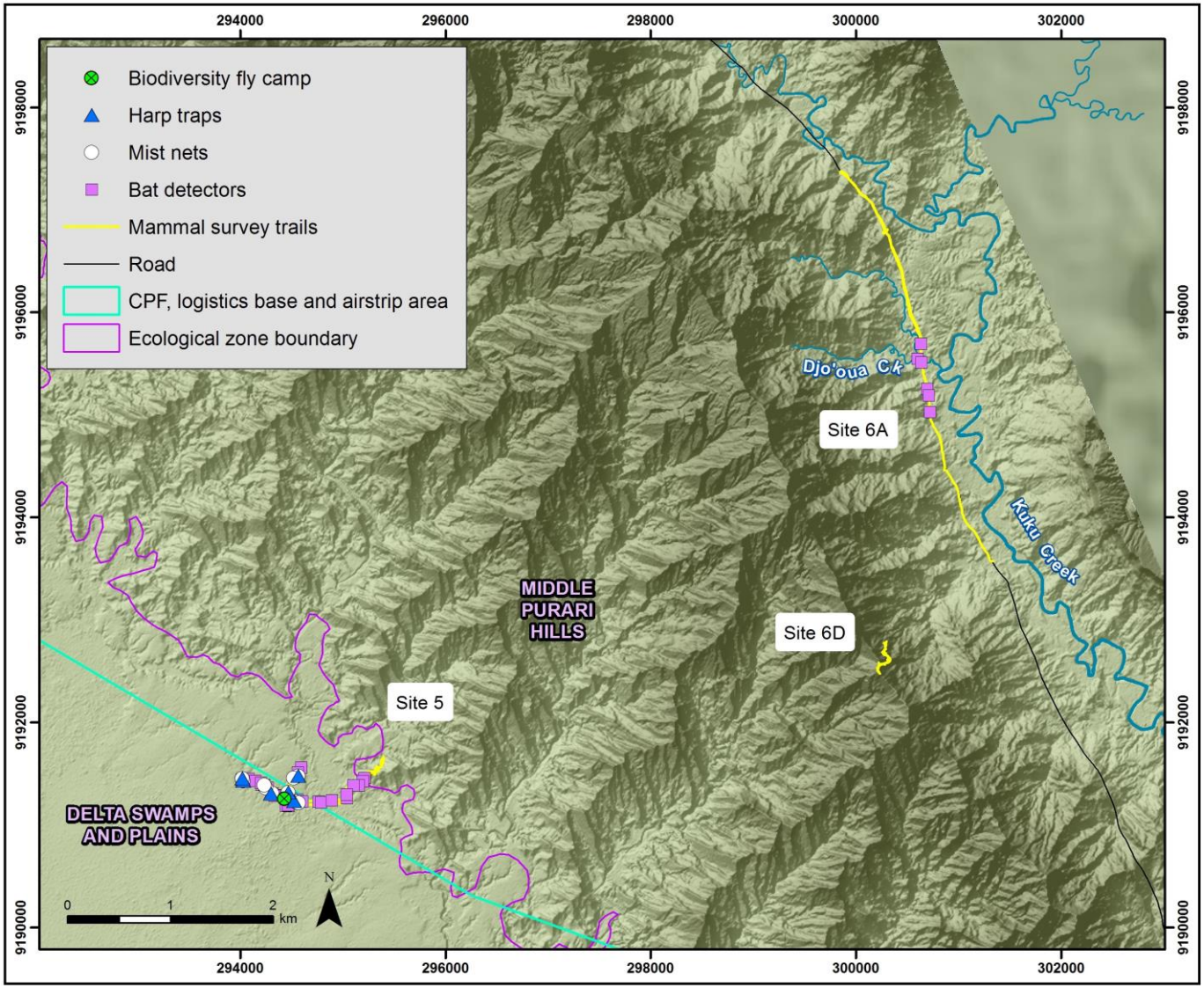



**Figure 5 – Bat survey coverage at Sites 5, 6A and 6D**

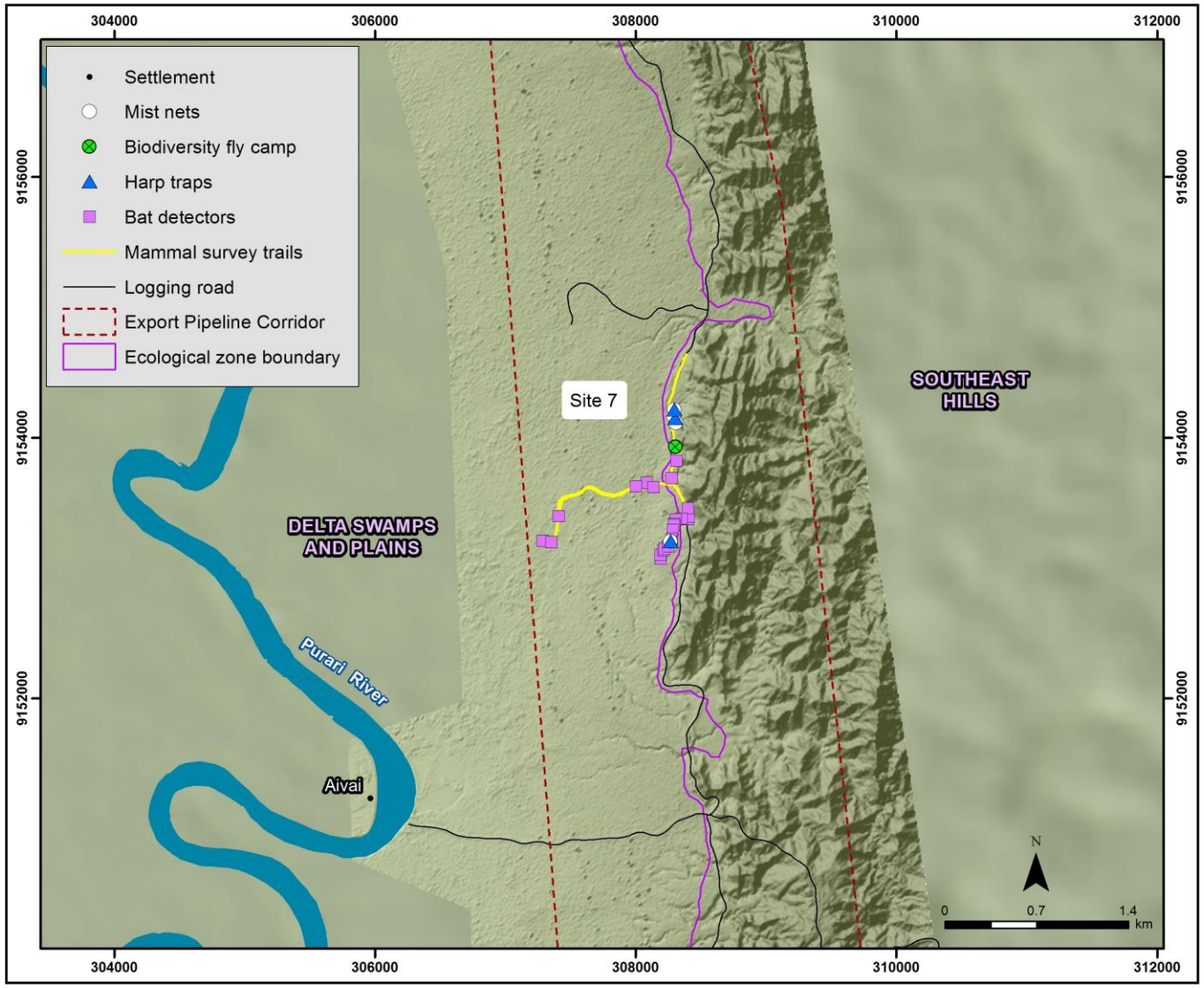



**Figure 6 – Bat survey coverage at Site 7**

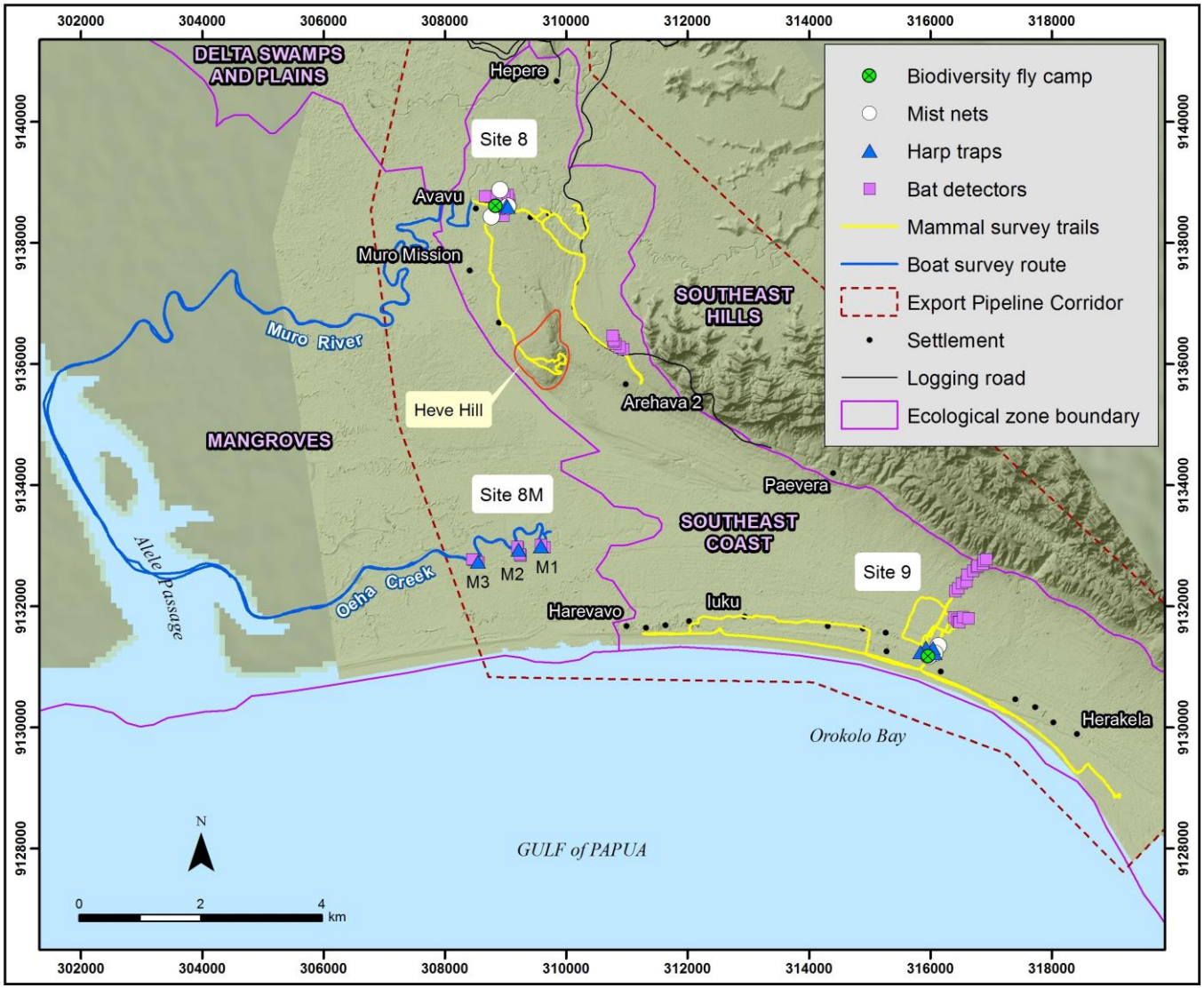



**Figure 7 – Bat survey coverage at Sites 8, 8M and 9**

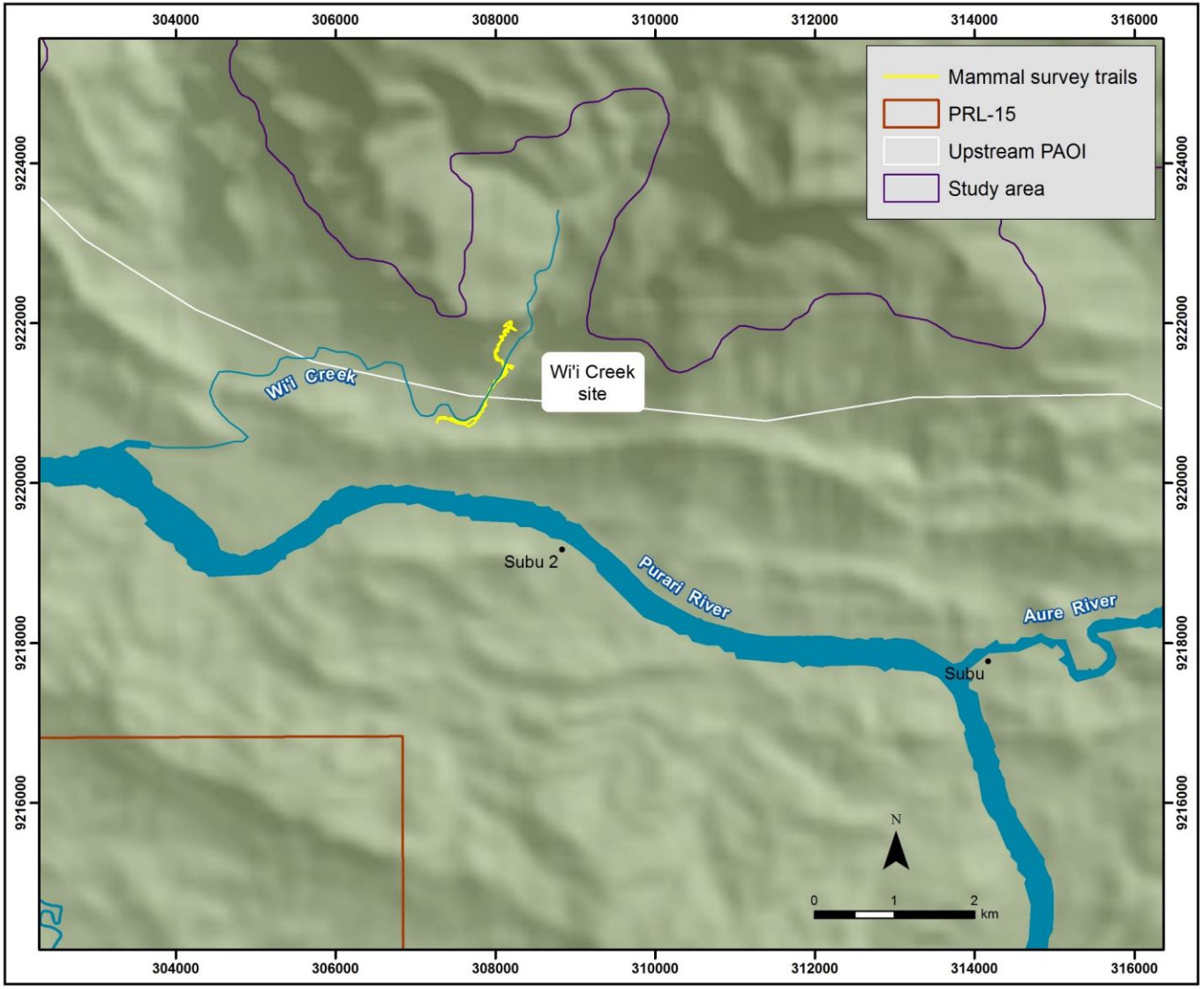



**Figure 8 – Bat survey coverage along areas of Wi'i Creek**

## 3.2 Survey methods

A variety of methods was used in order to maximize the chance of detection of species in the bat assemblage at each locality. Chance of detection was also maximized through the selection of appropriate capture and recording equipment, well-designed data analysis and good replication of trapping and recording sites. A total of 42 harp trap sites was established, which operated for a total of 111 trapping nights; and 71 mist net sites were established, which operated for a total of 38,304 net-meter-hours. In addition to trapping effort, data was available from 199 acoustic recording sites (Table 3).

**Table 3 – Bat survey effort across the 10 survey sites**

| Site | Harp trap positions | Harp trap nights | Mist net positions | Mist net meter-hours | Acoustic recording sessions |
|---|---|---|---|---|---|
| Site 1 | 6 | 14 | 17 | 4,392 | 27 |
| Site 2 | 4 | 12 | 12 | 4,932 | 20 |
| Site 3 | 6 | 15 | 8 | 4,032 | 24 |
| Site 4 | 7 | 17 | 8 | 4,500 | 19 |
| Site 5 | 6 | 19 | 14 | 11,304 | 34 |
| Site 6 | 0 | 0 | 0 | 0 | 6 |
| Site 7 | 3 | 15 | 4 | 4,104 | 20 |
| Site 8 | 3 | 6 | 4 | 3,456 | 22 |
| Site 8M | 3 | 6 | 0 | 0 | 12 |
| Site 9 | 4 | 7 | 4 | 1,584 | 15 |
| Totals | 42 | 111 | 71 | 38,304 | 199 |

### 3.2.1 Trapping

Capture provides information directly on species presence and the opportunity to collect reference echolocation calls to help attribute anonymously recorded signals on the unattended bat detectors. It also enables whole specimen vouchers to be taken in cases where identification requires direct comparison with material in existing collections.

Nylon mist nets were set singly or in series along tracks and in small clearings, across and alongside streams and in forest understorey. These are especially effective in capturing fruit and blossom bats that venture within a few meters of the ground (species of *Dobsonia*, *Nyctimene*, *Paranyctimene*, *Macroglossus* and *Syconycteris*), which can be abundant locally in Papua New Guinea (Bonaccorso 1998). They are much less effective at capturing echolocating bats, most of which can readily detect the nets.

Mist nets were usually moved after two or three nights in any position so as to maximize coverage of habitat types and to increase the likelihood of capturing rarer species.

In order to capture echolocating bats, two ‘triplebank’ harp traps (three sets of vertical fishing line arrays suspended over a catch-bag) were situated in potential bat flyways in the open spaces along tracks and in gaps among vegetation (Plate 1). Flanking mist nets were often erected alongside the harp traps to guide bats inwards (Plate 2). Given that bats learn quickly to avoid traps and nets, they were moved to new positions after one or two nights in each position. Harp trap and mist net positions are shown in Figures 2–7.

### 3.2.2 Acoustic detection

The ultrasonic echolocation calls of bats, which are produced for orientation in darkness and prey detection in flight, are useful for species identification because most species produce a unique and distinguishable signal type. Analysis of the recordings made using digital ultrasonic recorders (‘bat detectors’) can reveal echolocating bat diversity at sampling sites with minimal effort, and usually with much greater rates of encounter than trapping. Pettersson Elektronik D500X bat detectors were installed before dusk and then left unattended to record bat activity over a full night at each recording position. They were usually moved to a new position each night to sample the full range of vegetation habitats and bat ‘flight spaces’ at each survey site. This is termed 'passive detection' and results in the recording of ‘anonymous’ calls that need to be attributed to a species.

At the recording positions, microphones were oriented horizontally, and attached to tree trunks around 3 m above the ground (Plate 3). For each recording position a GPS position was recorded and associated with the serial number of the recording unit and deployment date, and notes were made regarding the habitat in front of the unit.

The recording settings for the D500X units were as follows: sampling frequency 500 kHz, Pre-trigger off, Recording length 1 sec, HP filter yes, Autorec yes, Trigger source 0, Trigger sensitivity 1 High, Input Gain 45, Trigger level 30, Interval 0, Timer 18:50 – 06:15.

Bat detector positions are shown in Figures 2–7.

