PAPUA LNG PROJECT

UPSTREAM ENVIRONMENTAL IMPACT STATEMENT

VOLUME 2: ENVIRONMENTAL AND SOCIAL BASELINE STUDIES

Part 6: Upstream Terrestrial Biodiversity Baseline Report
Annex 6: Upstream Dragonflies and Damselflies (Odonata) Baseline Report

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TOTAL E&P PNG LIMITED

December 2019
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Upstream Dragonflies and Damselflies (Odonata) Baseline Report

Papua LNG Project

Total E&P PNG Limited

The libellulid dragonfly *Rhyothemis regia*

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ACRONYMS AND ABBREVIATIONS

asl	above sea level
CEPA	Conservation and Environment Protection Authority
CPF	Central Processing Facility
DD	Data Deficient (IUCN threat category)
EN	Endangered (IUCN threat category)
ESHIA	environmental, social and health impact assessment
FIMS	PNG Forest Inventory Mapping System
IUCN	International Union for the Conservation of Nature
km	kilometers
km^2	square kilometers
LC	Least Concern (IUCN threat category)
LNG	Liquefied Natural Gas
m	meters
mm	millimeters
NT	Near Threatened (IUCN threat category)
PNG	Papua New Guinea
PRL-15	Petroleum Retention License 15
Project	Papua LNG Project
sp.	Abbrev. ‘species’ (singular)
spp.	Abbrev. ‘species’ (plural)
study area	upstream terrestrial biodiversity study area
TEP PNG	Total E & P PNG Limited
upstream PAOI	upstream project area of influence
WMA	Wildlife Management Area

GLOSSARY OF TECHNICAL TERMS

Asymptote	A straight line approached but never crossed by a curve (species recorded versus survey effort in the context of this report).
Central cordillera	Refers to the central mountainous spine of New Guinea that runs from the eastern edge of the Vogelkop Peninsula in Indonesian New Guinea to the eastern tip of mainland PNG.
Community structure	The taxonomic composition of a community; species assemblage.
Conservation listed species	Includes: (1) species listed under the IUCN Red List as threatened (Critically Endangered, Endangered or Vulnerable), Near Threatened or Data Deficient; (2) species listed as Protected under the PNG *Fauna (Protection and Control) Act 1966*; (3) species listed under CITES Appendix I or II.
Endemic	Belonging exclusively or confined to a particular place.
Endemism	Describes the percentage or ratio of endemic taxa occurring in a place; e.g. a high level of endemism.
Odonata	Refers to both damselfly and dragonfly species.
Protected	Species listed as Protected under the Papua New Guinea *Fauna (Protection and Control) Act 1966.*
Restricted-range	Species which have a total historical breeding range of less than 50,000 km^2.
Taxa	Plural of taxon; a systematic division (e.g. more than one species, genera, etc.).
Taxonomic	Taxonomy is the science of identifying, naming and classifying living organisms.

EXECUTIVE SUMMARY

A total of 97 species of odonates was documented from 12 sites in the study area, including 46 species of damselflies (Zygoptera) and 51 species of dragonflies (Anisoptera). The families Coenagrionidae and Platycnemididae dominated the damselfly fauna with 18 (39%) and 13 (28%) species out of 46 respectively. The family Libellulidae dominated the dragonfly fauna, representing 38 (74.5%) of the 51 species encountered.

Odonate diversity was highest in hill forest at Site 1 (46 species) and in hill and alluvial forest at Sites 5 and 7 (both 44 species). The fauna in the study area is dominated by species known to have broad distributions that extend outside the study area, however, 23 species are considered to qualify as restricted-range and nine of these are new-to-science or undescribed.

Four odonate species listed as Data Deficient by the IUCN were encountered; the small blue and black platycnemidid damselflies *Nososticta finisterrae* and *N. nigrifrons*, the isostictid damselfly *Selysioneura rhaphia* and the dragonfly *Diplacina cyrene*. All four are stream-dwelling species and each is known to occur more widely outside the study area in southern New Guinea. No odonates listed as Vulnerable, Endangered or Critically Endangered by the IUCN were encountered during the study and none are known or expected to occur within the study area.

Most of the IUCN listed, restricted-range and new-to-science species rely on small clear streams in hill forest and/or in well drained alluvial forest for their survival. Minimising impacts on these aquatic habitats, particularly in the Middle Purari Hills ecological zone, will be important for retaining the diversity of conservation significant and new-to-science species there.

The odonate fauna of the study area is a useful indicator group for long-term changes in habitat quality.

In summary, the odonate fauna of the study area represents a diverse faunal assemblage typical of, and contiguous with, adjacent areas along the southern foothills of mainland New Guinea. However, it also contains a significant number of new-to-science, undescribed and restricted-range species and maintaining these biodiversity values will require retention of as much of the freshwater stream habitat diversity as is feasible.