### 3.2.3 Reference echolocation calls

The usual goal in any analysis of acoustic recordings of bats is attributing the recorded 'anonymous' call types to a single species. This is usually done with the help of a 'reference library' of good quality calls recorded from confidently identified bats. For New Guinean bats the reference call library remains incomplete, and this approach is further confounded by the incomplete taxonomic resolution of some groups (see *Section 3.3.3*). Nevertheless, recent acoustic bat surveys have resulted in a steadily growing library of published call types (Leary and Pennay 2011; Armstrong and Aplin 2011, 2014a; Robson et al. 2012; Armstrong et al. 2015a, b), with others known to the authors as a result of resource development surveys in Papua New Guinea (K. N. Armstrong and K. P. Aplin unpublished data).

During this study, the opportunity was taken to obtain additional reference calls from confidently identified bats or those linked to a voucher specimen or tissue biopsy sample. These were recorded from nasal-emitting bats (Hipposideridae and Rhinolophidae) while stationary (held in the hand or allowed to hang and emit freely), and from mouth-emitting bats (Emballonuridae, Miniopteridae, Molossidae, Vespertilionidae) while flying in a tent or an enclosed building structure or after release into an open area. Calls were recorded in full spectrum WAC0 format with a Wildlife Acoustics Echo Meter EM3 bat detector (sampling rate 384 kHz).

### 3.2.4 Searches for bat roosts

Searching for the diurnal roosts of bats in caves and other structurally suitable sites can provide a variety of information relevant to documenting the bat community and determining the possible impacts of the Project:

- Records of bat species that otherwise evade capture in mist nets and harp traps.

- Reference echolocation calls that allow attribution of anonymously recorded calls from unattended bat detectors.
- An indication of the abundance of some species within an area.
- Information on breeding activity at the time of the visit.
- Insights into potential vulnerability of particular bat species to cave disturbance.
- The identification of roosting and breeding sites that might be given special consideration during Project development.

The geology of PRL-15 and areas along the export pipeline corridor is generally not conducive to the formation of large caves, as soft calcareous mudstones dominate over limestones in the sedimentary sequences. However, cavern-forming limestones are present outside of the study area, most notably along its northern margin, in the northeast corner along the Aure Scarp, and in the Kereru Range to the west of PRL-15.

Artificial structures such as bridges and culverts can also provide suitable roost habitat for bats. Bridges were investigated for bats at Sites 1 and 6A, and a combined mist net and harp trap array was set up below one bridge at Site 1.

During Phase 2 reports of large caves with bat colonies in the northeast of the study area were followed up by an on-ground visit. This resulted in the location of a substantial cave system with roosting bats. The entrance of this cave also contained a rich bone deposit accumulated by a species of owl (see *Section 3.2.5*).

### 3.2.5 Owl roost bone deposit

All species of owls accumulate prey remains below their roosts, as indigestible prey items (bones, hair) swallowed at night are regurgitated in ‘pellets’ during the day when the owl is at rest. If the roost is in a cave or rock shelter, the prey remains can survive for long periods and accumulate as large ‘bone deposits’.

A large owl roost bone deposit was located in an area of limestone karst on Wi’i Creek near the northeast border of the study area (see *Section 3.1.13*). A bulk sample of bone and sediment was collected from a sloping surface in the cave where the remains were judged to be accumulated only within the last few years. This sample was washed through a 1 mm mesh to remove the sediment, fixed in 70% ethanol, dried and then sorted to identify the range and relative abundances of prey items. The bulk of the assemblage consists of rodents and marsupials which are reported in the Upstream Non-Volant Mammals Baseline Study Report by K.P. Aplin, and the bats are reported below (*Section 4.1*).

### 3.2.6 Direct observations

Bats are generally difficult to identify by casual observation when in flight, except to allocate them to general groups such as ‘flying-fox’, ‘blossom bat’ or ‘small echolocating bat’. They are easier to identify if observed at a roost, whether this is within a cave or in a tree.

Flying-foxes almost always roost in groups and sometimes in very large aggregations of ’colonies’, and the species can usually be determined with use of binoculars. The geographic position, identity, and approximate group size was recorded for any observed flying-fox colony. These sites were systematically mapped during boat travel along various portions of the Purari River and its major tributaries.

## 3.3 Conventions used

Conventions relating to mapping coordinate systems, vegetation terminology, taxonomy and nomenclature, conservation status, endemism and restricted-range status follow those outlined in the Upstream Terrestrial Biodiversity Baseline Report.

### 3.3.1 Mapping coordinate systems

All coordinates used in the maps and listed in tables are given in the PNG94 geographic coordinate system (datum).

### 3.3.2 Vegetation terminology

Vegetation types are referred to in the text using a set of FIMS-equivalent terms developed specifically for the terrestrial biodiversity study. These follow closely the formal FIMS descriptors and are based on the founding vegetation descriptions (Paijmans 1976; Hammermaster and Saunders 1995) but are generally less cumbersome. A full list of FIMS vegetation types present within the study area, and equivalent terms used in the Biodiversity Study, is presented in the Terrestrial Biodiversity Baseline Report.

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

Specific vegetation types surveyed at each site are listed in Section 3.1. In most cases, however, more general terms are used that apply to multiple possible variants within the study area (and more widely in Papua New Guinea). These appear without capitals or a FIMS code, for example 'hill forest' and 'alluvial forest'. These generic descriptors follow the various basal FIMS vegetation types, in these examples coded 'H' and 'P' respectively.

### 3.3.3 Taxonomy and nomenclature

The scientific names used in this report generally follow the usage within the current IUCN Red List for mammals (http://www.redlist.org/). However, for some groups of New Guinean bats the taxonomy used in the Red List is known to underestimate the true species diversity, sometimes quite substantially. This insight derives from taxonomic revisions in progress by various members of the international scientific community and is generally underpinned by recent field collections and/or molecular genetic analyses.

Taxa that cannot be assigned unambiguously at present to any named taxon are placed into one of the following two categories of 'taxonomic ambiguity':

- **'sp.'**(singular) or **'spp.'** (plural). These abbreviations are used in cases where one or more taxa were not able to be identified to species level, for example: if an acoustic call type can be referred to a genus but there is insufficient information available to distinguish among two or more possible species; or where reference is made to multiple species within a genus without the need for more specific information, for example where the ecology of all species of a genus share a common behaviour (e.g. all *Miniopterus* spp. display a common roosting behaviour).
- **'cf.'** This abbreviation is used to refer to a species that is clearly allied to a named taxon (for example, *Syconyctis* cf. *australis*) but for which insufficient data are available to confidently assign a specimen to any particular species. The species may be part of a well-documented species complex but available specimens or evidence may be insufficient for species determination—for example, it may be part of a known species complex that has not yet been resolved and named formally by taxonomists.

The common names used in this report are also derived from the IUCN Red List (http://www.redlist.org/). These can conflict with the common names used in the main popular compilations on New Guinea bats by Flannery (1995) and Bonaccorso (1998) but usage also differs between these sources. For common names, there is no 'legal' system of arbitration of usage equivalent to the International Code of Zoological Nomenclature (ICZN 1999) that governs the use of scientific names, hence there is no agreed basis for favoring any one terminology over another.

### 3.3.4 Conservation status

The conservation status of species is based on the listings of the IUCN Red List, CITES and the Papua New Guinea *Fauna (Protection and Control) Act 1966*. The IUCN Red List has four main categories: 'Threatened' (with three subcategories that indicate the severity of the threat: Vulnerable (VU), Endangered (EN) and Critically Endangered (CR)), 'Near Threatened' (NT), 'Least Concern' (LC) and 'Data Deficient' (DD). A taxon listed as Data Deficient is considered too poorly known to adequately assess its level of threat, and is worthy of consideration in environmental impact assessments.

The inclusive term 'conservation listed' is used here for any taxon that is:

- Listed in any category other than 'Least Concern' in the IUCN Red List.
- Listed as Protected in the Papua New Guinea *Fauna (Protection and Control) Act 1966.*
- Listed in Appendix I or II of CITES.

### 3.3.5 Endemic and restricted-range species

Endemic species are those that occur only within a defined area (region, country, etc.). For the purpose of characterizing the bat fauna present within the study area, a classification scheme has been devised that summarizes levels of endemism according to variably defined regions (Table 4; see also Table 1). Restricted-range species are those with a distribution covering less than 50,000 $km^2$ (IFC 2012).

**Table 4 – Category definitions for levels of endemism relevant to the study**

| Category | Definition |
|---|---|
| 1 | Occur more widely in the Indo-Pacific. |
| 2 | Are endemic to New Guinea, its satellite islands, the Bismarcks and Maluku. |
| 3 | Are endemic to New Guinea and its satellite islands (Waigeo, Misol, Yapen, Biak, Aru, d'Entrecasteaux and Louisiades). |
| 4 | Are endemic to mainland New Guinea. |
| 5 | Endemic to southern mainland New Guinea, south of the central cordillera, and the southeast peninsula but not occurring west of Huon Gulf. |

## 3.4 Processing of acoustic recordings

A custom, multi-step acoustic analysis procedure developed to handle large echolocation recording datasets from insectivorous bats in Papua New Guinea (Armstrong and Aplin 2014b; Armstrong et al. 2016) was applied to the recordings made on the survey. Firstly, the WAV files downloaded from the D500x Compact Flash memory cards were scanned for bat echolocation calls using several parameters sets in the software SCAN'R version 1.7.7 (Binary Acoustic Technology), which also provides measurements (in "SonoBatTM compatible output") from each putative bat pulse. The output was then used to determine if putative bat pulses measured in SCAN'R could be identified to species. This was done using a custom [R] language script that performed three tasks:

1. Undertook a Discriminant Function Analysis on training data comprising reference calls (Armstrong and Aplin 2014a; Armstrong et al. 2015a; K.N. Armstrong and K.P. Aplin unpublished data) and representative anonymous call types.

2. From the measurements of each putative bat pulse from SCAN'R, calculated values for the first two Discriminant Functions derived from the training data that could separate the echolocation call types, and plotted these resulting coordinates over confidence regions for the defined call types.
3. Facilitated an inspection in a spectrogram of multiple examples of each call type for each recording night by opening the original WAV files containing pulses of interest in Adobe Audition CS6 version 5.0.2.

Species were then identified from the scored call types based on information in Leary and Pennay (2011), Armstrong and Aplin (2011), Robson et al. (2012), Armstrong and Aplin (2014a), Armstrong et al. (2015a), and K.N. Armstrong and K.P. Aplin (unpublished data).

## 3.5 Data analysis and limitations

### 3.5.1 Echolocation call types

The analysis of acoustic recordings is based on recognizing bat echolocation call types, followed by a separate step of allocating each call type to a particular species. This two-step approach, along with providing illustrated examples of the call types and their subsequent identifications, provides a greater level of transparency that allows for future verification in the identification of calls, a retrospective correction to the species name associated with a call type on the basis of new information, and a comparison of diversity across separated sites that is independent of species name allocations. Call types are named using a standardized nomenclatural scheme (**Table 5**) that was developed for regions where bat calls are poorly known and has assisted in numerous recent surveys across Papua New Guinea and Wallacea (Armstrong and Aplin 2011, 2014; Armstrong et al. 2015a, b; Armstrong and Aplin unpublished confidential reports).

The number of call types recognized may not equate to the same number of bat species, for three reasons: 1) two or more closely related bat species may produce calls that are so similar that they cannot be distinguished reliably using the available methods (e.g. Reinhold et al 2001; Milne 2002); 2) the males and females of a few bat species are reported to produce calls with a slightly different mean characteristic frequency, albeit of comparable type (e.g. Semon's Leaf-nosed Bat *Hipposideros semoni* in Australia; de Oliveira and Schulz 1997; K.N. Armstrong unpublished data); and 3) a single bat species may produce more than one call type (e.g. clutter calls, search phase calls, approach phase calls), some of which may resemble the calls of other species. With sufficient experience of related species, it is generally possible to control for the last of these factors, and to limit the analysis to the typically more diagnostic search phase calls. The other factors can be controlled through the development of an adequate reference call library. In this study, the specialists drew upon their extensive experience and that of others in documenting the call types of Papua New Guinean bats over the past eight years (Leary and Pennay 2011, Armstrong and Aplin 2011, Robson et al. 2012, Armstrong and Aplin 2014a, Armstrong et al. 2015a, and K.N. Armstrong and K.P. Aplin unpublished data). This is sufficiently detailed to allow the confident identification of most species, except those that have very similar call types (some that produce call types of the varieties *st.cFM* and *bFM*).

### 3.5.2 Estimating relative abundance from acoustic recordings

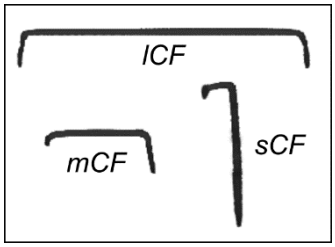
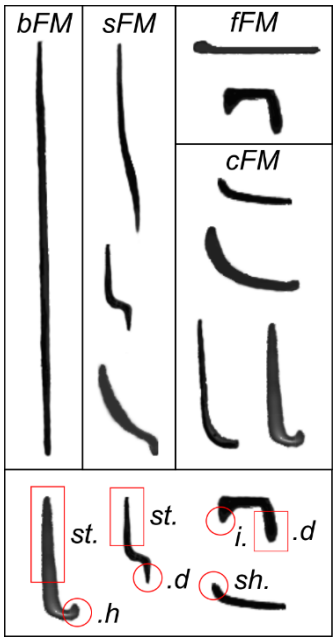
'Absolute' abundance of echolocating bat species at a site cannot be estimated from bat detector recordings because it is not possible to distinguish the calls from each individual. This is because a relatively large number of recorded pulses could be derived from either a few or many individuals.

One way of obtaining an appreciation of 'commonness' versus 'rarity' is to calculate 'relative' abundance across sampling nights and/or sites. With sufficient replication of passive recording sites, a common and widely distributed species will likely be recorded on a high proportion of all recording sessions, whereas a rare or localized species will be detected only occasionally. Positioning the units in a new place each night is useful in this respect as it reduces the chance that the same individual bats were recorded repeatedly.

In this study, the relative abundance of an individual echolocating bat species at each site was calculated by dividing the number of sessions in which the species was recorded by the total number of sessions recorded at the site.

**Table 5 – Echolocation call categories based on the morphology of the dominant type of search-phase pulses in high quality sequences**

Note: adapted from de Oliveira 1998a, b; Corben and O'Farrell 1999; Gannon et al. 2004; Armstrong and Aplin 2011; examples are from a Zero Crossings Analysis output and are not scaled equally. Pulses generally consist of three main sections: an Initial Frequency Sweep (IFS), followed by the main body (BST: Body Sub Type), and ending in a Terminating Frequency Sweep (TFS). The shape of the pulse is represented by the codes in the form 'IFS.BST.TFS', prefixed by a value representing the approximate mean characteristic frequency in kHz.

| Code | Description | Examples |
|---|---|---|
| CF | Constant Frequency Body Sub Type (BST)[1,2] |  |
| lCF | Long duration constant frequency pulse (>30 ms) | |
| mCF | Medium duration constant frequency pulse (15–30 ms) | |
| sCF | Short duration constant frequency pulse (<15 ms) | |
| | [1]Reserved for Hipposideridae and Rhinolophidae | |
| | [2]No use of IFS or TFS | |
| FM | Frequency Modulated Body Sub Type (BST) |  |
| bFM | Broadband, slight curvature only, no significant development of serpentine component (*sFM*) | |
| cFM | Curved, simple or curvilinear trace | |
| fFM | Flat, no decrease, or a very slight decrease in frequency over the pulse body, not classed as *CF* | |
| sFM | Serpentine, generally S-shaped | |
| Ends | Initial Frequency Sweep (IFS) | |
| i. | Inclined, a narrowband increasing frequency sweep | |
| sh. | Short, shallow or narrowband frequency sweep | |
| st. | Steeply decreasing, broadband frequency sweep | |
| | Terminating Frequency Sweep (TFS) | |
| .d | rooped, decreasing frequency sweep following the characteristic frequency in the main body of the call | |
| .h | Hooked, increasing in frequency | |

The relative abundance values are biased to some degree by differences in the detectability among the various species of bats, as well as the capabilities and settings of the recording equipment used.

Detectability varies among species based on several call characteristics, particularly the characteristic frequency and amplitude of emitted signals. Some bats produce signals of relatively low power (for example species of long-eared bats *Nyctophilus* spp.), others produce very high frequency signals that attenuate quickly (for example the Dusky Leaf-nosed Bat *Hipposideros ater*), and some produce calls with both these characteristics (e.g. woolly bats *Kerivoula* spp.). Call types with either of these characteristics are detectable only when the bat is close to the microphone. When multiple examples of such calls are recorded at a site it is a reliable indicator that they are common locally. However, failure to detect these calls might be an indication of rarity rather than of complete absence. For species with high power calls, a low detection rate (low relative abundance) is a reliable indication of rarity while failure to detect the call is a reasonable indication of absence.

The recording equipment chosen in the survey maximized the possibility that species with low amplitude or ultra-high frequency calls over 100 kHz would be recorded because the type of microphone present in the D500X hardware is high quality and reliable in humid atmospheres. In addition, the post-recording semi-automated data processing technique is designed to massively filter the many gigabytes of data in a way that minimizes the potential for discarding signals of interest, especially ultra-high frequency calls. Despite these precautions, some call types might still be slightly under-represented in the identifications, for example the calls of species with a characteristic frequency below 30 kHz (call types *cFM, sFM*) might be buried in background environmental noise making it difficult for the call detection software to recognize them. Also, infrequently encountered low-amplitude short-duration broadband signals (call type *bFM*) were possibly combined with clutter calls of other species (for example some *st.cFM* calls). Replication of recording sessions in all major habitats at each site, and the use of high quality ultrasonic recording equipment, further increased the chance of detection of all echolocating species with the study area.

### 3.5.3 Analysis of bat community structure

Bat community structure (i.e. the mix of species found at each recording site) was analyzed in three ways: 1) by visual examination of the relative abundance matrix; 2) by calculating a Bray-Curtis Dissimilarity Index and then performing Non-metric Multidimensional Scaling (NMDS) ordination analysis; and 3) through the calculation of Indicator Species values using the method of Dufrêne and Legendre (1997).

NMDS is an ordination method that displays the relative similarity of sites based on their component species in two-dimensional space. The Indicator Species metric combines a species' relative abundance with its relative frequency of occurrence in different categories of sites. The index is maximum when all individuals of a species are found in a single category of site, and when the species occurs in every site of that category. Lower values indicate more even distributions.

All analyses were conducted using custom-written [R] language scripts.

# 4 Results and Discussion

## 4.1 Species

### 4.1.1 Bat species inventory

At least 39 species of bat were recorded over all 10 survey sites at which trapping and acoustic recordings methods were used (Table 6). This included a total of 25 species that were trapped (21 species in harp traps; 16 species in mist nets; Table 7; Plates 4–6) and at least 24 species (represented by 24 call types) recorded by bat detectors (Table 8; Figure 9). One species was recorded exclusively from an owl roost bone deposit. Comments are made in an annotated list to justify the identifications made from echolocation call types (Appendix 4), some of which are supported by reference calls taken from bats captured on the survey (Appendix 5).

Of the 39 species of bat recorded, 34 were anticipated to occur in the study area (Table 6; see also Table 1). The remaining five species included three that were not expected to occur in the study area based on prior knowledge of distributions (range extensions), one that may represent an undescribed cryptic taxon (*Nyctophilus* cf. *microtis* (long ears)), and one distinctive call type that could not be attributed to a known species (*Hipposideros* sp. 1, represented as call type *75 mCF*).

Bulmer's Fruit Bat (*Aproteles bulmerae*) was confirmed for the study area based on skeletal remains in the Wi'i Creek cave owl roost deposit.