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

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

1.2. UPSTREAM TERRESTRIAL BIODIVERSITY STUDY AREA AND ECOLOGICAL ZONES

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

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

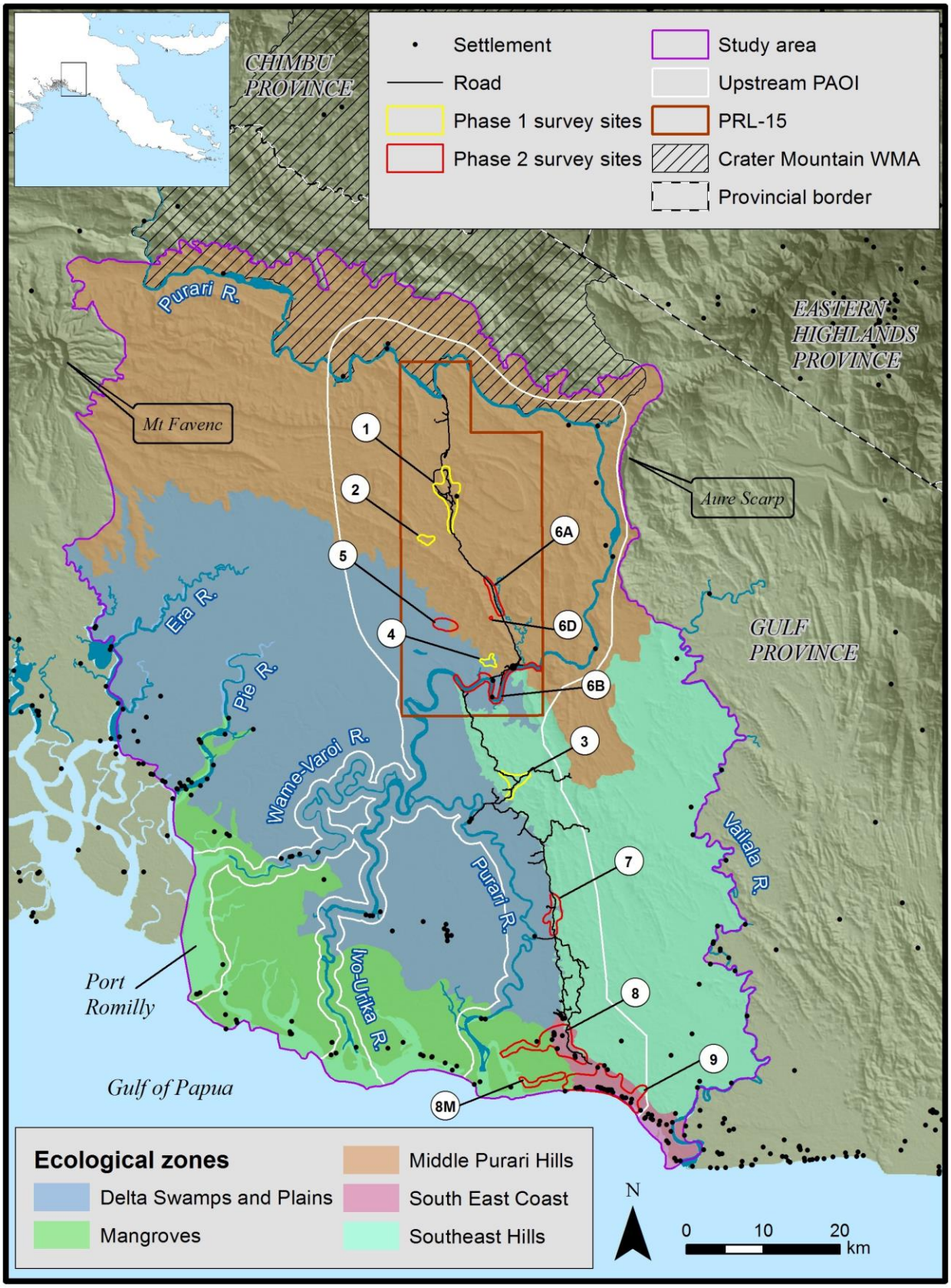

Figure 1. The study area and its component ecological zones, the upstream PAOI and the location of Phase 1 and 2 upstream terrestrial biodiversity study survey sites.

(Not all sites were surveyed under the odonate technical study. Information on the sites surveyed is presented in Section 3.2).

2. EXISTING INFORMATION

More than 600 species of dragonflies and damselflies (Odonata) are currently known from New Guinea and surrounding Melanesian islands (Michalski 2012, Kalkman & Orr 2013, Orr & Kalkman 2015). Although the New Guinea fauna shares some components with Australia (Theischinger & Hawking 2006) several major groups that are absent from Australia, such as Idiocnemidine and Platystictid damselflies, are species-rich in New Guinea and half of the odonate species and more than a quarter of the genera there are endemic. Odonates are useful indicators of environmental change because they are moderately large, relatively easy to identify, and have a complex life cycle that includes an aquatic larva and a 'terrestrial', flying adult stage (Clark & Samways 1996). However, despite this ease of identification the odonate fauna of New Guinea remains incompletely documented and numerous new species have been described from the region in the last 10 years (e.g. Englund & Polhemus 2007, Gassmann & Richards 2008, Kalkman et al. 2010, Orr et al. 2014, Theischinger & Richards 2015, 2016, Orr & Richards 2016).

The southern lowlands of New Guinea between the central cordillera and the south coast have a rich but poorly known odonate fauna. Until recently knowledge of this fauna was based almost entirely on a series of seminal papers by M. A. Lieftinck (e.g. Lieftinck 1949; see full list in van Tol 1992) who examined and described (among other collections) the odonate collections of the Archbold Expeditions to New Guinea (1933-1964). The papers by Lieftinck continue to provide the foundation for current taxonomic and biogeographical work on New Guinean odonates.

In their overview and assessment of New Guinea freshwater biotas Polhemus et al. (2004) used damselflies as one of the indicator taxa to delineate areas of freshwater endemism in the region. The entire study area above 50 m asl is included in their 'Area 25. Papuan Gulf Foreland' which extends across the basins of the Kikori, Purari, Vailala and Lakekamu rivers at elevations between 50 and 1,200 m asl. This region was characterised by Polhemus et al. (2004) on the basis of a number of endemic freshwater insects but only one odonate, the damselfly *Teinobasis debeauxi*, was included in that list.

Since 1995 a number of surveys have targeted odonates in the forested southern slopes and lowlands of both Indonesian Papua Province (Polhemus & Polhemus 1998) and PNG (Richards et. al. 1998, Richards 2000). Two of these, in the Lakekamu basin (Richards et al. 1998) and at Dark-End Lumber in the Kikori River basin (Richards 2000), resulted in the discovery and description of nine odonate species that are currently known only from the Papuan Gulf Foreland endemic area or that extend marginally into the adjacent coastal 'Papuan Gulf Coastal Lowlands' region (e.g. Theischinger & Richards 2006a, b, and c, 2008 and 2015, Gassman & Richards 2008, Michalski et al. 2012).