Among the 34 recorded species that were predicted, there are numerous taxonomic ambiguities that might affect this total. For example, captures identified as *Paranyctimene* cf. *raptor* probably also include examples of *P. tenax*; and those identified as *Nyctimene* cf. *'albiventer'* probably include at least two undescribed forms known to be present and widespread within Papua New Guinea. For the purposes of this report, the locally recorded representatives of these two species complexes are each here considered to represent a single taxon. Taxonomic issues relevant to species recorded within the study area are outlined in Appendix 2.

**Table 6 – Summary of all bat species encountered on the Phase 1 and 2 surveys**

Note: C—capture; E—detected echolocation calls; e?—echolocation calls indistinguishable from another closely related taxon (used for *Nyctophilus* cf. *microtis* and *Pipistrellus* spp. only); CE—detected via both capture and echolocation calls; NA—not applicable (non-echolocating bat species); S—seen; ***—IUCN listed (DD) status might be applicable if species identity can be confirmed (capture required); those with taxonomic ambiguity have no IUCN status attributed; inclusion in CITES Appendix II is indicated; Owl—collection in owl pellets; predicted taxa are listed in **Table 1**.

| | Call type | IUCN | CITES App II | Predicted | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 | Site 6a | Site 7 | Site 8 | Site 8M | Site 9 | Wi'i Creek Cave |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PTEROPODIDAE (11 spp.) | | | | | | | | | | | | | | | |
| *Aproteles bulmerae* | NA | CR | — | N | | | | | | | | | | | Owl |
| *Dobsonia minor* | NA | LC | — | Y | C | C | C | C | C | | C | C | | C | |
| *Dobsonia moluccensis* | NA | LC | — | Y | C | | | | | | | | | | Owl |
| *Macroglossus* cf. *minimus* | NA | LC | — | Y | C | C | C | | | | | C | | C | |
| *Nyctimene aello* | NA | LC | — | Y | | | | | | | C | C | | C | |
| *Nyctimene* cf. *albiventer* | NA | — | — | Y | C | C | C | C | C | | C | C | | C | |
| *Paranyctimene* cf. *raptor* | NA | — | — | Y | C | C | C | C | C | | C | C | | C | |
| *Pteropus macrotis* | NA | LC | yes | Y | | | | | | | | C | | C | |
| *Pteropus neohibernicus* | NA | LC | yes | Y | | | | | | | | | S | | |
| *Rousettus amplexicaudatus* | NA | LC | — | Y | | | | | | | | C | | | |
| *Syconycteris* cf. *australis* | NA | — | — | Y | C | C | C | C | C | | C | C | | C | |
| EMBALLONURIDAE (5 spp.) | | | | | | | | | | | | | | | |
| Emballonura dianae | *35 i.fFM.d* | LC | — | N | | | | | | | | | E | | |

| | Call type | IUCN | CITES App II | Predicted | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 | Site 6a | Site 7 | Site 8 | Site 8M | Site 9 | Wi'i Creek Cave |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Emballonura furax* | *52 i.fFM.d* | DD | — | Y | | | | | | | E | | | | |
| *Emballonura raffrayana* | *45 i.fFM.d* | LC | — | Y | E | E | E | | E | | | E | E | E | |
| *Mosia nigrescens* | *65 i.fFM.d* | LC | — | Y | E | E | CE | E | E | E | E | E | E | E | |
| *Saccolaimus mixtus* | *25 sFM* | DD | — | N | E | E | E | E | E | | E | E | E | E | |
| HIPPOSIDERIDAE (9 spp.) | | | | | | | | | | | | | | | |
| *Aselliscus tricuspidatus* | *115 sCF* | LC | — | Y | E | CE | CE | CE | CE | E | E | E | | CE | |
| *Hipposideros* cf. *ater* | *138 sCF* | — | — | Y | | | | C | | | | | | | |
| *Hipposideros calcaratus* | *128 sCF* | LC | — | Y | C | C | | | | | | | | | |
| *Hipposideros cervinus* | *140 sCF* | LC | — | Y | E | CE | E | E | E | | E | E | E | E | |
| *Hipposideros diadema* | *58 mCF* | LC | — | Y | E | CE | CE | CE | E | E | E | E | | E | |
| *Hipposideros maggietaylorae* | *125 sCF* | LC | — | Y | | E | E | C | E | | E | CE | | | |
| *Hipposideros wollastoni* | *88 mCF* | LC | — | Y | CE | CE | CE | CE | CE | E | CE | | | E | |
| *Hipposideros* sp. 1 | *75 mCF* | — | — | N | | | E | | | | | | | | |
| *Hipposideros* cf. *semoni* | *80 mCF* | *** | — | Y | E | | E | E | E | | E | E | | | |
| RHINOLOPHIDAE (2 spp.) | | | | | | | | | | | | | | | |
| *Rhinolophus euryotis* | *50 lCF* | LC | — | Y | E | | | | | | | | | | |

| | Call type | IUCN | CITES App II | Predicted | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 | Site 6a | Site 7 | Site 8 | Site 8M | Site 9 | Wi'i Creek Cave |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Rhinolophus* cf. *robertsi* | *33 lCF* | — | — | Y | E | E | | | | | | | | | |
| MINIOPTERIDAE (3 spp.) | | | | | | | | | | | | | | | |
| *Miniopterus* cf. *tristis* | *38 st.cFM* | — | — | Y | E | CE | E | CE | E | E | E | E | E | E | |
| *Miniopterus* cf. *medius* | *45 st.cFM* | — | — | Y | E | E | E | E | E | E | E | E | E | E | |
| *Miniopterus* cf. *australis* | *55 st.cFM* | — | — | Y | E | E | E | E | E | | E | E | E | E | |
| VESPERTILIONIDAE (7 spp.) | | | | | | | | | | | | | | | |
| *Kerivoula muscina* | *100 bFM* | — | — | Y | | | C | | | | C | | | | |
| *Murina* cf. *florium* | *80 bFM* | — | — | Y | E | | C | E | E | | E | E | | | |
| *Myotis* cf. *moluccarum* | *40 bFM* | — | — | Y | CE | E | E | E | E | E | E | | E | | |
| *Nyctophilus* cf. *microtis (long ears)* | *50 bFM* | — | — | N | CE | CE | CE | CE | CE | E | E | E | CE | CE | |
| *Nyctophilus* cf. *microtis (short ears)* | *50 bFM* | — | — | Y | e? | e? | Ce? | e? | e? | e? | e? | e? | e? | e? | |
| *Pipistrellus angulatus* | *50 st.cFM* | LC | — | Y | E | CE | E | CE | E | E | E | E | E | E | |
| *Pipistrellus papuanus* | *45 st.cFM* | LC | — | Y | e? | Ce? | e? | Ce? | e? | e? | e? | e? | e? | e? | |
| MOLOSSIDAE (2 spp.) | | | — | | | | | | | | | | | | |
| *Chaerephon jobensis* | *20 cFM* | LC | — | Y | | | | | E | | | | E | | |
| *Otomops papuensis* | *35 sFM* | *** | — | Y | | | | | | | | E | | | |

| | Call type | IUCN | CITES App II | Predicted | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 | Site 6a | Site 7 | Site 8 | Site 8M | Site 9 | Wi'i Creek Cave |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total species | 39 | | | 34 | 26 | 23 | 25 | 23 | 23 | 11 | 24 | 25 | 15 | 21 | 2 |

**Legend: Detection method colour code.**

| | |
|---|---|
| C | Capture |
| e? | Echolocation calls indistinguishable from another closely related taxon (used for *Nyctophilus* cf. *microtis* and *Pipistrellus* spp. only) |
| E | Detected echolocation calls. e? = echolocation calls indistinguishable from another closely related taxon (used for *Nyctophilus* cf. *microtis* and *Pipistrellus* spp. only). |
| CE | Detected via both capture and echolocation calls. |
| Owl | Collection in owl pellets. |

**Table 7 – Summary of bat captures using both harp traps (H) and mist nets (M) during the Phase 1 and 2 surveys**

| Taxon | Site 1 | | Site 2 | | Site 3 | | Site 4 | | Site 5 | | Site 7 | | Site 8 | | Site 8M | | Site 9 | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | H | M | H | M | H | M | H | M | H | M | H | M | H | M | H | M | H | M | H | M |
| PTEROPODIDAE | | | | | | | | | | | | | | | | | | | | |
| Dobsonia minor | | 1 | 2 | 4 | | 2 | | 1 | | 2 | | 9 | | 8 | | | | 4 | 2 | 31 |
| Dobsonia moluccensis | | 3 | | | | | | | | | | | | | | | | | | 3 |
| Macroglossus cf. minimus | | 3 | | 4 | | 2 | | | | | | | | 15 | 1 | | | 3 | 1 | 27 |
| Nyctimene aello | | | | | | | | | | | | 3 | | 42 | | | | 4 | | 49 |
| Nyctimene cf. albiventer | | 2 | | 11 | 1 | 14 | 1 | 9 | | 22 | | 22 | | 16 | | | | 1 | 2 | 97 |
| Paranyctimene cf. raptor | | 9 | | 9 | 1 | 21 | 2 | 3 | | 10 | 1 | 14 | | 6 | | | | 12 | 4 | 84 |
| Pteropus macrotis | | | | | | | | | | | | | | 1 | | | | 1 | | 2 |
| Rousettus amplexicaudatus | | | | | | | | | | | | | | 2 | | | | | | 2 |
| Syconycteris cf. australis | | 16 | 3 | 40 | 3 | 43 | | 18 | | 19 | | 28 | | 18 | | | 3 | 4 | 9 | 186 |
| EMBALLONURIDAE | | | | | | | | | | | | | | | | | | | | |
| Mosia nigrescens | | | | | 1 | 1 | | | | | | | | | | | | | 1 | 1 |
| HIPPOSIDERIDAE | | | | | | | | | | | | | | | | | | | | |
| Aselliscus tricuspidatus | | | 13 | 2 | 1 | | 1 | 1 | 1 | | | | | | | | 1 | | 17 | 3 |
| Hipposideros cf. ater | | | | | | | 1 | | | | | | | | | | | | 1 | |

| Taxon | Site 1 | | Site 2 | | Site 3 | | Site 4 | | Site 5 | | Site 7 | | Site 8 | | Site 8M | | Site 9 | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | H | M | H | M | H | M | H | M | H | M | H | M | H | M | H | M | H | M | H | M |
| Hipposideros calcaratus | 1 | | 1 | | | | | | | | | | | | | | | | 2 | |
| Hipposideros cervinus | | | 1 | | | | | | | | | | | | | | | | 1 | |
| Hipposideros diadema | | | | 1 | 4 | 1 | 1 | | | | | | | | | | | | 5 | 2 |
| Hipposideros maggietaylorae | | | | | | | 1 | | | | | | 1 | | | | | | 2 | |
| Hipposideros wollastoni | 5 | | 2 | | 4 | | 3 | | | 1 | 1 | 1 | | | | | | | 15 | 2 |
| MINIOPTERIDAE | | | | | | | | | | | | | | | | | | | | |
| Miniopterus cf. tristis | | | 1 | | | | 1 | | | | | | | | | | | | 2 | |
| VESPERTILIONIDAE | | | | | | | | | | | | | | | | | | | | |
| Kerivoula cf. muscina | | | | | 1 | | | | | | 1 | | | | | | | | 2 | |
| Murina cf. florium | | | | | 6 | | | | | | | | | | | | | | 6 | 0 |
| Myotis cf. moluccarum | 1 | | | | | | | | | | | | | | | | | | 1 | 0 |
| Nyctophilus cf. microtis (short ears) | | | | | 2 | | | | | | | | | | | | | | 2 | 0 |
| Nyctophilus cf. microtis (long ears) | 2 | | 1 | | 3 | 3 | 1 | | | 2 | | | | | 2 | | 4 | | 13 | 5 |
| Pipistrellus angulatus | | | 1 | | | | | 1 | | | | | | | | | | | 1 | 1 |
| Pipistrellus papuanus | | | 1 | 2 | | | | 1 | | | | | | | | | | | 1 | 3 |

| Taxon | Site 1 | | Site 2 | | Site 3 | | Site 4 | | Site 5 | | Site 7 | | Site 8 | | Site 8M | | Site 9 | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | H | M | H | M | H | M | H | M | H | M | H | M | H | M | H | M | H | M | H | M |
| Total bat individuals captured | 9 | 34 | 26 | 734392+4932 | 27 | 87 | 12 | 34 | 1 | 56 | 3 | 77 | 1 | 108 | 3 | 0 | 8 | 29 | 90 | 498 |
| No of harp trap positions | 6 | | 4 | | 6 | | 7 | | 6 | | 3 | | 3 | | 3 | | 4 | | 42 | |
| Harp trap nights | 14 | | 12 | | 15 | | 17 | | 19 | | 15 | | 6 | | 6 | | 7 | | 111 | |
| No of mist net positions | | 17 | | 12 | | 8 | | 8 | | 14 | | 4 | | 4 | | 0 | | 4 | | 71 |
| Mist net-meter hours | | 4,392 | | 4,932 | | 4,032 | | 4,500 | | 11,304 | | 4,104 | | 3,456 | | 0 | | 1,584 | | 38,304 |

**Table 8 – Relative abundance of bat echolocation call types recorded in the study area**

Note: cells with '*' had a relative abundance value of >0 but <0.05.

| | Site | 1 | | | | 2 | 3 | 4 | 5 | 6A | 7 | 8 | 8M | 9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | Call type | Ant 2 | Ant 3 | Ant 3 (hill) | Ant 5 (road) | | | | | | | | | |
| EMBALLONURIDAE | | | | | | | | | | | | | | |
| *Emballonura dianae* | 35 i.fFM.d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 | 0 |
| *Emballonura furax* | 52 i.fFM.d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 | 0 | 0 | 0 |
| *Emballonura raffrayana* | 45 i.fFM.d | 0.1 | 0 | 0 | 0.3 | 0.1 | 0.2 | 0 | 0.1 | 0 | 0 | 0.1 | 0.1 | 0.1 |
| *Mosia nigrescens* | 65 i.fFM.d | 0.4 | 0.6 | 0.8 | 0.6 | 1.0 | 0.7 | 0.7 | 0.6 | 0.7 | 0.6 | 0.8 | 0.3 | 1.0 |
| *Saccolaimus mixtus* | 25 sFM | 0.1 | 0 | 0 | 0 | 0.1 | 0 | 0.3 | 0.1 | 0 | 0.2 | 0.2 | 0.2 | 0.1 |
| HIPPOSIDERIDAE | | | | | | | | | | | | | | |
| *Aselliscus tricuspidatus* | 115 sCF | 0.6 | 1.0 | 0.6 | 0.6 | 1.0 | 0.5 | 0.5 | 0.8 | 0.8 | 0.4 | 0.1 | 0 | 0.5 |
| *Hipposideros cervinus* | 140 sCF | 0 | 0 | 0 | 0.4 | 0.2 | 0.3 | 0.1 | 0.2 | 0 | 0.4 | 0 | 0.1 | 0.2 |
| *Hipposideros diadema* | 58 mCF | 0.4 | 0.2 | 0.8 | 0.1 | 0.6 | 0.7 | 0.5 | 0.5 | 0.3 | 0.4 | 0.5 | 0 | 0.5 |
| *Hipposideros maggietaylorae* | 125 sCF | 0 | 0 | 0 | 0 | 0.1 | * | 0 | 0.1 | 0 | 0.1 | * | 0 | 0 |
| *Hipposideros wollastoni* | 88 mCF | 0.4 | 0.2 | 0.8 | 0.6 | 0.9 | 0.8 | 0.7 | 0.5 | 0.5 | 1.0 | 0 | 0 | 0.6 |
| *Hipposideros sp. 1* | 75 mCF | 0 | 0 | 0 | 0 | 0 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | Site | 1 | | | | 2 | 3 | 4 | 5 | 6A | 7 | 8 | 8M | 9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | Call type | Antelope 2 | Antelope 3 | Antelope 3 (hill) | Antelope 5 (road) | | | | | | | | | |
| *Hipposideros cf. semoni* | 80 mCF | 0 | 0.1 | 0 | 0 | 0 | * | 0.1 | * | 0 | 0.2 | * | 0 | 0 |
| RHINOLOPHIDAE | | | | | | | | | | | | | | |
| *Rhinolophus euryotis* | 50 lCF | 0.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Rhinolophus cf. robertsi* | 33 lCF | 0.1 | 0 | 0 | 0 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| VESPERTILIONIDAE | | | | | | | | | | | | | | |
| *Kerivoula muscina* | 100 bFM | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 | 0 | 0 | 0 |
| *Murina cf. florium* | 80 bFM | 0 | 0.1 | 0 | 0.1 | 0 | 0 | 0.1 | 0 | 0 | 0.1 | 0 | 0 | 0 |
| *Myotis cf. moluccarum* | 40 bFM | 0 | 0.2 | 0.2 | 0 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.1 | 0 | 0.2 | 0 |
| *Nyctophilus cf. microtis* | 50 bFM | 0.1 | 0.1 | 0 | 0 | 0.2 | 0.2 | 0.1 | 0.4 | 0.2 | 0.2 | 0.6 | 0.6 | 0.7 |
| *Pipistrellus angulatus* | 50 st.cFM | 0.6 | 0.8 | 0.2 | 0.5 | 0.7 | 0.7 | 0.6 | 0.4 | 0.7 | 0.7 | 0.7 | 0.8 | 0.9 |
| MINIOPTERIDAE | | | | | | | | | | | | | | |
| *Miniopterus cf. tristis* | 38 st.cFM | 0.4 | 0.9 | 0 | 0.9 | 0.5 | 0.4 | 0.5 | 0.4 | 0.7 | 0.2 | 0.5 | 0.3 | 0.4 |
| *Miniopterus cf. medius* | 45 st.cFM | 0.6 | 0.7 | 0.2 | 0.8 | 0.6 | 0.6 | 0.7 | 0.4 | 0.8 | 0.5 | 0.7 | 0.8 | 0.5 |

| | Site | 1 | | | | 2 | 3 | 4 | 5 | 6A | 7 | 8 | 8M | 9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | Call type | Antelope 2 | Antelope 3 | Antelope 3 (hill) | Antelope 5 (road) | | | | | | | | | |
| *Miniopterus cf. australis* | 55 st.cFM | 0.3 | 0.4 | 0 | 0 | 0.3 | 0.3 | 0.4 | 0.1 | 0 | 0.2 | 0.4 | 0.3 | 0.3 |
| MOLOSSIDAE | | | | | | | | | | | | | | |
| *Chaerephon jobensis* | 20 cFM | 0 | 0 | 0 | 0 | 0 | 0 | 0 | * | 0 | 0 | 0 | 0.1 | 0 |
| *Otomops papuensis* | 35 sFM | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | * | 0 | 0 |

Relative abundance scale. The intensity of colour (as well as the underlying relative abundance value) indicates the proportion of recording sites with calls of that species (e.g.0.5 = 50% of recording sites), The higher values/darker colours indicate species that were more commonly recorded (further explanation in section 3.5.2).

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1.0 |

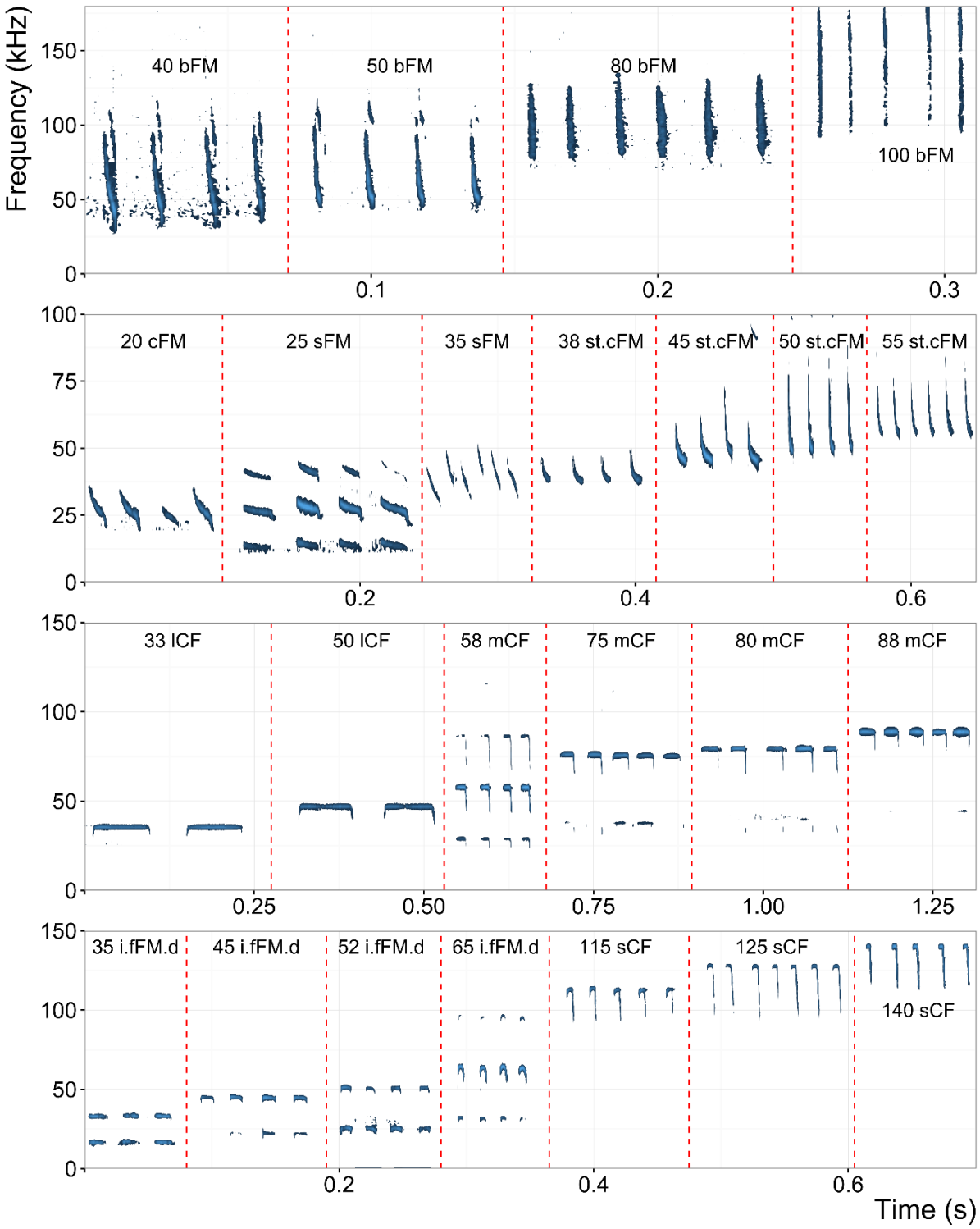



**Figure 9 – Representative sequence portions of the call types/species recognized from the acoustic recordings, grouped by main body type of the call**

Note: time between pulses has been compressed; note also the frequency scale on the y-axis and the time scale on the x-axis differs amongst plots. The species allocations of each call type are given in **Table 8** (see **Appendix 3** for detailed justifications).

### 4.1.2 Conservation listed bat species

#### *4.1.2.1 Bulmer's Fruit Bat Aproteles bulmerae—IUCN Critically Endangered, nationally Protected*

Discovery of the Critically Endangered Bulmer's Fruit Bat *Aproteles bulmerae* in the study area is consistent with other recent records of this species from cave deposits in areas of lowland karst in southern Papua New Guinea (Aplin et al. 2016). Prior to these discoveries, this species was considered to be a montane-adapted species with a very restricted distribution (e.g. Flannery 1995; Bonaccorso 1998). The new records extend the geographic and ecological range of Bulmer's Fruit Bat into the lowland karst landscape of southern Papua New Guinea and identify new areas where extant populations of Bulmer's Fruit Bat might be sought.

The reproductive and feeding behaviors of Bulmer's Fruit Bat remain poorly documented. The few observations of roosting behavior come from the inner chambers of large cave systems, and the only information on breeding (from a high elevation site in Western Province) suggests that birth of young occurs around February/March, probably after a pregnancy lasting several months (assuming parity with similar-sized fruit bats). While females and young are likely to be particularly vulnerable during a breeding season, cave roosting bats are both vulnerable and sensitive to roost intrusions or more general disturbance at any time of year.

The study area record of Bulmer's Fruit Bat consists of isolated teeth of juveniles, mixed in with more numerous teeth of juvenile Moluccan Naked-backed Fruit Bat. Given that these remains are exclusively from very young individuals suggests predation by owls of juvenile bats left unattended in a maternity roost while the adults forage. Because owls hunt only within a restricted distance of their own roost (usually within 1–2 km (Bilney et al. 2011) and probably less in closed primary forest), this in turn allows us to infer the nearby occurrence of a maternity roost used by Bulmer's Fruit Bat (possibly shared with the Moluccan Naked-backed Fruit Bat). The cave visited on 29 June 2016 is itself a candidate because the entrance chamber gave way to a large tunnel that clearly penetrated some distance into the hill. However, the surrounding karst landscape may well conceal other cave systems including larger sinkholes of the kind utilized by Bulmer's Fruit Bat elsewhere. Landowners are aware of the location of various large caves and sinkholes in this area, at least some of which are said to contain colonies of cave roosting fruit bats. The precise location of these caves has not been mapped, as they are remote from villages, accessible only on foot, and visits require overnight stays.

Given that Bulmer's Fruit Bat has been confirmed as a living animal at only two localities, with no recent census at either site (Aplin et al. 2016), any additional population of this species is of potential importance for its long-term survival. The Wi'i Creek cave itself is located within the broader study area. However, given the location of the cave, it is likely that some individuals of Bulmer's Fruit Bat would forage into at least the northern part of PRL-15 and that any caves, fissure or rock overhangs within this area could be utilized as temporary roost sites. This kind of casual use of dispersed roosts is documented for the Moluccan Naked-backed Fruit Bat (Hall 2008; K. P. Aplin unpublished data) and might be assumed also for Bulmer's Fruit Bat.

#### *4.1.2.2 IUCN Data Deficient species*

The echolocation call types include (or may include, if identifications are correct) four species listed by IUCN as Data Deficient: The New Guinea Sheath-tailed Bat *Emballonura furax*; Semon's Leaf-nosed Bat *Hipposideros* cf. *semoni*, the Papuan Sheath-tailed Bat *Saccolaimus mixtus*, and the Papuan Free-tailed Bat *Otomops papuensis* (see Table 8, and Appendix 2 for discussion of these allocations). Two of these species require consideration of whether they might have a restricted-range—*Saccolaimus mixtus* and *Otomops papuensis*. Relatively little is known about the distribution limits of these species, as there are relatively few collection records, and they are seldom recorded on acoustic surveys. However, the available records (as per the IUCN Red List profiles for each species; see also Bonaccorso 1998) indicate that each probably has a wide distribution, with only a relatively small proportion of each species present in the study area.

The New Guinea Sheath-tailed Bat is rarely ever captured and most records come from large caves where small numbers co-occur with large aggregations of the Large-eared Sheath-tailed Bat *E. dianae* (Flannery 1995; Bonaccorso 1998). In some localities in southern New Guinea the use of bat detectors has shown the New Guinea Sheath-tailed Bat to be locally abundant in both alluvial forest and hill forest habitats. This does not appear to be the case for the present study area where there is a report of one prior record from PRL-15 in the Southeast Hills ecological zone (Unpublished data) and one Phase 2 survey record from Site 7 within the export pipeline corridor. The paucity of records of this species within the study area is interpreted as a genuine indicator of rarity, which is not likely to be a seasonal phenomenon given the two survey periods were conducted in different seasons. The nearest records outside of the study area are from caves near Putei, in the Vailala River catchment to the east. The New Guinea Sheath-tailed Bat aggregates in caves to roost during the day, and will be particularly vulnerable to disturbance or loss of those habitats.

Semon's leaf-nosed bat is known from numerous localities on Cape York Peninsula in Queensland, Australia, but from only three widely separated localities in Papua New Guinea (Morobe and Gulf Provinces, National Capital District). Call type *80 mCF*, which is allocated tentatively to Semon's Leaf-nosed Bat, was recorded at each of survey sites 1, 3, 4, 5, 7 and 8 (Table 6) but it was nowhere abundant (Table 8). This species roosts in rocky overhangs, the twilight areas of deeper caves and tree hollows. Given the variety of spaces that it will use for roosting, it is probably less vulnerable to localized disturbance of natural habitats.

The Papuan Sheath-tailed Bat *S. mixtus* is known from widely separated localities in Central and Western Provinces of Papua New Guinea, and additionally from numerous localities on Cape York Peninsula. Although this species was not captured during the survey, the *25 sFM* call type recorded at nearly every survey site is consistent with calls emitted by Australian populations of *S. mixtus* and thus the authors are confident of this allocation. This species roosts in tree hollows, particularly the larger hollows in broken tree trunks or larger branches (K. N. Armstrong personal observations in Australia). It ranges widely at night while foraging over and amongst the forest canopy but colonies will be vulnerable when in the roost during the day.

From the acoustic survey, it is clear that the Papuan Sheath-tailed Bat is widespread in the lower Purari River catchment, ranging across all ecological zones and all major forest types including mangrove forest. It was also recorded during an unpublished survey but incorrectly reported as 'Molossid type 2 (*Mormopterus beccarii*)'. Elsewhere in Papua New Guinea, this call type has been recorded at only one other site—in the lower Ok Tedi catchment in Western Province (K. P. Aplin and K. N. Armstrong, unpublished).

The Papuan Sheath-tailed Bat is a moderately large bat that typically roosts in tree hollows or in small fissures and overhangs. The only major threat to its existence is loss of habitat, and loss of suitable roost trees in particular. It will be most susceptible to disturbance to colony aggregations in its diurnal roosts. The Purari River catchment with its extensive tracts of interconnected mangrove, alluvial and hill forests may represent a conservation stronghold for this species. While similarly robust populations may exist elsewhere in the lower Kikori River and Fly River catchments, to date they have not been discovered.

The Papuan Free-tailed Bat *Otomops papuensis* was described from immediately east of the study area and is still known from only a few scattered localities. Although its call type remains unknown, members of the genus *Otomops* share a distinctive call type that supports referral of call type *35 sFM* to this genus. An *Otomops* call type was detected once only, at Site 8, but the same call type was recorded at two sites in the southeast part of the study area. Both localities are within the Southeast Hills ecological zone. *Otomops* belongs to a guild of low-frequency emitting and high-flying species that are detected relatively infrequently during acoustic surveys and may be genuinely uncommon; others include species of *Chaerephon, Saccolaimus,* and *Taphozous*.

The population of the Papuan Free-tailed Bat identified in the southeast of the study area may be near to the western end of its distribution, as there are no records of the *35 sFM* call type anywhere to

the west (K. N. Armstrong and K. P. Aplin unpublished data). Although the Papuan Free-tailed Bat may still exist further to the east, either in Central Province or on the southeast peninsula of Papua New Guinea, the lowland habitats in these areas have been subject to a longer history of timber extraction and forest conversion than those in the study area and in Gulf Province generally. The main threats to the Papuan Free-tailed Bat undoubtedly are loss of foraging habitat and loss of trees with suitable roost hollows. Accordingly, the population of the Papuan Free-tailed Bat in the study area may be one of the most secure lowland populations of this species within Papua New Guinea.

As a final comment on all species mentioned here, it should be noted that little is known about breeding activity and seasonal patterns of habitat use for even the most common New Guinean bats, and that this is further confounded for many groups by uncertainty over taxonomic and distribution limits. For the purposes of impact assessment, it should be assumed that most bat species will depend year-round on access to foraging habitats; and further, that the courtship, mating and breeding activities of both cave-roosting and foliage/tree-roosting species will extend through much of the year, especially among those species that reproduce twice per year (see section 4.4.1). For these reasons, it is not possible to nominate particular times of year when bats are more or less vulnerable to disturbance.

*4.1.2.3 CITES listed species*

All species of *Pteropus* (flying-foxes) are listed in CITES Appendix II. There are prior records of two species in the study area—Large-eared Flying-fox *P. macrotis* and Great Flying-fox *P. neohibernicus* (Liem and Haines 1977). Both were recorded again during the Phase 2 survey.

### 4.1.3 Undescribed bat taxa

At least one of the bat species that was captured during the survey is almost certainly undescribed. Two morphologically distinct forms of *Nyctophilus* cf. *microtis* were captured— 'long ears' and 'short ears'—with one of the two being unnamed. Both forms have been captured elsewhere in southern Papua New Guinea as part of other environmental impact surveys.

The unallocated call type *75 mCF* is certainly the call of a species of *Hipposideros* but it could not be allocated to any known species. It may also represent an undescribed (and in this case, potentially uncaptured) species of bat. This call type has been recorded in other recent surveys in Western Province (K. P. Aplin and K. N. Armstrong, unpublished).

Additional undescribed species are probably present among the study area populations of striped tube-nosed fruit bats (genus *Nyctimene*) and bent-winged bats (genus *Miniopterus*). Each of these genera contains fewer available scientific names than the number of morphologically and genetically distinct forms occurring within Papua New Guinea. However, both groups are taxonomically confused (see **Appendix 2**) and it is not yet clear how many species are present and which of them have been named.

As detailed in **Appendix 2**, all taxa listed with a 'cf.' qualifier indicative of taxonomic ambiguity are likely to have been recorded by previous captures outside of the study area.

### 4.1.4 Endemic and restricted-range bat taxa

Most of the species found in the study area are known to be distributed widely throughout mainland New Guinea, and also extend to island groups to the east or west, or south to Australia (encompassing endemism categories 1–3; Table 1). Three taxa are distributed on New Guinea but do not occur elsewhere (category 4; Wollaston's Leaf-nosed Bat *Hipposideros wollastoni*; the Fly River Leaf-nosed Bat *Hipposideros muscinus*; and the Fly River Woolly Bat *Kerivoula muscina*). Three taxa are endemic to Papua New Guinea (Bulmer's Fruit Bat *Aproteles bulmerae*; the Papuan Free-tailed Bat *Otomops papuensis* and Watts's Pipistrelle *Pipistrellus wattsi*).

Bulmer's Fruit Bat can be safely categorized as a restricted-range taxon because it is known from only a few widely-separated localities, with large gaps in distribution through the better surveyed

areas of Papua New Guinea, including parts of Western, Eastern and Southern Highlands Provinces (Bonaccorso 1998), Although the new records from the lowland karst landscape of southern New Guinea have increased its potential geographic range, the lack of records from previously surveyed cave systems in this area, such as those in the Vailala catchment (McKean 1972) and around Fogamai'u in the Kikori catchment (Flannery 1995; Bonaccorso 1998), point to a patchy distribution within this landscape.

Three other bats that are known to occur, or that could occur, in the study area require consideration of whether they might qualify as restricted-range taxa—Papuan Sheath-tailed Bat *Saccolaimus mixtus*; Papuan Free-tailed Bat *Otomops papuensis*; and Watts's Pipistrelle *Pipistrellus wattsi.* For both species, it has been assumed that their ranges might extend from the study area east to the lowlands of Milne Bay Province, as this represents a common biogeographic pattern shared across multiple groups of vertebrates (Beehler 1993). An inclusive polygon that covers all lands below 500 m from the Darai Plateau ridge and Hegigio valley, east through the study area to Milne Bay and that includes all coastal habitats (including mangroves), freshwater swamp vegetation (including grassland, herbland or pandanus swamp) as well as Swamp forest (Fsw), hill forest and alluvial forest forms, has an area of c. 40,000 $km^2$. If the range and/or habitat requirement of either species is narrower than implied by these broad limits, then the species would be consistent with the definition for restricted-range species. In the case of the Papuan Free-tailed Bat, records in both the study area and Milne Bay Province (record supported by examination of museum specimens; K. P. Aplin unpublished observations) suggest a much wider distribution than is currently illustrated for this species (Bonaccorso and Hamilton 2008).

The distribution of the Papuan Sheath-tailed Bat *Saccolaimus mixtus* is poorly known in PNG. In Australia, it occupies much of the Cape York Peninsula, and current IUCN Red List Profile mapping shows its distribution in lowlands south of the Fly River delta in Western Province and a small area around Port Morseby (Thomson et al. 2008). It is possible that it could extend throughout the intervening region, and beyond, as suggested by the calls attributed to it from the present study. The Papuan Sheath-tailed Bat is seldom encountered because it flies over canopy, and it is certainly possible that it is more common than is currently recognized.

### 4.1.5 Migratory and congregatory species

#### *4.1.5.1 Migratory behaviors*

No New Guinean bats are known to undertake seasonal 'migrations' between New Guinea and any other landmass. However, many New Guinean bats are probably capable of long-distance flights and some may regularly travel 10s of kilometers in search of food resources. This behavior is best documented among regional populations of the larger flying-foxes (Hall and Richards 2000). Outside of their breeding seasons, these species forage across very large territories, typically moving in small groups from one clump or trees to another as they come into flower or fruit. During breeding seasons, they aggregate in large numbers to form 'camps' where mating occurs and the young are born and raised until they are capable of independent flight (see below).

Long distance movements can also occur among the smaller insectivorous species, some of which are capable of sustained rapid flight. This is most likely to occur in species that have specific roost requirements for all or part of the year (e.g. during a breeding season) such that roost sites and foraging sites are widely separated. However, it might also occur as a more regular strategy if an area that offers abundant food resources lacks appropriate daytime roosts.

One part of the study area that may be exploited on a regular 'migratory' basis is the Mangroves ecological zone. As presented below (*Section 4.2*), the species composition of the mangrove bat community is suggestive of a dominant nightly 'fly-in, fly-out' behavior. This is an important observation because the conservation of the mangrove bat community (which might be important in protecting mangrove ecology) thus depends on retention of suitable areas of habitat not only within the Mangroves ecological zone but also in surrounding zones.

#### *4.1.5.2 Congregatory behaviors*

Many New Guinean bat species are congregatory in the sense that they habitually roost together in large groups, or else they come together seasonally in moderate to large groups for mating and the birth and rearing of young.

Flying-foxes of the genus *Pteropus* have complex social behaviors (Hall and Richards 2000) and many species are known to congregate seasonally in large 'camps' where they participate in social interactions such as mating, and where the females bear and rear their young (Eby 1991; Webb and Tidemann 1996; Tidemann et al. 1999; Tidemann and Nelson 2004). Major camps are often located in mangroves or in areas of riparian forest or freshwater swamps where open space over rivers and swamps facilitates flight access in and out of roost trees.

Two species of flying-fox were recorded in the study area (Giant Flying-fox *P. neohibernicus* and Big-eared Flying-fox *P. macrotis*) and local residents are familiar with these animals across all ecological zones. Small social and feeding congregations of a few tens of individuals can be observed almost anywhere in the study area and at any time of year, often associated with fruiting breadfruit trees (*Artocarpus altilis*). By contrast, there are relatively few reports of larger congregations. One locality that may qualify as a seasonal 'maternity camp' is the oxbow wetland system to the west of survey Site 4. Residents of Poroi 2 and Mapaio Fish Camp villages reported much larger congregations in this area (uncertain which species), with females carrying dependent young observed in May–June. Other 'camps' are probably situated in the Mangrove ecological zone, but may be less fixed in position. Residents of coastal villages along Orokolo Bay described large congregations that are hunted regularly, but the precise location of these colonies was said to vary from year to year—quite possibly a response to the hunting.