Between 2011 and 2012 a series of three odonate surveys was undertaken across the northern study area in support of a proposed hydro-electric dam development project. That study produced the most detailed and accurate assessment of odonates that has been conducted within the study area to date. The data from that study are not currently available for use and no further reference can be made to the locations or results of those surveys. No other odonate surveys have been conducted within the study area.

3. METHODS

3.1. SURVEY SITES AND TIMING

The study area is centered on the Purari River catchment in Gulf Province, PNG, and extends west to include parts of the Era and Pie catchments and east to the Vailala River in the southeast study area. It covers an extensive area of intact forest ecosystems, with low human population density in most areas. The geographical extent and ecological zonation of the study area and a detailed summary of the physical environment, including climatic regimes within the catchment, are presented in the Upstream Environmental and Social Baseline Report.

Intensive odonate surveys were conducted at eight principal survey sites in the study area (Sites 1–5, 7–8 [excluding 8M] and 9, shown in Figure 1) and four additional sites (6A,B,D and 8M) were accessed briefly (1–2 days) from Sites 5 and 8. Surveys were conducted in two phases separated by a period of approximately five months and representing seasonal variation. The coordinates, elevations, survey schedule, and search effort at each of the sites surveyed are presented in Table 1 and survey trails at each site are presented in Figures 2–7.

3.2. VEGETATION AND HABITAT FEATURES PERTINENT TO ODONATES AT EACH SITE

Detailed vegetation characteristics for each site are presented by Venter et al (2016), whereby only specific habitat issues relevant to the odonates are discussed.

Vegetation types are referred to in the text using a set of FIMS-equivalent terms developed specifically for the upstream terrestrial biodiversity baseline study. These follow closely the formal FIMS descriptors; they are based on the founding vegetation descriptions (Paijmans 1976; Hammermaster and Saunders 1995) but are generally less cumbersome.

Where a specific vegetation type is referred to in the text it is capitalized and followed in brackets by its FIMS code, for example ‘Hill forest (Hm)’ and ‘Open alluvial forest (Po)’. Specific vegetation types surveyed at each site are listed below. In most cases, however, more general terms are used that apply to multiple possible variants within the study area (and more widely in PNG). 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.

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

Table 1. Locations, schedule and search effort at each of the survey sites.

Location	UTM PNG94-55S		Alt (m asl)	Arrival	Departure	Trails (m asl)		Search Effort (Man hours)
						Min	Max	
Phase 1	**Easting**	**Northing**						
Site 1	294689	9209644	100	19 Jan, 15:30	27 Jan, 09:00	50	170	140.4
Site 2	291894	9202769	95	27 Jan, 09:15	2 Feb, 10:00	55	120	93
Site 3	303459	9171560	130	2 Feb, 10:15	9 Feb, 10:45	80	170	102.5
Site 4	300251	9186944	30	9 Feb, 11:00	16 Feb, 10:45	15	30	103.8

Location	UTM PNG94-55S		Alt (m asl)	Arrival	Departures	Trails (m asl)		Search Effort (Man hours)
						Min	Max	
Phase 2	**Easting**	**Northing**						
Site 5	294432	9191260	20	21 Jun, 17:00	2 Jul, 09:20	20	20	132.5
Site 6A	300655	9195465	n/a	27 Jun, 10:15	27 Jun, 16:10	30	50	11.75
				28 Jun, 08:20	28 Jun, 15:00			12.7
Site 6B	299876	9184880	n/a	25 Jun, 10:00	25 Jun, 15:00	5	30	10
Site 6D	300280	9192765	n/a	26 Jun, 10:15	26 Jun, 16:00	185	250	11.5
Site 7	308305	9153930	15	2 Jul, 09:30	9 Jul, 12:25	5	30	118.7
Site 8	308835	9138610	5	9 Jul, 12:40	15 Jul, 09:20	0	15	75.5
Site 8M	M1 309575	9133025	n/a	11 Jul, 08:45	11 Jul, 12:00	0	5	3.25
	M2 309180	9132980						
	M3 308595	9132770						
Site 9	315970	9131180	0	15 Jul, 09:30	19 Jul, 13:45	0	5	75
Total man hours								**890.6**

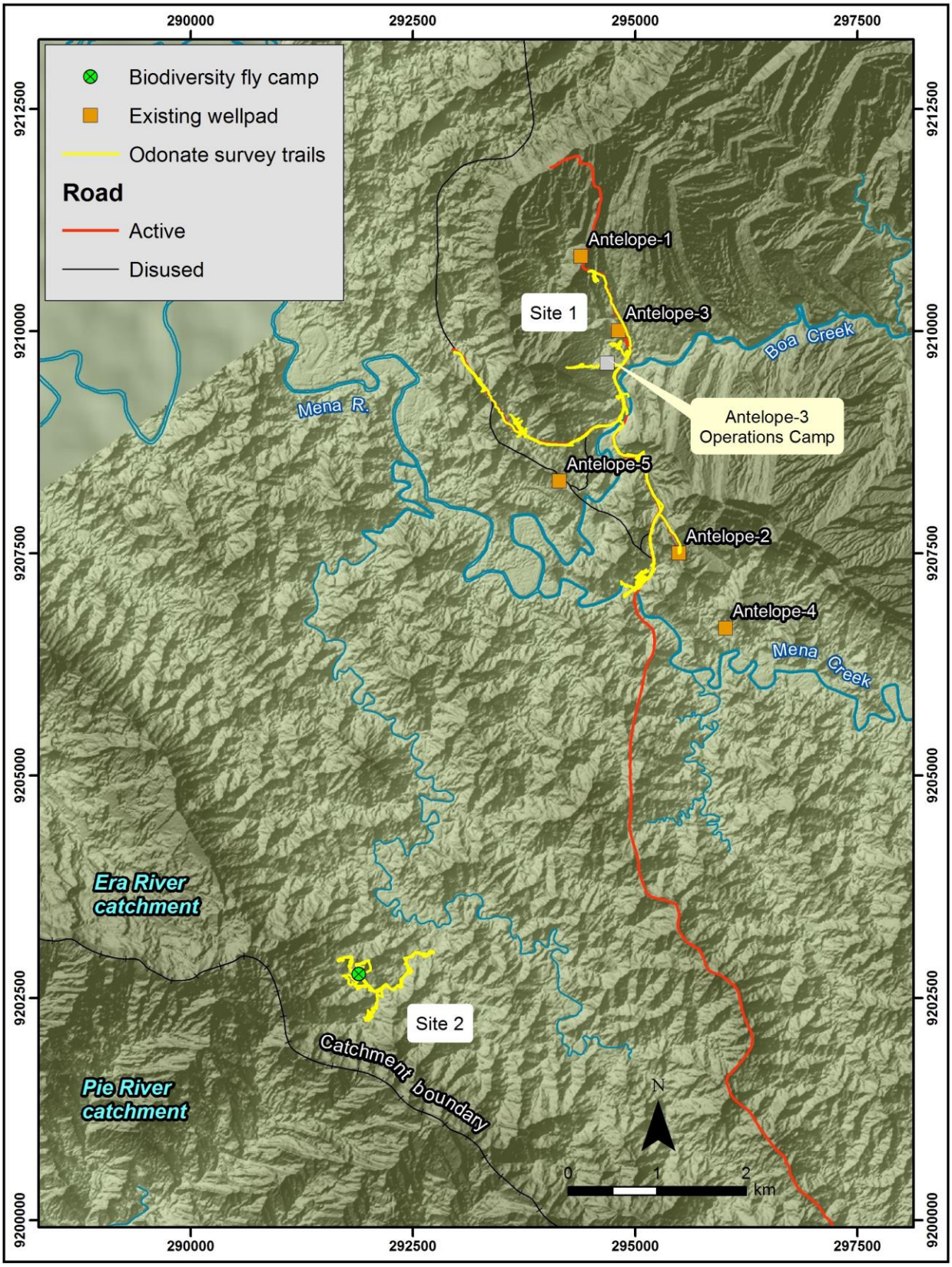

Figure 2. Odonata survey trail coverage at Sites 1 (above) and 2 (below).

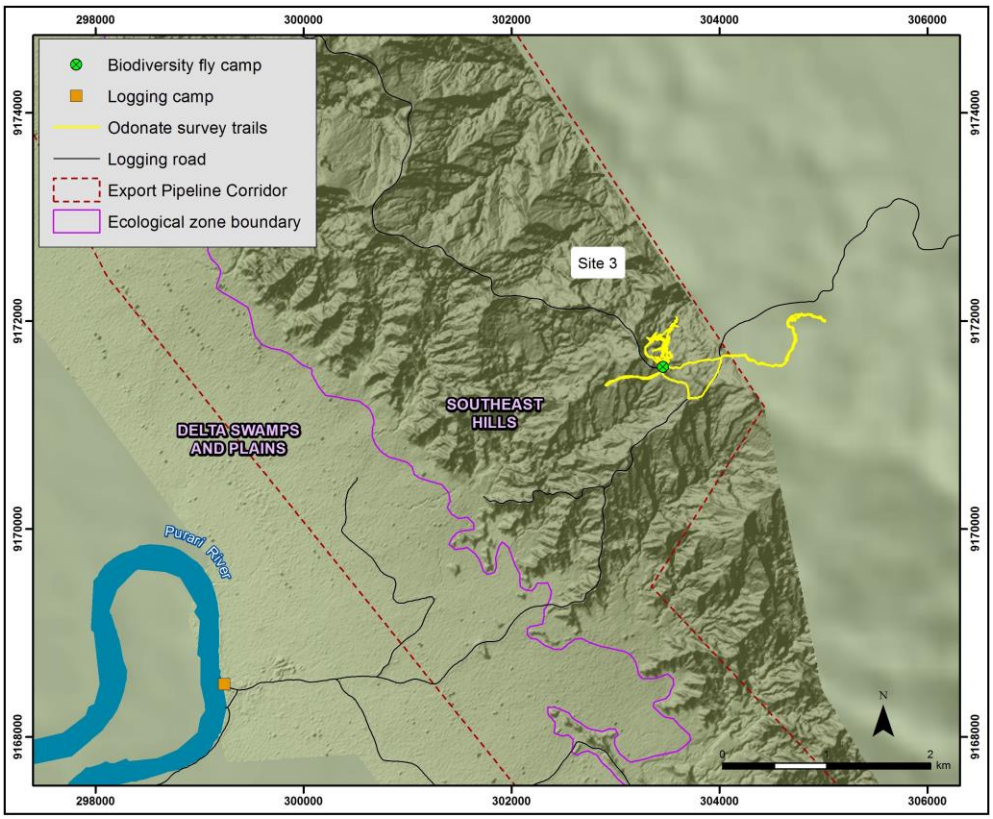

Figure 3. Odonata survey trail coverage at Site 3.