The Moluccan Naked-backed Fruit Bat *Dobsonia moluccensis* is known to congregate in large groups (100s to many 1,000s of individuals) inside caves, but little else is known of its behavior and ecology. In Chimbu Province, mating occurs in April-June and young are born in August-November (Dwyer 1975), but there is some evidence for regional differences in timing (Flannery 1995).

In areas close to human settlements, they typically occupy caves that afford the best protection against hunters (Flannery 1995; Bonaccorso 1998). However, in remote areas, smaller groups are sometimes observed in small caves or fissures, under rock overhangs or among exposed tree roots (Flannery 1995; K. P. Aplin, personal observations). Large caves are also commonly the sites of maternity roosts where females congregate to give birth and rear their young, however females with late term pregnancies or carrying new-born young have also been observed in smaller roosts (K.P. Aplin, personal observations). This flexibility in regard to roost size means that the Moluccan Naked-backed Fruit Bat is not restricted to areas with large cave systems, but may exist in other kinds of landscapes, provided some sheltered roosts can be accessed. The same may also be true for Bulmer's Fruit Bat, which is closely related to the genus *Dobsonia* and is very similar to the Moluccan Naked-backed Fruit Bat in size and appearance.

Moluccan Naked-backed Fruit Bats were captured at Site 1 and their distinctive wing-beat was heard at night in other sites in the Middle Purari Hills ecological zone. Residents of Wabo, Ura, Subu and Poroi 2 villages in the northern part of the study area all reported caves with flying-fox colonies within their clan territories and some of these are hunted on a semi-regular basis. These colonies are most likely dominated by the Moluccan Naked-backed Fruit Bat, but some might also include groups of Bulmer's Fruit Bat. Further south in the study area it is likely that one or both of these species makes use of smaller fissures and overhangs in the many cliff-lines and other minor rock outcrops of calcareous mudstone.

The Common Rousette *Rousettus amplexicaudatus*, a medium-sized cave-roosting fruit bat, was captured only at Site 8. It is likely that this species uses caves in Heve Hill. There are no other records of *R. amplexicaudatus* from either the Purari or Kikori River catchments but it is recorded from caves

near Putei in the Vailala River catchment to the east of the study area (McKean 1972). The reason for its absence from seemingly suitable karst country to the north and west is unknown.

The echolocating bats recorded during the survey include many species that are known to roost in caves, either throughout the year or when congregating to breed. Notable examples are the various species of *Miniopterus*, *Emballonura* and *Aselliscus*, as well as several species of *Hipposideros* (*calcaratus*, *cervinus*, *diadema* and *maggietaylorae*). All of these species of bats were recorded regularly by the bat detectors and at the majority of sites. Large cave systems suitable as congregatory breeding sites are likely to be concentrated in areas with limestone in the northern part of the study area including in the Kereru Range.

During both survey periods, females of the Trident Leaf-nosed Bat *Aselliscus tricuspidatus* were captured in advanced stages of pregnancy at sites far (>20 km) from any major limestone outcrops (e.g. Sites 2 and 9). Unlike species of *Miniopterus* and (to a lesser extent) *Emballonura* that are adapted for fast and potentially long-distance flight, the Trident Leaf-nosed Bat is a slow flying species that must have been roosting close to the point of capture. This is an important observation as it suggests that some insectivorous bat species that are normally thought of as obligate cave roosting species are capable of using (and breeding in) dispersed smaller-scale rocky outcrops; and further, that such sites may be important for the maintenance of regional connectivity in populations of insectivorous bats.

The reproductive behavior of all New Guinean *Miniopterus* spp. remains undocumented. However, if their biology mirrors that of other species of this genus in Australia and Eurasia, females very likely congregate annually in large maternity roosts. In Australia, these congregations are focal points for populations that are otherwise dispersed hundreds of kilometers from the breeding site. If this pattern applies in New Guinea, caves in the northern part of the study area may represent the key breeding sites for huge numbers of bats that forage all the way to the coast.

### 4.1.6 Invasive Alien species

No invasive alien species of bat have been recorded in the study area and none are expected to occur.

## 4.2 Bat community structure

### 4.2.1 Fruit bat communities

Among the non-echolocating fruit bats, all species are probably more or less equally susceptible to capture in mist nets, although this will be dependent on their usual pattern of flight relative to ground level. For this group, relatively abundances can be explored from the net capture data (Table 7).

Several patterns are evident within the mist net dataset. Among the fruit bats the most uncommon species was the Common Rousette, which was captured only at Site 8 (Table 7). As noted above, this may reflect the proximity of this site to Heve Hill, an isolated patch of karst that might contain a colony of this species.

Another species with localized occurrence in the study area is the Greater Tube-nosed Fruit Bat *Nyctimene aello*, which was captured only at Sites 7, 8 and 9, and with peak abundances at Site 8 (Table 7). Although this species is currently ranked Least Concern by the IUCN, in the past it has been listed in other categories on account of the relatively paucity of museum specimens. In the Purari River catchment it appears to be restricted to parts of the Delta Swamps and Plains and Southeast Coast ecological zones (and potentially also the Mangroves), though it can be locally abundant in these habitats and presumably plays a significant role in pollination and seed dispersal for some tree or palm species. A similar pattern has been observed elsewhere in Papua New Guinea such as in the Sepik River catchment (K. P. Aplin unpublished data) where *N. aello* is confined to low-lying alluvial habitats and is most abundant in swamp habitats or along major watercourses. Access to preferred (but as yet unidentified) food items rather than competition probably explains the restricted

occurrence of this species, as it has no obvious ecological vicars in the hill forest bat community. One possible explanation of its distribution in the Purari catchment is that mangrove forest represents its core habitat, with other records being peripheral. However, this explanation does not work for the Sepik lowlands that lack extensive mangrove habitats. Reliance on the resources of freshwater swamp habitats is another possibility. In any event, protection of the fruiting tree or palm resources will be the key factor in guaranteeing regional persistence of this species.

Another interesting pattern is observed for the Dagger-toothed Long-nosed Fruit Bat *Macroglossus minimus*. This species was moderately abundant in hill forest habitats at Sites 1–3, as well as the low elevation habitats at Sites 8, 8M and 9, but there is a notable gap in its occurrence in the well-sampled alluvial forest habitats at Sites 4 or 5. This bimodal distribution could potentially be due to seasonal movement between the two habitats in pursuit of particular flowering or fruiting resources, but this would not explain their absence from Site 4 and 5, which were sampled in two different seasons. Another possibility is that the two populations represent different species of *Macroglossus*, one restricted to hill forest habitats and the other associated with mangroves/swamp forest habitats. Genetic studies of Melanesian *Macroglossus* are underway to determine the number of species and their wider distributions. Until these results become available it is reasonable to assume that any regionally occurring species of *Macroglossus* will have broad geographic distributions, while the frequency of capture in both habitats identified them as locally abundant species.

### 4.2.2 Insectivorous bat communities

The study area contains five Ecological Zones within the 600 m elevational range, which also contain three general types of FIMS forest (alluvial, hill, mangrove). Each species of bat encountered in the study area is already known to be distributed at relatively low elevations (sea level up to at least the study site maximum of 600 m; Bonaccorso 1998). A detailed analysis of bat habitat preference that could be used to identify an elevated risk of the project for some species that might be restricted to particular Ecological Zones within the study area is limited by a general lack of knowledge on habitat preference. The distribution of Papua New Guinean bats within each of their geographical limits is understood to rely primarily on elevational limits of relatively broad-scale forest types, and knowledge of finer-scale habitat preference is generally lacking unless it relies on the presence of caves. In addition, some of the study sites spanned more than one Ecological Zone (for example Sites 5, 7, 8 and possibly 9), reducing the potential for gaining a clear understanding of fine-scale structuring of bat species amongst the defined Ecological Zones. Despite such limitations, exploratory analyses were chosen that are generally used to extract out the most obvious patterns amongst species and defined habitats, all of which relied on calculations of relative abundance. In addition to a visual examination of the relative abundance matrix, a Non-metric Multidimensional Scaling (NMDS) ordination analysis was performed with explicit reference to either Ecological Zone or general forest type (hill forest, alluvial forest, a mix of the two, or mangrove; see section 3.3.2 for further information on these definitions). Further examination of species that might be conspicuously associated with particular habitats was made by calculating Indicator Species values using the method of Dufrêne and Legendre (1997).

For the echolating insectivorous bat species, relative abundances are calculated as the proportional representation of each call type among recording positions in each site (*see Section 3.5.2*). The values for an individual species are directly comparable among sites, and thus can be used to estimate the relative commonness or rarity of that species in different habitats. However, differences in detectability between species limit the capacity to compare relative abundances between species—a common species that has a low energy call and is hard to detect may appear much less abundant than one that is actually less common but is easy to detect because of its call type. Fortunately, these parameters are quite well understood for bats so it is possible to make these adjustments during the interpretation of observed patterns.

There were marked differences in the relative abundances among the insectivorous bat species (Table 8). Variation that can be attributed to differences in detectability include the uniformly low abundances of species of *Murina* and *Kerivoula* that emit very low energy calls and must fly very

close to the microphone to be detected. Other variation is probably more indicative of genuine differences in natural abundance or rarity; for example, *Mosia nigrescens*, *Miniopterus* cf. *medius*, *M.* cf. *propitristis* and *Pipistrellus angulatus* are probably all genuinely common, while the larger-bodied, high-flying species of *Chaerophon*, *Otomops* and *Saccolaimus* may be all relatively uncommon.

Comparing patterns among sites within species, several species were more commonly recorded in the low elevation sites where the dominant habitats are alluvial forest or mangrove forest—this is particularly notable for *Nyctophilus* cf. *microtis*, which was recorded more frequently at Sites 8, 8M and 9 than anywhere else, and less marked but still notable for *Saccolaimus mixtus*.

All of the leaf-nosed bats (Hipposideridae) were relatively abundant in all of the ecological zones except for the Mangroves, where they were rare or absent. A similar paucity of leaf-nosed bats has been reported for mangrove habitats across northwest Australia (McKenzie and Rolfe 1986; McKenzie and Start 1989) but the reason for this pattern has not been identified. In the present dataset, the rarity of leaf-nosed bats in the mangroves contrasts sharply with the abundance in this zone of certain other species including *Miniopterus* cf. *medius*, *Pipistrellus angulatus* and *Nyctophilus* cf. *microtis*, and to a lesser extent the emballonurid bats (species of *Emballonura*, *Mosia, Saccolaimus*). What distinguishes most of these species (*Nyctophilus* cf. *microtis* is an exception) from the leaf-nosed bats is their capacity for fast long-distance flight that may allow them to reside around the periphery of the mangroves and to travel into them each evening for feeding. Since this would not be possible for the slow-flying leaf-nosed bats or *Nyctophilus* cf. *microtis*, the difference between these taxa must reflect a contrasting availability of roost sites. It is inferred that *Nyctophilus* cf. *microtis* must be able to find suitable roosts within the mangrove habitat such that it can maintain a large resident population, and speculate that leaf-nosed bats may be excluded from this habitat by an absence of suitable roosts. One management implication of this new finding is that the areas fringing the mangrove community may be of special importance in supporting the dominant bat species in the communities that forage nightly within the mangroves.

Two species were recorded exclusively (though neither very often) in the mangrove habitat—Large-eared Sheath-tailed Bat *Emballonura dianae* and Greater Northern Free-tailed Bat *Chaerephon jobensis*. Neither species has a preferred association with mangroves elsewhere within its range (Flannery 1995; Bonaccorso 1998), although *C. jobensis* is moderately common in mangrove habitats across northwest Australia (McKenzie and Rolfe 1986; McKenzie and Start 1989).

Two quantitative methods were applied in attempt to detect general patterns of community structure according the Ecological Zone and general forest type.

An NMDS analysis with samples labelled either by ecological zone or forest type (**Figure 10**) reinforces the impression that there is little overall differentiation between the bat communities of hill and alluvial forest. By contrast, the mangrove forest bat communities are more clearly differentiated from the remainder. When the NMDS analysis is labelled by ecological zone the Mangroves and Southeast Coast are both partially differentiated from the other zones as well as from each other; however, all zones show partial overlap which may reflect the variation in disturbance history among sites in each of the well-sampled zones.

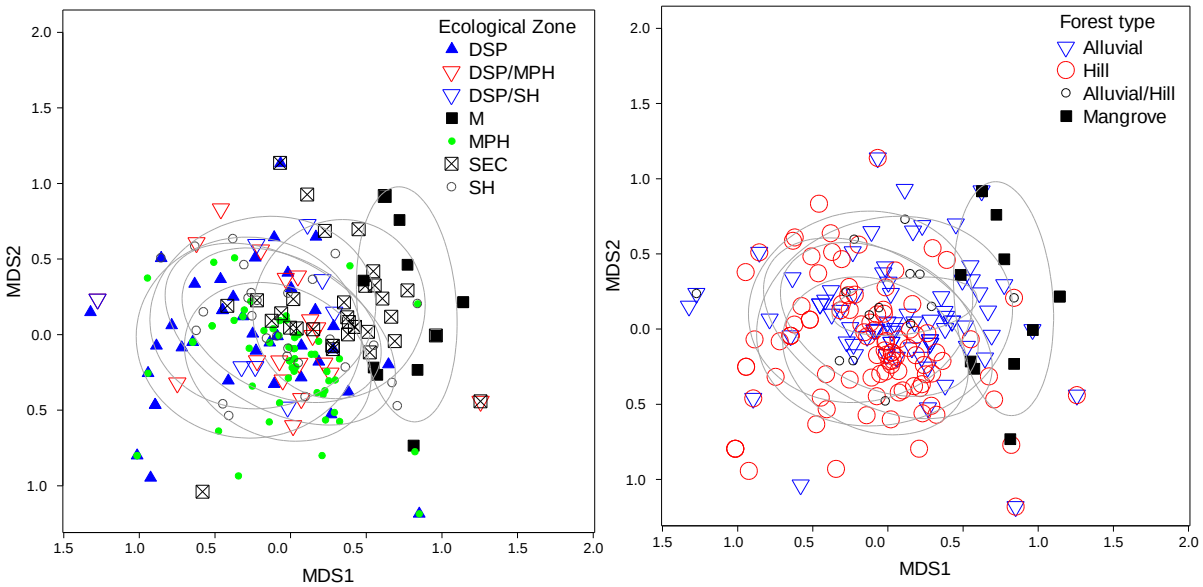



**Figure 10 – Non-metric Multidimensional Scaling ordination of the presence-absence data matrix derived from the acoustic dataset**

Note: Each point is a recording site and the symbols are labelled either by Ecological Zone (left plot) or forest type (right plot) at the recording location. Codes for Ecological Zone: DSP—Delta Swamps and Plains; DSP/MPH—ecotone between Delta Swamps and Plains and Middle Purari Hills; DSP/SH—ecotone between Delta Swamps and Plains and Southeast Hills; M—Mangroves; MPH—Middle Purari Hills; SEC—Southeast Coast; SH—Southeast Hills. Codes for forest type: A—alluvial forest; H—hill forest; A/H—ecotone between alluvial forest and hill forest; M—mangrove forest. Confidence ellipses are one standard deviation around mean scores on each axis.

The Indicator Species analysis (Dufrêne and Legendre 1997; shown here for groupings based on forest types; groupings using ecological zones support similar inferences) more clearly identifies the suites of species that were conspicuously common in different habitats (Figure 11). As would be expected from the NMDS analysis, the mangrove forest habitat shows the most distinctive profile, with minimal representation of hipposiderids and higher than average values for *Miniopterus* cf. *medius* and *Nyctophilus* cf. *microtis*. More surprisingly, there is evidence of differentiation between the hill forest and alluvial forest sites for several species, with *Hipposideros wollastoni* and *Aselliscus tricuspidatus* both more common in the hill forests and *Hipposideros diadema, Mosia nigrescens* and *Nyctophilus* cf. *microtis* all more common in the alluvial forests. Two species show their highest index values in the alluvial/hill forest ecotone sites—*Hipposideros wollastoni* and *H. cervinus*, with the latter rarely encountered outside of this context.

Although some of the inferences made here regarding community structure are tentative, there is sufficient evidence of patterning to suggest that insectivorous bat community structure will prove to be a sensitive tool for monitoring of habitat condition across the study area.

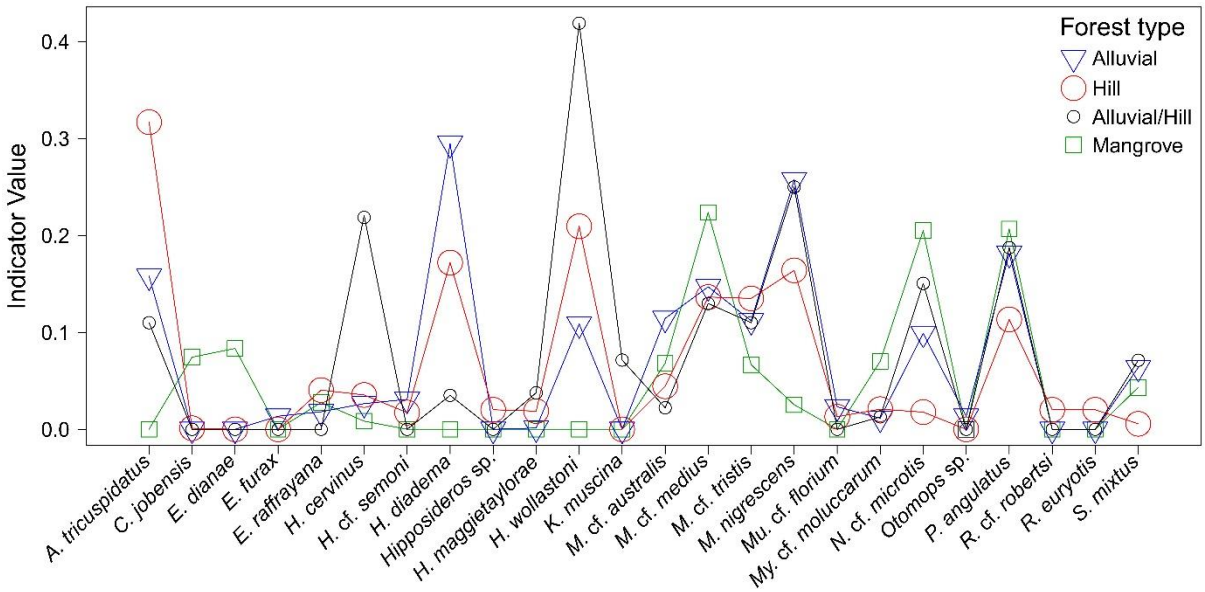



**Figure 11 – Indicator Values (Dufrêne and Legendre 1997) for each species within each of four defined broad forest types**

## 4.3 Knowledge gaps

The similarity of bat community composition across the ten major sampling sites suggests that the survey was effective in documenting the major elements of the regional bat community. Nevertheless, it is likely that the study area supports several other bat species. In all, 13 additional species were predicted to occur based on regional records (compare Tables 1 and 6).

As explained in *Section 3.5,* there are a variety of reasons why a bat species may be unrepresented in an acoustic or trapping survey. Some species of bat probably occur at relatively low density and they may be difficult to capture and/or detect because of the amplitude or high characteristic frequency of their echolocation calls.

Species that were anticipated for the study area (as listed in Table 1) but were not captured or recorded on acoustic detectors are listed in Table 9, with comments on the possible reasons for their lack of detection. Most are Least Concern on the IUCN Red List but three are Data Deficient and two may also qualify as restricted-range taxa.