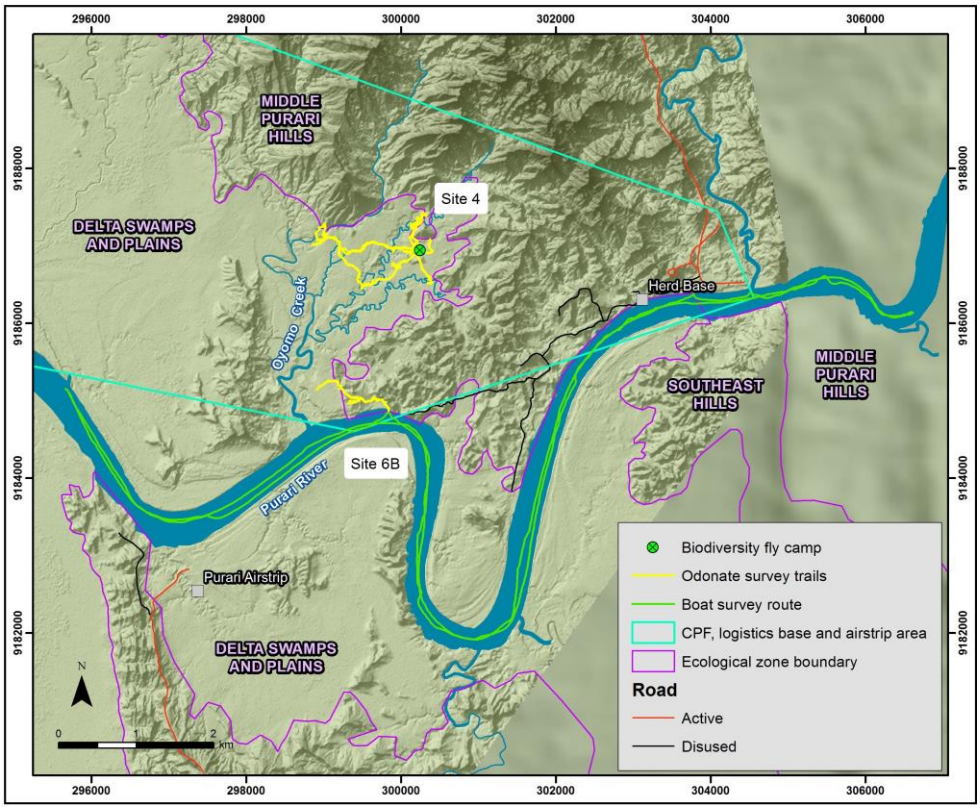

Figure 4. Odonata survey trail coverage at Sites 4 and 6B.

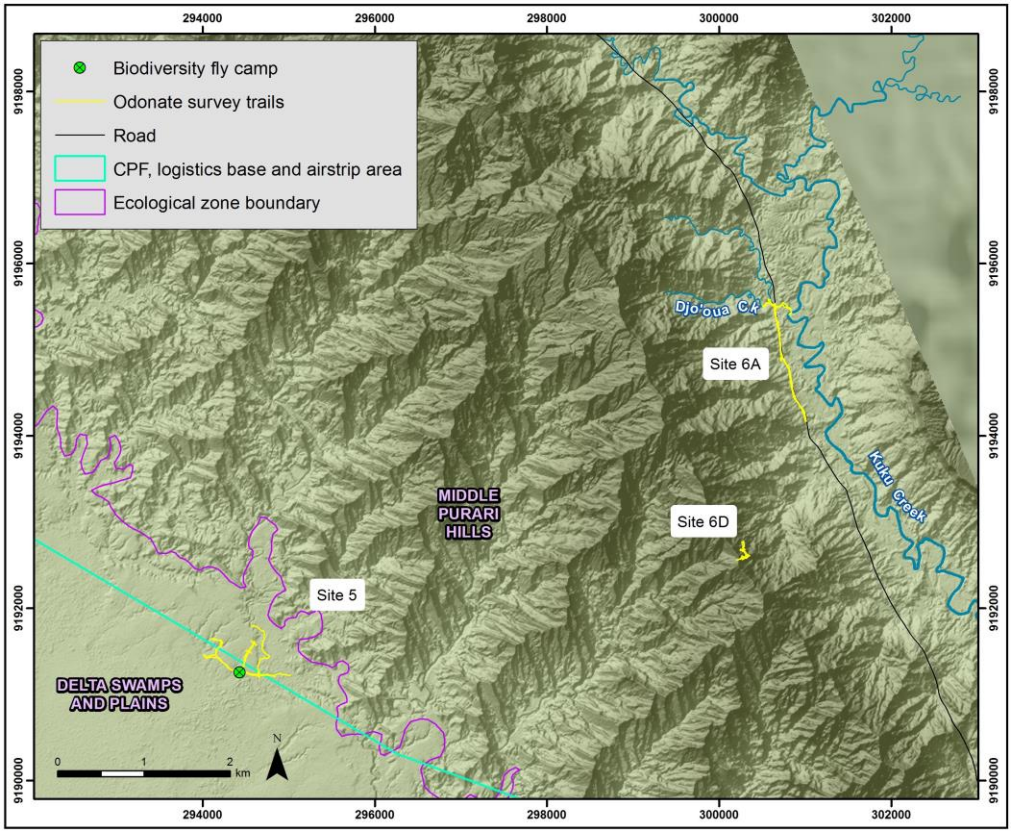

Figure 5. Odonata survey trail coverage at Sites 5, 6A and 6D.