**Table 9 – Bat species that were anticipated but not recorded in the study area, with possible reasons for their lack of detection**

Note: IUCN categories are described in *Section 3.3.4*; in this table N/A signifies that the identity of the species is unknown, hence an IUCN ranking is not available. RR = restricted-range.

| English name | Scientific name | IUCN | Possible reason for non-detection |
|---|---|---|---|
| Mountain Tube-nosed Fruit Bat | Nyctimene certans | LC | A montane-adapted species. If present at all, restricted to highest elevation forests. |
| Bare-rumped Sheath-tailed Bat | Saccolaimus saccolaimus | LC | Call type is very low frequency and fainter calls might be indistinguishable from background signals. It may not be present in closed rainforest habitats in Papua New Guinea. |
| Becccari's Sheath-tailed Bat | Emballonura beccarii | LC | Call type is known (call type *65 i.fFM.d*), which is similar to that of *Mosia nigrescens*. It is known from localities just north of the study area (Bonaccorso and Leary 2008) but is difficult to capture and is more likely to be recorded by examination of roost caves. |
| Fly River Leaf-nosed Bat | Hipposideros muscinus | DD/RR | Call type is known (*94 mCF*) and should be recorded if species is present. Possibly excluded from Purari River catchment by competition with the morphologically similar *H. wollastoni*. |
| Arcuate Horseshoe Bat | Rhinolophus arcuatus | LC | Call type is known (*70 lCF*) and should be recorded if the species is present. It may be restricted to higher elevation hill forests. |
| Eastern Horseshoe Bat | Rhinolophus megaphyllus | LC | Call type is known (*70 lCF*) and should be recorded if the species is present; potential for confusion with *R. arcuatus*. The few New Guinean records come from slightly higher elevations (> 260 m asl). |
| Large-eared Horseshoe Bat | Rhinolophus philippinesnsis | LC | This taxonomically unresolved group of horseshoe bats is represented in the study area by *R.* cf. *robertsi*. |
| Bent-winged Bats | Miniopterus spp. incl. M. macrocneme | N/A | Uncertain if any other species of *Miniopterus* are present. If they are, may not be distinguishable by call types from the 3 recorded taxa or possibly *Pipistrellus* spp. |
| Short-winged Pipistrelle | Philetor brachypterus | LC | Call type is known (*30 st.cFM*) and has good detectability. Most records of this species come from higher elevations (>1,500 m asl). |
| Golden-tipped Bat | Phoniscus papuensis | LC | Possibly present. Calls are very low energy and have low range of detectability, thus likely to be detected rarely even if present. |
| Watts' Pipistrelle | Pipistrellus wattsi | DD/RR | Not captured. Call type is unknown and may not be distinguishable from other *Pipistrellus* spp. |

| English name | Scientific name | IUCN | Possible reason for non-detection |
|---|---|---|---|
| Beccari's Free-tailed Bat | Mormopterus beccarii | LC | Call type is known (*20 cFM*) and is sometimes recorded on acoustic detectors. The species may be genuinely uncommon in many regions. |

The Data Deficient Fly River Leaf-nosed Bat *Hipposideros muscinus* has been captured and detected acoustically during recent surveys in Western Province, though never appears to be very common (K. P. Aplin and K. N. Armstrong, unpublished data). With the amount of effort applied during the present program, this species should have detected if it is widely distributed in the study area. Lack of detection presumably means that it is either absent or else very localized. One possibility is that *H. muscinus* and the similar-sized Wollaston's Leaf-nosed Bat *H. wollastoni* (that was detected and captured regularly) have mutually exclusive areas of occupancy. The authors are unaware of any instance of sympatric co-occurrence of these species.

The Data Deficient Small Melanesian Bent-winged Bat *Miniopterus macrocneme* may have been recorded on the bat detectors, but if so, the call cannot be confidently identified as belonging to this species. Although reference calls are available from a number of different forms of *Miniopterus* as a result of surveys across Papua New Guinea during the past 7 years, to date it has not been possible to confidently allocate scientific names to the various forms. The genus *Miniopterus* contains one of the most complex taxonomic problems within the New Guinea bat fauna and a large- scale taxonomic research effort will be needed to resolve species boundaries and establish appropriate names. All species of *Miniopterus* probably possess similar basic biological traits, will likely be threatened by the same general processes, and will be protected by the same suite of mitigative measures.

The Data Deficient Watts's Pipistrelle *Pipistrellus wattsi* is known from just east of the study area and it may be present. Its call type is unknown and may not be distinguishable from other species of *Pipistrellus* that also show similarity to *Miniopterus* spp. All species of *Pipistrellus* probably possess similar basic biological traits, will likely be threatened by the same general processes, and will be protected by the same suite of mitigative measures.

## 4.4 Important bat habitats and localities

As documented above, the bat fauna is relatively uniform in species composition across most of the sampled ecological zones and forest types. This result suggests that the populations of most bat species occurring in the study area are dispersed rather than strongly clumped within the landscape; i.e. that most of the locally occurring species are able to exist across many or all of the sampled habitats.

Despite this generalization, there are grounds to identify several habitats and localities that may be of particular importance for bats.

### 4.4.1 Cave systems

The study area supports widespread and abundant populations of several bat species that are known to roost exclusively or primarily in cave systems, either throughout the year or on a seasonal basis for breeding activity. The cave systems used by these species are features of vital importance for the maintenance of their regional populations, and presumably for the ecological functioning of local forest systems.

Bat species that probably utilize substantial cave systems within the study area include several fruit bats (Bulmer's Fruit Bat, the Moluccan Naked-backed Fruit Bat, the Common Roussette), many of the leaf-nosed bats (Trident, Diadem, Maggie Taylor's and Spurred Leaf-nosed Bats) and several Sheath-tailed Bats (Large-eared, New Guinean, and Raffray's) and all of the regionally occurring bent-winged bats. Although many of these species also make use of smaller roosts (see below), particularly

outside of breeding seasons, in all species it is likely that a significant proportion of the regional population visit the larger roosts during their annual cycles.

Caves are of paramount importance in the breeding cycles of the bat species that use them. Relatively little is known about the reproductive cycles of most cave-roosting bat species in PNG, but patterns have been noted to vary amongst species. For example, females of the Moluccan Naked-backed Fruit Bat "give birth to a single young annually in a loosely synchronous breeding peak that varies with local conditions", with birthing anytime between August and November at the end of the dry season (Bonaccorso 1998). Presumably, parturition is timed to coincide with an increase in food resource availability associated with the wet season. By contrast, the Common Roussette (and also foliage roosting species such as the Common Tube-nosed Fruit Bat) produce young twice per year. Little is known also about reproduction in the smaller insectivorous bats that form aggregations numbering from a few individuals to many thousands. It is assumed that species such as the Little Bent-winged Bat give birth around December, and others such as Maggie Taylor's Leaf-nosed Bat are known to give birth a little earlier from early November. The Large-eared Sheath-tailed Bat gives birth in both June and October (Bonaccorso 1998). Given that female bats will be pregnant before these times, and that they also aggregate to mate, bats are engaged in some part of the breeding cycle for most times of the year, especially those that produce young twice per year. This highlights the importance of cave roosts for bats—not only as a diurnal refuge, but also as a site for social interaction (especially those forming very large colonies) and mating, and for females to find refuge when pregnant and raising young. Loss of caves has the potential to be significant in terms of habitat loss and disruption of breeding cycles, even if individuals are not lost when their habitat is destroyed.

Large cave systems are probably confined to the larger outcrops of limestone within the study area. The location of important roost caves has not been mapped in detail within the study area but landowners interviewed during the Phase 1 and 2 surveys reported numerous examples in the hills to the north of the Purari River between Subu and Uraru villages, along the western slopes of the Aure Scarp in the northeast corner of the study area, and in the Kereru Range, to the west of PRL-15. The location of many such caves is known to landowners who make occasional to semi-regular visits to some of them to hunt bats. In most cases, visits to these sites require two or more days of travel from villages or set-off points along the river. One relatively accessible area on Wi'i Creek (see below) was visited during the Phase 2 survey.

### 4.4.2 The Wi'i Creek cave and its environs

The primary importance of this locality derives from the occurrence of remains of the Critically Endangered Bulmer's Fruit Bat (*Aproteles bulmerae*) in the owl roost bone deposit. Because its remains are uniformly derived from juvenile bats, Bulmer's Fruit Bat is using as a breeding roost either as yet unexplored, deeper chambers of the Wi'i Creek cave itself, or other as yet unlocated cave systems in the same general area. Large limestone bluffs are present on both sides of Wi'i Creek and there is much scope for other substantial cave systems to be present in this area. The more elevated country to the northwest of Wi'i Creek is also karstic and very likely contains additional large sinkholes and associated cave systems.

Of the various localities where Bulmer's Fruit Bat has now been detected, the Wi'i Creek area is the least remote and, judging from the morphology of the one cave system observed thus far, it may be the most accessible for research into this poorly studied species. Unfortunately, these attributes also render the site potentially more vulnerable to hunting and disturbance than the others, although there was little evidence in June 2016 that the site and its environs had been visited anytime recently.

### 4.4.3 Heve Hill

Heve Hill is an isolated karst feature within an alluvial landscape. Although it probably does not contain any cave systems with large openings to the surface, there are many smaller sinkhole features, some of which open episodically to allow access from the surface into subterranean stream tunnels. These almost certainly contain large and diverse bat colonies of regional significance, and

they may include sites used by species such as *Miniopterus* spp. that typically need high and constant humidity within their maternity roosts.

Although no acoustic detection was undertaken at the locality, the capture of several individuals of the Common Rousette (*Rousettus amplexicaudatus*) in alluvial forest and garden habitats at nearby Site 8 is a good indication that sizable caves may be present locally. Although the same caveats presented in *Section 4.4.5* might be applied to the Common Rousette in terms of its status as an 'obligate' cave roosting species, the authors' experience with this medium-sized species suggests that it does roost exclusively in large cave chambers that provide adequate flight space and further, that it is not found in forest at any great distance from areas of karst that offer suitable roosts. For this reason, the species is distributed patchily in lowland New Guinea, with large areas where it seems to be absent.

### 4.4.4 Flying-fox camps

The location of major flying-fox camps used for seasonal courtship and breeding congregations is not yet known. One candidate site has been identified—the oxbow wetlands to the west of survey Site 4—but the locality has not been visited and it remains unclear which of the two locally documented species uses this area, in what numbers, and whether the congregation is a maternity camp or another kind of social grouping. Within the southern part of the study area, local residents reported that large flying-fox camps can be found within the extensive tracts of mangrove forest but that their position may change over time. Other camps may be present in low-lying areas with open alluvial forest or freshwater swamp habitats. The location of these camps might shift in response to natural factors, hunting activity or other forms of disturbance such as boat traffic.

### 4.4.5 Dispersed roosts for 'cave-roosting' bats

A significant finding of the acoustic survey is the broad distribution and abundance in the study area of several species that are generally regarded as 'obligate' cave-roosting species. This includes various hipposiderids (*Aselliscus tricuspidatus, Hipposideros diadema, Hipposideros wollastoni*) and miniopterids (*Miniopterus* cf. *tristis* and *Miniopterus* cf. *medius*)—all of these species are thought to roost typically in caves, with shallow rocky overhangs and fissures sometimes mentioned as secondary roost sites (Flannery 1995; Bonaccorso 1998).

The status of the various hipposiderid bats as local residents rather than nightly immigrants is supported by their regularity of capture and acoustic detection, aspects of their morphology that are inconsistent with regular long-distance flights, and the occurrence of females with advanced pregnancies in at least one very small species (*Aselliscus tricuspidatus*). These observations point to the regular use of local roosts and, for some species, the use of these sites not only as a base for foraging but also for breeding. By contrast, the species of *Miniopterus* are capable of nightly long distance flight and they may be capable of undertaking nightly movements between remote roosts and foraging sites. Whether they do so or not is unknown. More certain is that all species of *Miniopterus* make seasonal movements to congregate in communal maternity roosts, though even this remains undocumented by any detailed scientific studies in Papua New Guinea.

An important implication of these observations is that small fissures or rock overhangs suitable for use by cave-roosting bats must be dispersed widely through the study area. However, since features of this kind were not widely observed during the field work it is clear that they are not locally ubiquitous but rather localized to areas in the landscape that were not readily accessible during the surveys. In the northern part of the study area the most likely candidate features are the numerous sandstone and mudstone scarps that occur throughout much of the rugged landscape of PRL-15. Further south, localized features such Heve Hill and the Paevera Hills may provide similar features, which, in the case of Heve Hill, may also include larger cave systems. However, away from these landscape features these species must either use smaller-scale features such as overhangs along incised creeks, hollows in standing or fallen trees, or clusters of epiphytes (see below).

Several of the sampled habitats in the study area probably lack the necessary structural features to support the 'obligate cave roosting' bat guild. The most extensive of these habitats is the mangrove forest where there are conspicuous gaps in community composition—most notably the near complete absence of hipposiderid bats. Yet even in this habitat, cave roosting bats such as species of *Miniopterus* and *Emballonura* appear to dominate the nightly acoustic recordings. It is likely that these strong, fast-flying species are spending the days in surrounding habitats (where they can access tree hollows, fallen logs and other kinds of roosts) and are foraging nightly in the adjacent mangroves. If this is correct, the further implication is that the bat communities of the mangrove habitats are dependent for their continued existence on the survival and quality of flanking habitats.

Other habitats that may lack suitable local roosts for 'cave roosting' bats include low-lying swamp vegetation such as swamp grassland and swamp herbland. However, these are more localized within the landscape and their resources may be exploited by a wider range of bat species.

### 4.4.6 Large and/or senescent trees

Large and/or senescent trees are likely to play a major role in maintaining the diversity of local wildlife. For example, the tree hollows that provide daytime shelter for many species of vertebrates (including some bats) are larger and more numerous in large, old trees, and epiphyte load also tends to be larger and more diverse in such trees. Large and/or senescent trees may be essential for maintaining local populations of a wide variety of bats that use hollows for shelter and reproduction. Several conservation-listed species identified as present or potentially present in the study area are known to use tree hollows, including the restricted-range and Data Deficient Papuan Free-tailed Bat *Otomops papuensis* and the Data Deficient Papuan Sheath-tailed Bat *Saccolaimus mixtus*. Bats that are known to congregate for breeding purposes in tree hollows include some *Hipposideros* spp., all *Nyctophilus* spp., and at least some *Pipistrellus* spp. (Flannery 1995; Bonaccorso 1998).

Tree size and longevity are determined by numerous factors including soil type, drainage, terrain and disturbance history. Forest that includes numerous 'large' trees is expected to be found in many parts of the study area, especially where large-statured forest types occur, including undisturbed hill forest and some forms of alluvial forest. In contrast, landforms with poor soils, steep unstable terrain and/or that experience regular prolonged flooding often have fewer large and/or senescent trees. Large tree densities typically are much lower in heavily logged forest where these trees are either targeted directly or else damaged during timber removal.

Within the study area, large trees will be of greatest importance in the following contexts:

- Logged forest, including hill forest and alluvial forest, along the export pipeline corridor in the Southeast Hills ecological zone.
- Hill forest on unstable terrain within PRL-15, such as that sampled at Site 2 in the Middle Purari Hills ecological zone. This occurs on the inherently unstable mudstone/siltstone-dominant Orubadi Beds geological formation in which soils are susceptible to rapid erosion with slumping and land slips common. As surveyed at Site 2, this habitat type features extensive areas of naturally occurring regrowth vegetation and much of the forest is small statured, even in its mature form. In this context, any large and/or senescent hollow-bearing trees are more valuable on account of their naturally low density and dispersed occurrence.
- Naturally small statured vegetation types on periodically or permanently inundated landforms, including freshwater swamp habitats.

In these environments, large trees may be defined as those with >75 cm diameter at breast height (dbh).

## 4.5 Conservation value of the study area

The high diversity of bats sampled across all ten sampling sites indicates that the bat assemblage is intact overall, despite the habitat modifications that have occurred in some areas through the exploration activities of the oil and gas industry and timber extraction by the forestry sector.

Intact bat communities on a regional scale have high conservation value, whether or not they include taxa that are listed as threatened. It is widely acknowledged that bats perform a variety of roles within the forest ecosystem, with the most important being the keystone roles of flower pollination, seed dispersal of fruiting plants, and regulation of insect populations (Fujita and Tuttle 1991; McConkey and Drake 2006; Kalka et al. 2008; Williams-Guillén et al. 2008; Lobova et al. 2009). In many habitats across New Guinea bats are probably the most abundant group of mammals, and they seem to be disproportionately so in any areas that are naturally resource poor. Accordingly, they underpin many aspects of ecosystem functionality and thus warrant conservation effort.

The discovery of a new locality for Bulmer's Fruit Bat near the northern border of the study area is a finding that greatly enhances the conservation value of the study area. The two known extant populations of this species are both situated at significantly higher elevations, one at c. 2,400 m asl in Western Province and the other at c. 1,500 m asl in Chimbu Province (Aplin et al. 2016). The Wi'i Creek cave is at c. 320 m asl and the surrounding landscape rises to no more than 600 m asl over a distance of 10s of kilometers. This locality thus represents a very different context for this species residing in and using habitats within the lowland – hill zone elevational range. The fact that the Wi'i Creek remains of Bulmer's Fruit Bat clearly derive from a maternity roost further enhances the potential conservation value of the locality.

Two of the Data Deficient bat species identified in the study area on acoustic recordings may represent regionally significant populations—the Papuan Free-tailed Bat *O. papuensis* and the Papuan Sheath-tailed Bat *S. mixtus*.

The study area may be near to the western limit of the distribution of the Papuan Free-tailed Bat, as there are no capture records and none of its call type anywhere to the west (K. N. Armstrong and K. P. Aplin unpublished data). It is not known whether it still exists further to the east, either in Central Province or on the southeast peninsula of Papua New Guinea. In both of these areas, the lowland habitats are more widely impacted by timber extraction and forest conversion than those in the study area and in Gulf Province generally.

The records of Papuan Sheath-tailed Bat in the study area are also of great importance. Almost nothing is known of this species in Papua New Guinea, thus it is remarkable that echolocation calls attributed to it were detected at almost every survey site. It is clearly widespread in the Purari River catchment, present across a reasonable elevation range, and occurs in multiple forest types including mangroves. The Purari River catchment with its extensive tracts of interconnected mangrove, alluvial and hill forests may represent a conservation stronghold for this species.

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# 6 Plates

**Plate 1** A harp trap for capturing bats in the forest understorey.

**Plate 2** A mist net (folded) flanking a harp trap, to entangle bats or funnel them into the harp trap.

**Plate 3** A Pettersson Elektronik D500X bat detector in a waterproof bag, with a microphone on a 3-meter extension cable and protected from rain in a plastic funnel.

**Plate 4** Photographs of some of the non-echolocating fruit bats, tube-nosed fruit bats and blossom bats captured on the survey. **A**: *Dobsonia moluccensis*; **B**: *Dobsonia minor*; **C**: *Nyctimene* cf. *albiventer*; **D**: *Paranyctimene* cf. *raptor*; **E**: *Syconycteris* cf. *australis*. Photos: Stephen J. Richards.

**Plate 5** Photographs of some of the echolocating bat species captured on the survey. **A**: *Hipposideros ater*; **B**: *Hipposideros maggietaylorae*; **C**: *Hipposideros wollastoni*; **D**: *Nyctophilus* cf. *microtis*; **E**: *Miniopterus* cf. *tristis*. Photos: Stephen J. Richards.