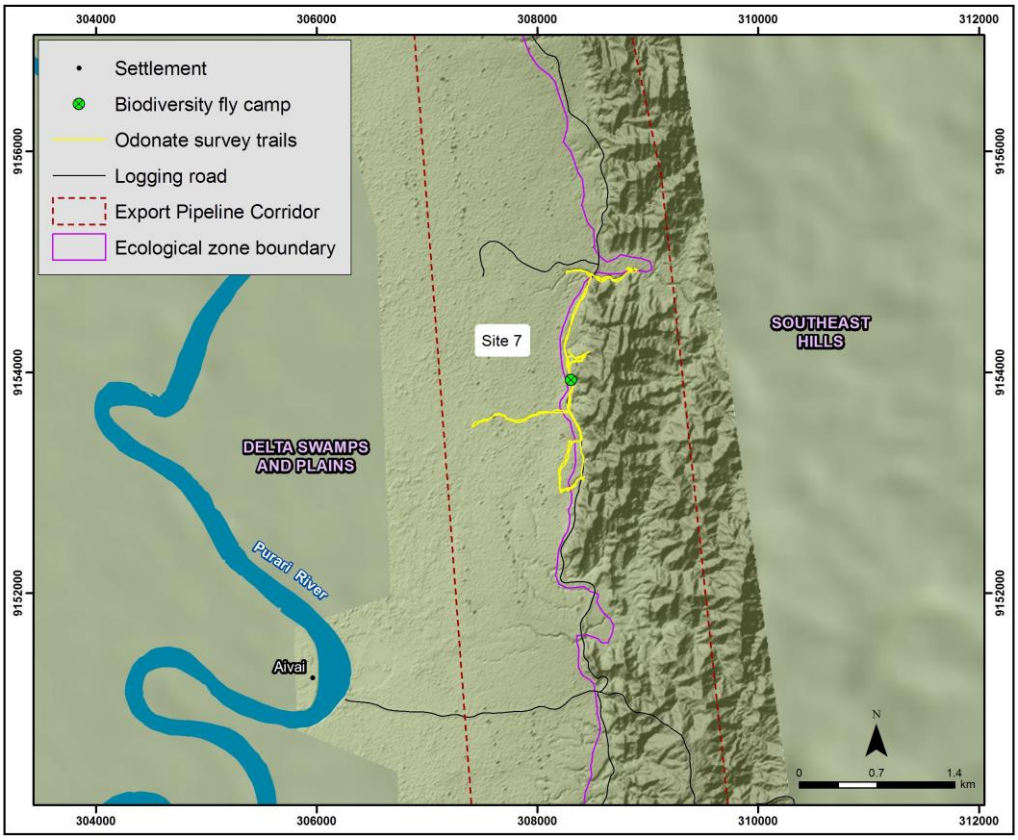

Figure 6. Odonata survey trail coverage at Site 7.

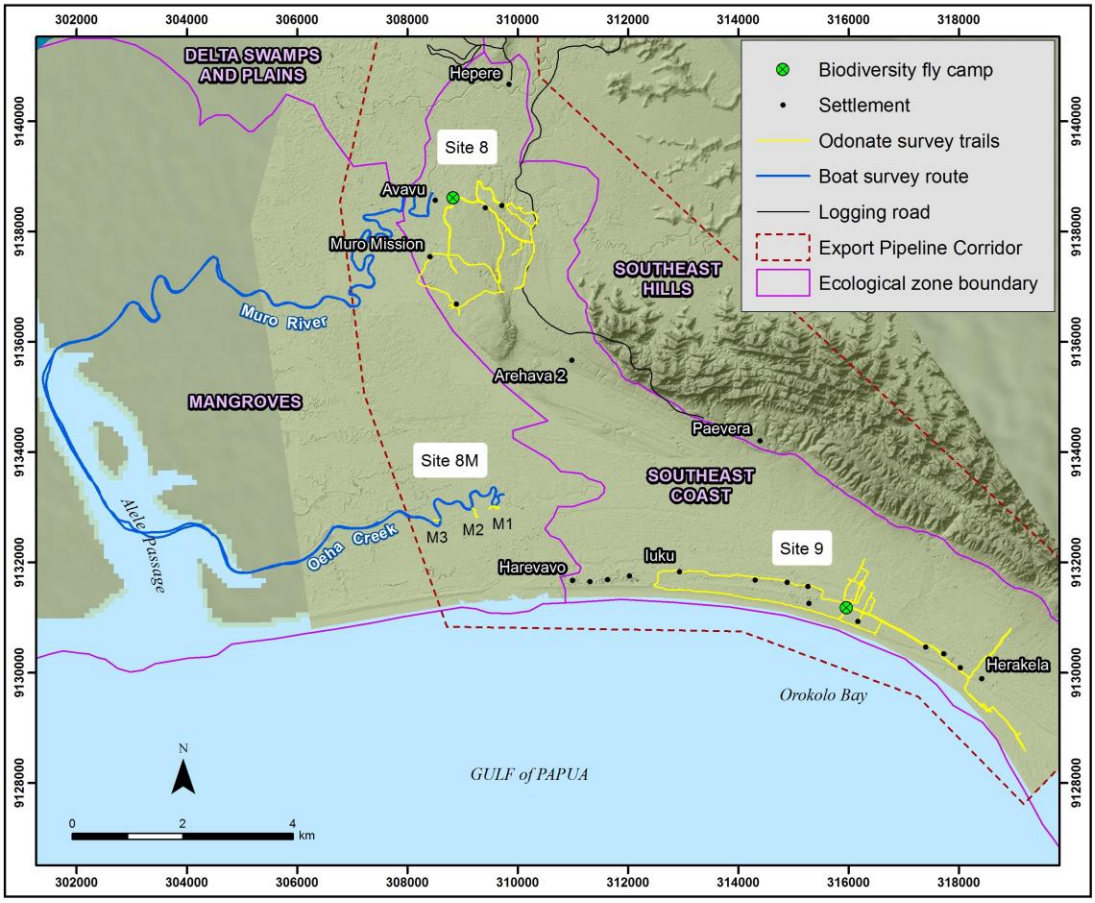

Figure 7. Odonata survey trail coverage at Sites 8, 8M and 9.

Site 1 was located in Hill forest (Hm) in the upper Era River catchment in the Middle Purari Hills ecological zone (Figures 1, 2). Road transport at this site provided access to a broader geographical area than was available at most other sites (Figure 2) and the main focus at Site 1 was to survey the Elk-Antelope gas field. This site provided access to large water courses at Boa Creek and Mena Creek, and numerous small, clear tributary streams that drain into these larger water bodies within the surveyed area. A number of temporary ponds that had formed as a result of road construction and other infrastructure development provided additional aquatic habitats for a number of odonate species.

Site 2 was in Hill forest (Hm) in the Mena basin headwaters of the upper Era River catchment in the Middle Purari Hills ecological zone (Figures 1, 2). Located near the divide between the Era and Pie catchments this site gave access to the proposed trunkline west route option. Aquatic habitats at this site were restricted to a shallow stream adjacent to the camp, and numerous very small (< 2 m wide) seepages and creek-lines that flowed mainly after rain.

Site 3 was in Hill forest (Hm) in the Southeast Hills ecological zone, about 2.5 km from the border with the Delta Swamps and Plains (Figures 1, 3). Located about 8 km northeast of Evara village on the Purari River, it provided access to habitats in the northern section of the proposed export pipeline corridor. The forest in this area had been extensively logged and water was scarce, being restricted to several small (~2–5 m wide), clear and shallow (<30 cm deep) streams among deeply dissected ridges. A number of creek-lines were nearly dry, with water restricted to isolated rock-pools in the creek-bed.

Site 4 was in Open Alluvial forest/Swamp forest with isolated patches of Hill forest (Po/Fsw/Hm) in the Delta Swamps and Plains ecological zone, near the border with the Middle Purari Hills (Figures 1, 4). The area is dominated by alluvial forest containing a variety of shallow, freshwater swamp habitats and numerous shallow streams.

Site 5 was also in Open Alluvial forest/Swamp forest with isolated patches of Hill forest (Po/Fsw/Hm) in the Delta Swamps and Plains ecological zone. The extensive areas of Hill forest (Hm) to the east of camp in the Middle Purari Hills were accessed only briefly during odonate surveys (Figures 1, 5). A complex of shallow, inter-connected freshwater swamp habitats to the west of camp and a large stream to the east of camp provided a variety of aquatic habitats for odonate species.

Site 6A was in Hill forest (Hm) in the Middle Purari Hills and sampling was restricted to moderately disturbed forest in the vicinity of an existing road within PRL-15 that runs parallel to Kuku Creek; to several small, clear tributaries of Kuku Creek with sandy and rocky substrates that intersect the road; and to the banks of the main channel of Kuku Creek (Figures 1, 5).

Site 6B straddled two ecological zones, the Middle Purari Hills in the east and the Delta Swamps and Plains in the west. The Hill forest (Hm) at the eastern edge of the site was characterized by a series of steep slopes near the Purari River that were drained by small, clear-flowing streams and this habitat graded into Open Alluvial forest/Swamp forest with isolated patches of Hill forest (Po/Fsw/Hm) where the terrain was flatter and streams were slower flowing.

Site 6D was on a steep ridge in Hill forest (Hm) in the Middle Purari Hills (Figures 1, 5). Much of the forest at this site was heavily disturbed from slumping of terrain. Important habitats for odonates included several small, shallow seepages and a larger (> 5m wide) steep but shallow stream with reduced canopy cover due to a major land slip.

Site 7 was in Small Crowned Hill forest (Hs) and Open Alluvial forest (Po) on the border of the Southeast Hills and the Delta Swamps and Plains ecological zones (Figures 1, 6). The forest in this area had been extensively logged. Several small (~2–5 m wide), clear and shallow (<30 cm deep) streams with rocky and sandy substrates drained the deeply dissected ridges to the east of camp. All streams draining the Southeast Hills became slow-flowing and muddier within 1–200 m of entering the Delta Swamps and Plains, and aquatic habitats in this zone were dominated by slower flowing streams, isolated forest pools and shallow swampy habitats.

Site 8 was in the Southeast Coast ecological zone (Figure 1). Although classified as Alluvial forest (Pl) the areas surveyed had been extensively modified for village houses, gardens, and by extensive logging. A small area of Hill forest (Hm) in the Southeast Hills ecological zone south of the fly camp (Figure7) was visited only briefly. Aquatic habitats included the large, navigable Muro River, and a number of smaller tributary streams, the flow rates of which were influenced by tidal movements. The riparian vegetation along most streams in this area had been severely modified, or substantially or entirely removed, for construction of gardens. A series of swamps adjacent to the fly camp that were dominated by sago palms (*Metroxylon sagu*) provided habitat for a suite of swamp-dwelling odonate species.

Site 8M comprised of three sites in the Mangrove ecological zone that were accessed briefly by boat from Site 8. Located on Oeha Creek, mangrove sites M1–3 were within the proposed pipeline route corridor, 1.3–1.5 km inland from the coast (Figures 1, 7).

Site 9 was also in the Southeast Coast ecological zone (Figures 1, 7). Most of the area is classified as Land use (O). The fly camp was located adjacent to the foreshore in Orokolo Bay. Coconut palms dominate the foreshore vegetation. A series of drainage channels running parallel to the coast north of the camp provided aquatic habitats for a number of odonate species, and these overflowed and flooded the forest floor after heavy rain. A series of freshwater wetlands was present within the beach dune system at the eastern edge of the bay, and these pools and swamps provided additional aquatic habitat for odonates. Mangrove vegetation (M) was accessed briefly at both the eastern and western edges of the bay.

3.3. SURVEY METHODS

Intensive searches were conducted for adult dragonflies and damselflies along and around all available water-bodies, during the morning, on sunny afternoons, and in the evenings. Survey tracks for odonate sampling at each site are illustrated in Figures 2–7. Activity patterns of odonates vary among species, with some taxa preferring to perch in early-morning sun patches in the forest, others defending territories along streams, and others flying in forest gaps predominantly at dusk, and rarely perching. Water-bodies examined included seepages, small closed-canopy streams, larger streams

and small forest pools. Additional surveys were conducted along forest trails and in clearings, especially helipads, where large dragonflies often hunt for small flying insect prey. Surveys were conducted by 2–3 (usually 2) searchers using long-handled insect nets. Search effort (man-hours) for odonate sampling is summarised in Table 1.

Larval odonates were not targeted during this study because the larvae of most New Guinean taxa remain unknown. Larvae are predaceous and providing sufficient prey to rear individuals to metamorphosis for identification in the field would have been labour intensive and, based on studies of other tropical species, development rates of most species encountered would have been too slow to permit successful rearing in the field. As a result, identifications based on larval collections would be problematic at best for most species.

3.4. SURVEY EFFORT

Odonate surveys at the 12 sites totalled 890.6 man-hours of survey effort (Table 1). Survey effort varied from 75–140.4 man-hours per site at the eight principal sites, with Site 1 having the highest, and Site 9 the lowest survey effort. This variation reflected differences in total days available for sampling at each site.