**Plate 6** Photograph of *Mosia nigrescens* roosting beneath a leaf. Photo: Stephen J. Richards.

# 7 Appendices

## Appendix 1 – Re-identification of bat call types recorded during the November-December 2008 surveys in the southeast part of the study area

Note: Justifications for the revised IDs are given in Appendix 3

| Original ID and comment (unpublished data) | Revised ID and corresponding call type |
|---|---|
| Hipposiderid type 1 (probably *Aselliscus tricuspidatus*). "Probably *Aselliscus tricuspidatus*; closely matches reference calls recorded from this species in the same region (Leary and Pennay, unpublished)." | *Aselliscus tricuspidatus (115 sCF)* |
| Hipposiderid type 2 (unknown hipposiderid, possibly *Hipposideros ater*). "Possibly fundamental frequency of *Hipposideros ater* because pulses recorded are at approximately half the dominant harmonic frequency (c. 160 kHz) usually associated with that species." | *Hipposideros wollastoni (88 mCF) -* |
| Hipposiderid type 3 (possibly *Hipposideros cervinus*). "Strong likelihood that this call represents *H. cervinus*. The species utilises two main harmonics, producing calls at 66.5–69.5 khz and also at 136.5–138 kHz." | *Mosia nigrescens (65 i.fFM.d)* |
| Hipposiderid type 4 (possibly variant of *Hipposideros diadema*). "Most likely a call variant from *H. diadema*; however, could be fundamental harmonic of *H. maggietaylorae*, which has calls with dominant harmonic at 121-130 kHz." | *Mosia nigrescens (65 i.fFM.d)* |
| Hipposiderid type 8 (possibly *Hipposideros diadema* or *Mormopterus* sp./*M. planiceps*). "Possibly fundamental harmonic of *H. diadema*; however, some Australian Molossid bats (e.g. *Mormopterus* spp.) occasionally produce similar calls in this frequency range." | *Mosia nigrescens (65 i.fFM.d)* |
| Hipposiderid type 5 (almost certainly *Hipposideros diadema*). "These calls are almost certainly from *Hipposideros diadema*; they closely match reference calls recorded from the species in both PNG and northern Australia." | *Hipposideros diadema (58 mCF)* |
| Hipposiderid type 6 (unknown hipposiderid). "Unknown Hipposiderid bat. Note dominant harmonic at c. 50-52 kHz in both graphs and secondary (fundamental) harmonic at c. 25 kHz in bottom graph." | *Emballonura furax (52 i.fFM.d)* |
| Hipposiderid type 7 (possibly *Hipposideros semoni*). "Possibly another, lower frequency variant of the above species; however, male *H. semoni* in Australia produce calls with dominant harmonic at c. 94 kHz, and the above call could represent fundamental harmonic of such calls." | *Emballonura raffrayana (45 i.fFM.d)* |
| Rhinolophid type 1 (possibly *Rhinolophus philippinensis*). "Probably *R. philippinensis*. The intermediate form of this species produces calls similar to this at Iron Range on Cape York (T. Reardon 2008, pers. comm.), although this form is considered to be endemic to Australia (Churchill 2008)." | *Rhinolophus philippinensis (high frequency PNG phonic type (38 lCF)* |
| Vespertilionid type 1 (possibly *Chalinolobus nigrogriseus*). "The above two calls are very similar to those produced by *Chalinolobus nigrogriseus* in northern Australia." | Miniopterus large size (38 st.cFM) |
| Vespertilionid type 2 (possibly *Scotorepens sanborni*). "Calls of this type recorded in northern Australia would most likely be attributable to *Scotorepens sanborni*, a species which may also occur in the study area." | Miniopterus large size or *Scotorepens sanborni (40 st.cFM)* |
| Vespertilionid type 3 (*Pipistrellus* sp.). "The steep initial frequency sweep, short pulse duration and upturned tail (forming a 'backwards J' shape) in these calls is | *Pipistrellus sp? (48 st.cFM)* |

| Original ID and comment (unpublished data) | Revised ID and corresponding call type |
|---|---|
| reminiscent of the *Pipistrellus* species that occur in northern Australia (Milne 2002)." | |
| Vespertilionid type 4 (*Nyctophilus* or *Myotis*). "Calls of this type are produced by *Nyctophilus* species and *Myotis* species in northern Australia." | *Nyctophilus sp. or Myotis cf. moluccarum (40 bFM) -* |
| Vespertilionid type 5 (possibly *Kerivoula*). "The above two calls are similar to reference calls recorded in eastern Australia from *Phoniscus papuensis*, a species that also occurs in PNG. The closely related *Kerivoula* species, of which several are known to occur in PNG, may also produce calls of this<br><br>type, so it is not possible to be certain that these calls are from *P. papuensis*." | *Kerivoula cf. muscina (60 bFM)* |
| Miniopterid type 1 (possibly *Miniopterus schreibersii*). "These two calls are very similar to reference calls recorded in eastern Australia from *Miniopterus schreibersii oceanensis* (referred to as *M. orianae oceanensis* by Churchill 2008)." | *Miniopterus intermediate size (45 st.cFM)* |
| Miniopterid type 2 (possibly *Miniopterus australis*). "The relatively flat characteristic frequency section (bottom of pulse) and flat to slightly down-turned tail on these calls suggests that they may have been produced by another *Miniopterus* species." | *Miniopterus small size (55 st.cFM)* |
| Miniopterid type 3 (possibly *Miniopterus australis*). "This call is more typical (than the previous two calls) of *Miniopterus australis* as recorded in eastern Australia." | *Miniopterus small size (55 st.cFM)* |
| Molossid type 1 (*Tadarida australis*). "This call type was probably produced by *Tadarida australis*; however, pulse duration is shorter and frequency slightly lower than usually encountered from this species in eastern Australia." | Insect |
| Molossid type 2 (*Mormopterus beccarii*). "The above two calls are almost certainly from *Mormopterus beccarii*." | *Saccolaimus mixtus (25 sFM)* |
| Unknown type 1 (emballonurid/molossid). "Several sequences like this were recorded and it is not known for certain that they were even produced by bats." | Insect |
| Unknown type 2 (*Chaerephon jobensis*). "Several noisy sequences like this were recorded and it is not known for certain that they were even produced by bats." | Insect |
| Unknown type 3 (emballonurid/molossid/hipposiderid). "Unknown species – could be an Emballonurid, or Molossid, or low harmonic of a Hipposiderid." | Insect |
| Unknown type 4 (molossid). "Unknown species – possibly a Molossid such as *Mormopterus* sp." | Probably *Otomops papuensis (30 sFM)* |
| Unknown type 5 (molossid). "Unknown species. The long pulse duration (>10 ms) is suggestive of a Molossid call; and the shape is similar to *Mormopterus beccarii*. That species, however, produces calls with dominant harmonics at 44-50 kHz or 22-27 kHz (this call is around 36 kHz)." | Miniopterus large size (38 st.cFM) |
| Unknown type 6 (emballonurid/vespertilionid). "Unknown species. Top graph shows short, almost straight pulses, somewhat similar to those of some Emballonurid species but not uncommon also in some Vespertilionid species. Bottom graph shows distinctive pulse repetition pattern of paired pulses about 5ms apart with pairs separated by about 2 seconds." | Miniopterus large size or *Scotorepens sanborni* (40 st.cFM) / plus insects |

## Appendix 2 – Taxonomic Notes

A significant proportion of the bat species recorded during the survey are listed with the taxonomic qualifier 'cf.', which indicates uncertainty regarding the referral of the study area population to the named form. Taxonomic uncertainty among New Guinean bats has two primary causes.

The first cause of uncertainty is the 'broad-brush' nature of much of the existing taxonomy that is based on quite basic morphological comparisons, done without the benefit of information from morphometric or genetic analyses. In such cases, one broadly distributed species as currently recognized can contain two or more actual species with narrower distributions and contrasting ecological niches. These underestimations of true species diversity often become apparent during field work when morphologically distinct forms are noted as occurring together or in close geographic proximity, or when tissue samples are subjected to genetic analysis (e.g. DNA barcoding for identification purposes).

Genetic investigations of Melanesian bats are currently underway, supported by a research grant to K. N. Armstrong and K. P. Aplin. Results obtained to date from this project, together with those contained in a few prior publications (e.g. Appleton et al. 2004; Cooper et al. 2001) indicate that genetic studies of any widely distributed bat 'species' in the Melanesian region is likely to reveal the presence of additional species 'hidden' within the current arrangement. These additional species are often called 'cryptic' species, although with close examination (and the benefit of hindsight) it is often possible to find morphological characters that allow the species to be distinguished based on external and/or cranial features. In most cases, the 'cf.' qualifier has been applied to species that are strongly suggested as being composites of two or more species, usually based on field observations by the authors or studies of museum specimens, and sometimes supported by pilot genetic data.

The second kind of ambiguity relates to uncertainty over the applicability of a name. Two examples mentioned in the following tabulation are *Miniopterus magnater* and *Nyctimene papuanus*. These names are likely to be applicable to species captured on the survey, but there is uncertainty in both cases over which of the various forms of *Miniopterus* and *Nyctimene* they should be assigned to because taxonomic work has not yet established species boundaries and the diagnostic characters associated with each name.

When taxonomic uncertainty is encountered within the context of an environmental impact assessment, the key obligations are: 1) to clearly indicate these uncertainties when compiling an inventory of species; 2) to assess the likelihood that undescribed species might be present; and 3) to assess the likelihood that any undescribed species have been encountered elsewhere. The obligation stops short of resolving known or newly recognized taxonomic issues, which for mammals typically requires a program of taxonomic research involving:

(1) Consideration of all prior, potentially applicable names, including those that have been previously considered to be junior synonyms (alternative names that do not apply).

(2) Examination of type material for any names that might potentially be applicable (this commonly requires visits to European or US museums as they do not loan type specimens and digital scans are not yet available.

(3) Genetic analysis, which is now expected of almost any piece of taxonomic work on mammals, and requires the use of advanced techniques over and above simple DNA barcoding.

The following notes are provided to support the listing of 14 bat taxa with a 'cf.' qualifier that is indicative of taxonomic ambiguity, and of one species listed as 'sp. 1' that indicates a probable undescribed species. In each case, background information is provided to explain the nature of the ambiguity and/or complexity. Where possible, the authors' current assessment is provided as to the likely wider distribution of the various undescribed or unrecognized species that were encountered in the study area.

| Species | Comment |
|---|---|
| *Macroglossus cf. minimus* | All Melanesian populations of *Macroglossus* are currently treated as one species, *M. minimus*, with a wider distribution that extends from mainland South East Asia to the Solomon Islands and northern Australia. New Guinean populations are morphologically heterogeneous and preliminary genetic results (K.N. Armstrong and K.P. Aplin, unpublished data) confirm the presence of several distinct taxa, and work is ongoing to identify species boundaries, map their distributions and establish appropriate taxonomic names.<br><br>Only one morphological form was captured during the survey but its pattern of distribution among the sites is suggestive of the presence of cryptic species. Morphologically similar populations are known from other localities across a broad elevational range in southern New Guinea, including sites in Western Province. |
| *Nyctimene cf. albiventer.* | There is a considerable volume of unpublished genetic and morphological data that shows diversity in the genus *Nyctimene* to be far higher than suggested by current listings (N. Irwin, University of Queensland unpublished data; K.N. Armstrong and K.P. Aplin, unpublished data). Most of the uncertainty concerns the smaller members of the genus, which are currently treated as one or two species (*N. albiventer* and *N. draconilla*; e.g. Flannery 1995; Bonaccorso 1998). Even a cursory examination of this material in museums reveals the presence of multiple distinct morphological forms. Moreover, it is clear that none of these New Guinean populations are particularly close to examples of true *N. albiventer,* which was described from Morotai Island in North Maluku Province of eastern Indonesia. The species name *papuanus* is available for a New Guinean species, and the names *vizcaccia* and *bougainville* based on island populations to the east might also apply to species found on the New Guinea mainland.<br><br>Two forms of small-bodied *Nyctimene* (recognizable as such from dental differences) were collected during the survey. Both forms were recorded at multiple sites spread across all major habitats. Because the more striking differences concern the dentition, which cannot always be assessed reliably on a live animal in the hand, many of the captured individuals could not be assigned to one or other form. For this reason, all of the small *Nyctimene* are currently listed as *N*. cf. *albiventer*. Tissue samples were taken from all captured *Nyctimene* (mainly wing punches), so it will be possible to retrospectively assign all individuals to species if required. |
| *Paranyctimene cf. raptor* | The genus *Paranyctimene* currently contains two named species (*P. raptor* and *P. tenax*) but the taxonomic and distributional boundaries of these forms are unclear. Examination of museum specimens suggests the possibility of additional cryptic taxa in the genus. Independent genetic and morphological research is currently being undertaken on *Paranyctimene* (K. N. Armstrong and K. P. Aplin, unpublished data).<br><br>Two forms of *Paranyctimene* (recognizable as such from dental differences) were captured during the survey. Both were captured at multiple sites spread across all major habitats. However, as for the *Nyctimene*, it was not always possible to examine the dentition, so many individuals were recorded only as *Paranyctimene* sp. and all are currently listed under the single name *P*. cf. *raptor*. Tissue samples were taken from all captured *Paranyctimene* (mainly wing punches), so it will be possible to retrospectively assign all individuals to species if required. |

| Species | Comment |
|---|---|
| *Syconycteris cf. australis* | A single species *Syconycteris australis* is currently recognized as occupying the lowland to lower montane habitats across a large area of eastern Indonesia and Melanesia through to the Bismarck Archipelago and eastern Australia. Preliminary genetic results indicate that more than one species is present within this area (K.N. Armstrong and K.P. Aplin, unpublished data) and work is currently in progress to identify species boundaries, map their distributions and establish appropriate taxonomic names.<br><br>One form of *Syconycteris* was captured on the survey (small-bodied with reddish fur). Morphologically similar populations are widespread across the lowlands and hill zone of southern New Guinea. |
| *Hipposideros cf. ater* | At least two call types have been recorded from Papua New Guinean individuals with morphology resembling *Hipposideros ater* (type specimen is from Sri Lanka). There are clear morphological and genetic differences among Australasian and Asian *H. ater*, and it is unlikely that this name can be applied to any of the Australasian forms. Work is currently underway (T.B. Reardon and K.N. Armstrong, unpublished data) to identify species boundaries, map their distributions and establish appropriate taxonomic names.<br><br>One individual of *H*. cf. *ater* was captured at Site 4 during the Phase 1 survey. The call type of this individual is similar to calls recorded elsewhere in southern Papua New Guinea (K.N. Armstrong and K.P. Aplin, unpublished data). |
| *Hipposideros sp. 1/*<br><br>*Hipposideros cf. semoni* | Two call types (*75 mCF* and 80 *mCF*) recorded occasionally within the study area are referrable to one or two species of hipposiderid bat but neither can be identified unambiguously. Both call types are considerably lower in characteristic frequency than the calls of *H. wollastoni* (88 *mCF*) and *H. muscinus* (92 *mCF*) (the latter occurs regionally in the Strickland and Lakekamu Basins but was not detected during the present survey).<br><br>The 80 *mCF* call type is here assigned to *H.*cf. *semoni* as it matches the calls made by female *Hipposideros semoni* in northern Australia (unusually, males of this species call at a different frequency c. 94 kHz; K.N. Armstrong unpublished data)—however this is not a confirmed identification. *H. semoni* is known from only a few localities in Papua New Guinea (Central, Eastern Highlands and Morobe Provinces, 600–1,400 m asl: Bonaccorso 1998) and it has not been captured recently. Accordingly, its call type in Papua New Guinea remains undocumented. Previous captures attributed to this species may misidentified, given its similarity to *H. muscinus* (a key diagnostic feature is simply the size of the 'wart' on the posterior noseleaf), and certainly the record of *H. semoni* from Brown River is probably a misidentification of either *H. muscinus* or *H. wollastoni* (based on examinations of the specimen in the Papua New Guinea National Museum and Art Gallery by K. P. Aplin).<br><br>The *75 mCF* call type might be a variant of the *80 mCF* type. However, a similar call type has been recorded (without a *80 mCF* variant) at several sites in Western Province, supporting the likelihood that it is a separate species. To date, no captured *Hipposideros* from any survey in Papua New Guinea have produced this call type.<br><br>Capture and reference recordings are required to resolve the identity of the *75 mCF* and *80 mCF* call types. They are here conservatively assigned to two separate taxa. |

| Species | Comment |
|---|---|
| *Rhinolophus cf. robertsi* | The species *Rhinolophus philippinensis* currently encompasses numerous size forms and phonic (call) types from the Philippines, Indonesia, Timor-Leste, New Guinea and northern Australia. A taxonomic revision is currently being undertaken (K.N. Armstrong unpublished data) that will build on previous work of Cooper et al. (1998), and the taxon is likely to be split into several species as a result. Here the associated detected call frequency of *33 ICF* has been associated with the larger-bodied of two forms known from Australia, for which the available name *robertsi* is probably appropriate. However, Australian '*robertsi*' produces calls with a characteristic frequency of about 26 kHz, so the Australian and Papua New Guinean populations will need to be compared genetically and morphologically before they are considered to be conspecific.<br><br>A similar *33 ICF* call type has been recorded in several localities in the Kikori basin (reported as *R. maros* by Richards 2005) and in Western Province (K.N. Armstrong and K.P. Aplin, unpublished data).<br><br>A *38 ICF Rhinolophus* call type recorded acoustically in 2009 at several sites in the southeast part of the study area (unpublished data) may not be the same taxon. In Western Province the *33 ICF* call type was recorded together with a *45 ICF* type which is also likely to be a member of the *philippinesis* group. All other kinds of *Rhinlophus* found in New Guinea emit calls at significantly higher frequencies, always above 50 kHz (Leary and Pennay 2011; K.N. Armstrong and K.P. Aplin, unpublished data).<br><br>In order to definitively identify these low-frequency emitting *Rhinolophus*, it will be necessary to capture them so that they can be properly compared with the various other regional forms. |
| *Miniopterus cf. australis*<br><br>*Miniopterus cf. medius*<br><br>*Miniopterus cf. tristis* | The Old World genus *Miniopterus* is acknowledged globally to be one of the most taxonomically complex and difficult of all groups of bats (e.g. Goodman et al. 2011). The genus is morphologically conservative, with few contrasts beyond subtle variations in fur colour and body size, and its behavior and ecology are also consistent across several continents, with annual assembly of regional populations of females in large maternity cave roosts being a distinctive feature across the group. Bent-winged bats are capable of long distance flight but their congregational breeding behavior means that the degree of isolation of key maternity roosts corresponds to genetic identity more than patterns of dispersal and habitat use outside of breeding periods.<br><br>In recent years, progress has been made in several parts of the world to tease apart the taxonomic complexity of regional *Miniopterus* faunas (e.g. Appleton et al. 2004; Goodman et al. 2011). Based on this work, two general predictions can be made: 1) that there is likely to be higher species diversity in any geographic area than has been determined through traditional morphological approaches; and 2) any species that has been thought to have distributions that span multiple zoogeographic regions or to be widely distributed across scattered island groups is very likely a composite of many different species.<br><br>New Guinean *Miniopterus* have received little attention even under traditional morphological taxonomy and only one, very preliminary genetic study has been published (Appleton et al. 2004). Even so, it is clear from the limited results of this study that there are more species of this genus in New Guinea than currently listed by the IUCN (which is based largely on Bonaccorso 1998). Furthermore, many of the species names currently applied to New Guinean *Miniopterus* are inappropriate. For example, the |

| Species | Comment |
|---|---|
| | name *australis* which was proposed for a bat from the Loyalty Islands near New Caledonia is clearly not applicable to other populations of small-bodied *Miniopterus* in Australia, New Guinea and elsewhere. Similarly, the name *medius* proposed from Java (Indonesia) is unlikely to apply to those populations in New Guinea and Australia that have traditionally carried this name. Only one species name within *Miniopterus* has been proposed thus far for a Papua New Guinean taxon (*M. magnater* from the Sepik Basin) and it is likely that most if not all of the remaining species are unnamed.<br><br>To make progress on this issue for New Guinean *Miniopterus* the following steps will need to be taken: 1) genetic studies of modern samples from across New Guinea; 2) genetic and morphological comparison of the genetically identified groups with name-bearing populations outside the country; and 3) morphological examination of older collections (perhaps also with DNA recovery from representative specimens) to map the wider distributions of the identified species and to check for additional forms that otherwise remain unsampled. An independent funded grant to Armstrong, Aplin and others will allow the first of these steps to be undertaken during the next 1–2 years.<br><br>Until these steps are taken, placing of scientific names on New Guinean *Miniopterus* is effectively a meaningless exercise, and speculating about the conservation status of any of the species is similarly difficult. IUCN listing of *Miniopterus macrocneme* as Data Deficient on the grounds of taxonomic issues whilst leaving other species as Least Concern is misleading and paints a false picture of the current knowledge of the group in the New Guinea region.<br><br>For this report, a naming protocol has been adhered to that requires each species be assigned a species name with appropriate ambiguity if needed. Three *Miniopterus* call types were identified and one individual captured that allowed us to match one call type to a particular morphology. This was one of the larger New Guinean *Miniopterus* that are usually called *M. tristis* (described from the Philippines), so the name *M*. cf. *tristis* has been applied to this call type. The two other call types are probably made by intermediate-sized and small species of *Miniopterus* and the names *M.* cf. *medius* and *M*. cf. *australis* have been assigned arbitrarily to these call types.<br><br>*Miniopterus* call types with equivalent characteristic frequencies have been recorded in recent surveys at other sites in southern New Guinea, including sites in the Strickland and Fly River catchments. The question of whether the widely distributed call types are genuinely made by the same species across this geographic range remains to be answered. In the case of the study area populations, additional captures are required to allow morphological and genetic comparisons to be made. |
| *Kerivoula muscina* | One species of *Kerivoula* is listed for mainland Papua New Guinea, but captures in recent years suggest the possibility of a second cryptic taxon (K.N. Armstrong and K.P. Aplin, unpublished data). Only one individual of *Kerivoula* was captured during the survey and echolocation calls of this genus are not readily distinguished from those of some related taxa such as *Murina* spp. The small number of available specimens and tissues from Papua New Guinea need to be examined in more detail to resolve species boundaries, map their distributions and establish appropriate taxonomic names. |

| Species | Comment |
|---|---|
| *Murina cf. florium* | The name *'florium'* has been attributed to disjunct occurrences of the genus *Murina* from Flores and Timor, Papua New Guinea and Australia. It is highly unlikely that a single species is represented across this range and even within Papua New Guinea it is likely that more than one species is represented (K.N. Armstrong and K.P. Aplin, unpublished data). |
| *Myotis cf. moluccarum* | The name *M. moluccarum* was applied by Simmons (2005) and Reardon and Bonaccorso (2008) to a taxon thought to be distributed widely across Papua New Guinea. However, genetic data published by Cooper et al. (2001) indicate that at least two species of *Myotis* are present in southern New Guinea. *Myotis* call types have been recorded from various sites but only a few of these have associated voucher specimens.<br><br>Only one *Myotis* individual was captured during the Phase 1 and 2 surveys. An attempt to record its call type was unsuccessful. |
| *Nyctophilus cf. microtis (long ears)*<br><br>*Nyctophilus cf. microtis (short ears)* | Two forms of long-eared bat were captured on the Phase 1 and 2 surveys, differing mainly in the length of the ears. One of these forms is likely to be true *N. microtis* (type locality Sogeri, Central Province), the other an unnamed species. The taxon *N. bicolor* (based on one specimen from the Aroa River of Central Province) has been associated with *N. microtis* (e.g. Laurie and Hill 1954). Although it has larger ears than typical *N. microtis* it represents a distinct species that is not closely related to either of the two forms mentioned here (H. Parnaby pers. communication).<br><br>Both forms of *N. microtis* have been captured at other localities in southern Papua New Guinea during recent surveys (Aplin and Armstrong, unpublished data), including localities in the Strickland River basin. To publish the new species, it will be necessary to examine the type specimen of *N. microtis* (held in the Natural History Museum, London) and to carry out genetic analysis to support differentiation of a second species. |

## Appendix 3 – Annotated list of species identified from echolocation call types

| EMBALLONURIDAE |
|---|
| Large-eared Sheath-tailed Bat *Emballonura dianae*<br><br>Call type *35 i.fFM.d*<br><br>Call shape typical of *Emballonura*, and identification based on the recording of reference calls made elsewhere (K. P. Aplin and K. N. Armstrong, unpublished data). |
| New Guinea Sheath-tailed Bat *Emballonura furax*<br><br>Call type *50 i.fFM.d*<br><br>Call shape typical of *Emballonura*, and identification based on the recording of reference calls made elsewhere (K. P. Aplin and K. N. Armstrong, unpublished data). |
| Raffray's Sheath-tailed Bat *Emballonura raffrayana*<br><br>Call type *45 i.fFM.d*<br><br>Call shape typical of *Emballonura*, and identification based on the recording of reference calls made elsewhere (K. P. Aplin and K. N. Armstrong, unpublished data). |
| Lesser Sheath-tailed Bat *Mosia nigrescens*<br><br>Call type *65 i.fFM.d*<br><br>Attributable based on reference calls collected elsewhere in Papua New Guinea (Leary and Pennay 2011; K. P. Aplin and K. N. Armstrong, unpublished data), as well as reference calls recorded on the survey. Characteristic frequency recorded from bats in flight ranged from c. 58 kHz to almost 70 kHz, which appears to be the normal range for this species, but it may also conceal the presence of Beccari's Sheath-tailed Bat *Emballonura beccarii* whose range extends into the northern part of the study area (Bonaccorso and Leary 2008). |
| Papuan Sheath-tailed Bat *Saccolaimus mixtus*<br><br>Call type *25 sFM*<br><br>Attributed to *Saccolaimus mixtus* based on characteristic frequency, the 'serpentine' pulse shape (including that observed in one feeding buzz) and the harmonic profile (most energy in the second harmonic, faint fundamentals at c. 12 kHz could be seen in some examples), though characteristic frequency was higher than has been recorded for this species in Australia (K. N. Armstrong unpublished data). Unlikely to be a molossid such as a species of *Otomops* because the harmonic profile is typical of the Emballonuridae rather than Molossidae. Capture or spotlighting is required to support an attribution. A less likely possibility is the Bare-rumped Sheath-tailed Bat *S. saccolaimus*, but this species has a slightly lower characteristic frequency than *S. mixtus* (Milne 2002; Milne et al. 2009; K. N. Armstrong unpublished data). Note that this attribution needs confirmation through a capture. |
| HIPPOSIDERIDAE |
| Trident Leaf-nosed Bat *Aselliscus tricuspidatus novaguinea*<br><br>Call type *115 sCF*<br><br>Attributable to this species based on information in Leary and Pennay (2011), and also on reference calls recorded on this survey and elsewhere in Papua New Guinea (K. P. Aplin and K. N. Armstrong, unpublished data). |
| Fawn-coloured Leaf-nosed Bat *Hipposideros cervinus*<br><br>Call type *140 sCF* |

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| Attributable to this species based on information in Leary and Pennay (2011), and also on reference calls recorded on this survey and elsewhere in Papua New Guinea (K. P. Aplin and K. N. Armstrong unpublished, data). |
| Diadem Leaf-nosed Bat *Hipposideros diadema griseus*<br><br>Call type *58 mCF*<br><br>Attributable to this species based on information in Leary and Pennay (2011), and also on reference calls recorded on this survey and elsewhere in Papua New Guinea (K. P. Aplin and K. N. Armstrong, unpublished data). |
| Maggie Taylor's Leaf-nosed Bat *Hipposideros maggietaylorae*<br><br>Call type *125 sCF*<br><br>Attributable to this species based on information in Leary and Pennay (2011), and also on reference calls recorded on this survey and elsewhere in Papua New Guinea (K. P. Aplin and K. N. Armstrong, unpublished data). |
| Unidentified leaf-nosed bat *Hipposideros* sp. 1; and<br><br>Semon's Leaf-nosed Bat *Hipposideros* cf. *semoni*<br><br>Call types *75 mCF* and *80 mCF*<br><br>Pulses of medium duration (15–30 ms), and with a tonal characteristic frequency below that of *H. wollastoni* were recorded on the survey, but no captures were made of bats emitting these frequencies. It is not clear whether these two call types are attributable to a single species or to two different species. Female *H. semoni* emit calls around 82 kHz on Cape York, Australia (K. N. Armstrong, unpublished data) and calls of this frequency in the study area are tentatively assigned to this taxon (*Hipposideros* cf. *semoni*). The frequency range of female *H. semoni* might extend to 75 kHz, but until this is confirmed by captures it is preferred to assign this call frequency to a separate species (*Hipposideros* sp. 1). Potential candidates for the 75 kHz call are *H. corynophyllus* and *H. edwardshilli*, but these are only known to occur at higher elevations around Telefomin (*H. corynophyllus*) or further north in West Sepik Province (*H. edwardshilli*). |
| Wollaston's Leaf-nosed Bat *Hipposideros wollastoni parnabyi*<br><br>Call type *88 mCF*<br><br>Attributed based on reference calls recorded on this survey and elsewhere in Papua New Guinea (K. P. Aplin and K. N. Armstrong, unpublished data). |
| RHINOLOPHIDAE |
| New Guinea Horseshoe Bat *Rhinolophus euryotis*<br><br>Call type *52 lCF*<br><br>Attributable based on reference calls recorded elsewhere in Papua New Guinea by K. P. Aplin and K. N. Armstrong (unpublished data) and Leary and Pennay (2011). |
| Large-eared Horseshoe Bat *Rhinolophus* cf. *robertsi*<br><br>Call type *33 lCF*<br><br>Attributable with high confidence to one of the incipient Australasian taxa in the *Rhinolophus philippinensis* complex. The characteristic frequency (of the second harmonic) is most similar to that of the large form ('*robertsi*') in northern Australia and is presumably the same or a closely related species (K. N. Armstrong unpublished data). |
| MINIOPTERIDAE |

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| Unidentified bent-winged bat *Miniopterus* cf. *tristis*<br><br>Call type *38 st.cFM*<br><br>Attributable to one of several medium–large candidate species of *Miniopterus* (all except *M. australis*; the name tristis is assigned for convenience only). Feeding buzzes that dropped significantly in frequency below search phase pulses—typical of *Miniopterus*—were present. This call type is known from elsewhere in southern Papua New Guinea. |
| Unidentified bent-winged bat *Miniopterus* cf. *medius*<br><br>Call type *45 st.cFM*<br><br>Most likely one of several candidate species in the Miniopteridae (the name *M. medius* is assigned for convenience only). Species of *Pipistrellus* overlap in characteristic frequency but this call type was sometimes associated with feeding buzzes that dropped significantly in frequency below search phase pulses—typical of *Miniopterus*. No captures of this taxon were made, but this call type is known from elsewhere in southern Papua New Guinea. |
| Unidentified bent-winged bat *Miniopterus* cf. *australis*<br><br>Call type *55 st.cFM*<br><br>Most likely the small-bodied *Miniopterus* cf. *australis* or an allied undescribed taxon, but a species of *Pipistrellus* is also possible, since the calls of several Papua New Guinean *Pipistrellus* (Vespertilionidae) overlap in characteristic frequency. Feeding buzzes that dropped significantly in frequency below search phase pulses—typical of *Miniopterus*—were present. No captures of this taxon were made, but this call type is known from elsewhere in southern Papua New Guinea. |
| VESPERTILIONIDAE |
| Fly River Woolly Bat *Kerivoula muscina*<br><br>Call type *100 bFM*<br><br>Attributable to this call type until more information is available. One reference call taken from a capture (**Appendix 4**) showed it to be very similar to the call of *Murina* cf. *florium*. These two species may be indistinguishable based on echolocation calls. The single example encountered in the recordings was a higher frequency version that was probably made close to background vegetation. |
| Unidentified Myotis *Myotis* cf. *moluccarum*<br><br>Call type *40 bFM*<br><br>Attributable to this genus based on reference calls from elsewhere in Papua New Guinea, and examples of *Myotis macropus* from Australia (K. N. Armstrong unpublished data). The name *M. moluccarum* is applied by Simmons (2005) and Reardon and Bonaccorso (2008) to a taxon thought to be distributed widely across Papua New Guinea, but there is a possibility that the study area call recordings derive from a second species of *Myotis* that is thought to be present in Papua New Guinea (Cooper et al. 2001). |
| Flute-nosed Bat *Murina* cf. *florium*<br><br>Call type *80 bFM*<br><br>Attributable to *Murina* cf. *florium* based on reference calls recorded on the survey from several captured individuals, and elsewhere in Papua New Guinea (K. P. Aplin and K. N. Armstrong, unpublished data). This call type is also very similar to those of both *Kerivoula* cf. *muscina* (also captured on the survey) and *Phoniscus papuensis* so the identification is ambiguous (though capture confirms this taxon present at Site 3). |
| Papuan Long-eared Bat *Nyctophilus* cf. *microtis*<br><br>Call type *50 bFM* |

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| Attributable to *N. microtis* and/or an affiliated undescribed taxon based on reference calls recorded on this survey. Two potentially different *Nyctophilus* taxa were captured (**Appendix 2**) that show indistinguishable call types. In addition, some calls of this type may be attributable to other species of *Nyctophilus*, or *Pharotis imogene* whose calls have not yet been characterized. |
| New Guinea Pipistrelle *Pipistrellus angulatus* /<br><br>Papuan Pipistrelle *Pipistrellus papuanus*<br><br>Call type *50 st.cFM*<br><br>Reference calls were recorded from several individuals of two species of *Pipistrellus* (thought to be *P. angulatus* and *P. papuanus*) captured on the survey. These were designated as *45 st.cFM*, which is slightly lower in characteristic frequency than the many examples of calls with a characteristic frequency of c. 50 kHz seen in the anonymous recordings. However, it is noted that the characteristic frequency of calls of FM-emitting bats can vary from the normal search-phase signals when they are flown in a small space such as a room. Until further information becomes available, it is considered that the *50 st.cFM* may represent both *P. angulatus* and *P. papuanus*. However, it is also possible that the calls of either *P. angulatus* or *P. papuanus* intermingle with those from *Miniopterus* cf. *medius 45 st.cFM*. Further work needs to be undertaken to resolve the call differences between the various species of *Pipistrellus* and *Miniopterus* in Papua New Guinea. |
| MOLOSSIDAE |
| Greater Northern Free-tailed Bat *Chaerephon jobensis*<br><br>Call type *20 cFM*<br><br>Attributable to this species based on the similarity of calls from Australia (Milne 2002). Few examples were noted, and none were of sufficient quality to include harmonics. This identification needs to be supported by a capture. |
| Papuan Free-tailed Bat *Otomops papuensis*<br><br>Call type *35 sFM*<br><br>Only a single call sequence without higher harmonics was observed for this call type, but a very similar call type was recorded during an unpublished study and illustrated in their report. The slight difference in observed call frequency (35 vs 30 sFM) is compatible with intraspecific (and intra-individual) variation in call types among molossid bats.<br><br>Vouchered reference calls are not available for either of the New Guinean species of *Otomops*. However, the 30–35 kHz *sFM* call type is similar in shape to Kenyan species of *Otomops* (K. N. Armstrong, unpublished observations) and is higher in characteristic frequency than the call type of *Chaerephon jobensis*, which has a similar shape. There are two candidate species within *Otomops*—*O. papuensis* and *O. secundus*—but *O. papuensis* is more likely given previous records from the Vailala River (Lawrence 1948). This identification needs to be supported by a capture. |

## Appendix 4 – Summary of reference echolocation recordings made from captured echolocating bats

Note: L—liver in ethanol; WP—wing biopsy punch in ethanol

| Field No | Camp | Genus | Species | Voucher | Tissue | How recorded | Call type |
|---|---|---|---|---|---|---|---|
| A104 | Site 2 | Hipposideros | diadema | released | WP | hand | 58 mCF |
| A105 | Site 2 | Aselliscus | tricuspidatus | released | WP | hand | 115 sCF |
| A132 | Site 2 | Hipposideros | wollastoni | vouchered | L | hand | 88 mCF |
| A145 | Site 2 | Aselliscus | tricuspidatus | released | WP | hand | 115 sCF |
| A146 | Site 2 | Aselliscus | tricuspidatus | released | WP | hand | 115 sCF |
| A147 | Site 2 | Hipposideros | cervinus | vouchered | L | hand | 140 sCF |
| A148 | Site 2 | Pipistrellus | cf. papuanus | vouchered | L | tent | 45 cFM |
| A156 | Site 2 | Pipistrellus | cf. papuanus | released | WP | on release | 45 cFM |
| A157 | Site 2 | Pipistrellus | cf. angulatus | released | WP | on release | 45 cFM |
| A164 | Site 2 | Hipposideros | calcaratus | vouchered | L | hand | 128 sCF |
| A183 | Site 3 | Hipposideros | wollastoni | released | WP | hand | 88 mCF |
| A199 | Site 3 | Murina | cf. florium | vouchered | L | tent | 80 bFM |
| A201 | Site 3 | Murina | cf. florium | vouchered | L | tent | 80 bFM |
| A210 | Site 3 | Murina | cf. florium | vouchered | L | tent, lab | 80 bFM |
| A211 | Site 3 | Murina | cf. florium | vouchered | L | tent, lab | 80 bFM |
| A239 | Site 3 | Kerivoula | cf. muscina | vouchered | L | tent | 100 bFM |
| A240 | Site 3 | Hipposideros | diadema | released | WP | hand | 58 mCF |
| A241 | Site 3 | Hipposideros | diadema | released | WP | hand | 58 mCF |
| A242 | Site 3 | Hipposideros | diadema | released | WP | hand | 58 mCF |
| A243 | Site 3 | Hipposideros | diadema | released | WP | hand | 58 mCF |
| A244 | Site 3 | Mosia | nigrescens | released | WP | lab | 65 i.fFM.d |
| A246 | Site 3 | Mosia | nigrescens | vouchered | L | lab | 65 i.fFM.d |
| A251 | Site 3 | Hipposideros | diadema | released | WP | hand | 58 mCF |
| A266 | Site 3 | Hipposideros | wollastoni | released | WP | lab | 88 mCF |
| A292 | Site 3 | Murina | cf. florium | vouchered | L | tent | 80 bFM |

| Field No | Camp | Genus | Species | Voucher | Tissue | How recorded | Call type |
|---|---|---|---|---|---|---|---|
| A293 | Site 3 | Murina | cf. florium | vouchered | L | tent | 80 bFM |
| A297 | Site 4 | Hipposideros | wollastoni | released | WP | hand | 88 mCF |
| A299 | Site 4 | Hipposideros | wollastoni | released | WP | hand | 88 mCF |
| A310 | Site 4 | Hipposideros | diadema | released | WP | hand | 58 mCF |
| A315 | Site 4 | Miniopterus | cf. tristis | vouchered | L | lab | 38 st.cFM |
| A335 | Site 4 | Hipposideros | cf. ater | vouchered | L | hand | 138 sCF |
| A336 | Site 4 | Hipposideros | maggietaylorae | vouchered | L | hand | 120 sCF |
| 2/28 | Site 5 | Hipposideros | wollastoni | released | — | hand | 88 mCF |
| 2/75 | Site 7 | Hipposideros | wollastoni | vouchered | L | hand | 88 mCF |
| 2/120 | Site 7 | Kerivoula | muscina | vouchered | L | tent | 80 bFM |
| 2/229 | Site 8 | Hipposideros | maggietaylorae | vouchered | L | hand | 120 sCF |
| 2/305 | Site 9 | Aselliscus | tricuspidatus | vouchered | L | hand | 115 sCF |
| 2/308 | Site 9 | Nyctophilus | cf. microtis | vouchered | L | hut | 50 bFM |