3.5. VOUCHER MATERIAL

In order to properly identify taxonomically difficult species, a subset of specimens was preserved as museum vouchers for subsequent examination. Specimens were fixed in acetone and stored in glassine envelopes in plastic boxes containing naphthalene and silica gel to prevent mould and deterioration. Voucher specimens were exported under permit from the PNG Conservation and Environment Protection Authority (CEPA), export permit numbers 016026 and 016115, to confirm identifications, and will subsequently be deposited in the South Australian Museum, Australia. Representatives of most species were photographed alive.

3.6. PROTOCOLS USED

3.6.1. Taxonomic issues and nomenclature

The odonata of New Guinea remains poorly known and many groups of dragonflies and damselflies are currently undergoing revision. Particularly problematic groups include ‘flatwing’ damselflies of the family Argiolestidae (e.g. Kalkman et al. 2010), and libellulid dragonflies of the genus *Diplacina* (Michalski 2012). In some cases, it is therefore not possible to assign an established name to a species encountered during the surveys. The following system of abbreviations is applied in this report to account for various levels of uncertainty.

- **‘sp.’** (singular) or **‘spp.’** (plural)—used in cases where one or more taxa could not be identified to species level, or where reference is made to multiple species within a genus without the need for more specific information.

- **‘sp. 1’, ‘sp. 2’, etc.**—for example: *Metagrion* sp. 1, *Nososticta* sp. 1, *Nososticta* sp. 2. The numeric system is used where taxonomic identity is confidently resolved and the species is scientifically undescribed. Distinction is made between: (a) species newly discovered during the Project surveys and therefore presently known only from within the study area; (b) species known only from within the study area, and; (c) species known to occur more widely across New Guinea.

Several recent studies have proposed changes to some family and genus-group names for Australian and New Guinean odonates. This report follows the terminology for damselflies adopted by Kalkman & Orr (2013) who, among other changes, accept the placement of the speciose genus *Nososticta* in the family Platycnemididae. For dragonflies, the terminology follows Orr & Kalkman (2015). The term ‘dragonfly’ is commonly used in two different ways in the literature: either to denote the entire order Odonata (including both dragonflies and damselflies), or to denote only the sub-order Anisoptera, or ‘True Dragonflies’, excluding the sub-order Zygoptera or ‘Damselflies’. The term ‘odonate’ is used throughout this report to indicate the entire order, including both dragonflies and damselflies. The term ‘dragonfly’ and ‘damselfly’ are used in the specific sense to indicate these respective subfamilies.

Species are described in this report as ‘new-to-science’ where they were discovered for the first time during the Project survey, and ‘undescribed’ if they remain scientifically unnamed but were previously known from outside of the study area.

3.6.2. Conservation status

The conservation status of each species encountered was determined using the internationally recognized IUCN Red List of Threatened Species (Red List).

The Red List provides taxonomic, conservation status and distribution information on plants and animals. The IUCN Red List criteria identify three categories of threatened species which are considered to be facing a heightened risk of extinction: Critically Endangered (CR), Endangered (EN) and Vulnerable (VU). No odonate species in these categories, or in the category Near Threatened, were encountered. The only two IUCN categories used in this report are Least Concern (LC) and, for those species for which data are insufficient to reach a conclusion, Data Deficient (DD). Species that have not been assessed by the IUCN are listed as Not Evaluated (NE). In this report, the term ‘conservation listed’ is applied to all species listed by the IUCN as Data Deficient.

No odonate species are protected under PNG law or listed under Appendix I or Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

3.7. ANALYSIS

3.7.1. Accumulation curves

Species accumulation curves were constructed for odonates for each complete day of sampling at each site.

3.7.2. Calculating endemism

Each species was given an endemism code of 1–5 based on their known extents of distribution. These data were extracted predominantly from Kalkman and Orr (2013) and Orr and Kalkman (2015), supplemented with additional information from Michalski (2012). However, it should be taken into consideration that the knowledge of distributions for many New Guinean odonates remains rudimentary. The scoring system employed to produce these codes was developed for the upstream terrestrial biodiversity baseline study and is presented in Table 2. Each site was assessed for its significance as an area of high endemism based on the percentage of species at the site with codes of 1–5. Species of uncertain taxonomic status are excluded from the analysis. Geographic range estimates are provided for potential restricted-range species, defined as those with an area of occupancy of less than 50,000 km^2. Conservative maximum ranges were estimated in ArcGIS using digital elevation models (DEM; provided by TEP PNG), landform (Bryan & Shearman 2008) and vegetation mapping (PNG FIMS) and based on information about distribution and habitat preferences, including terrain, vegetation types and elevations of prior available records.

Table 2. Endemism codes used to assess levels of endemism of odonate species

Code	Definition
1	Occurs more widely in the Indo-Pacific
2	Endemic to New Guinea, its satellite islands, the Bismarcks and Maluku
3	Endemic to New Guinea and its satellite islands (Waigeo, Misol, Yapen, Biak, Aru, d’Entrecasteaux and Louisiades)
4	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.

4. RESULTS/DISCUSSION

4.1. SPECIES DIVERSITY

A total of 97 species of odonates was documented during the Project surveys, including 46 species of damselflies and 51 species of dragonflies (Appendix 1). The families Coenagrionidae and Platycnemididae (including the speciose genus *Nososticta* that was formerly included in the Protoneuridae or Disparoneuridae) dominated the damselfly fauna with 18 (39%) and 13 (28%) species out of 46 respectively. The family Libellulidae dominated the dragonfly fauna, representing 38 (74.5%) of the 51 species encountered. Odonate diversity was highest at Sites 1 (46 species), 5 and 7 (both 44 species). The high diversity at Sites 1 and 5 reflects the much greater search effort at these sites than at the other six principal sites (Table 1), and at Site 1 a network of roads provided access to a wider geographic area and a greater range of habitats than was accessed at the other sites. The high diversity encountered at Site 7 appears to reflect the high diversity of aquatic microhabitats available over a short distance at the boundary of the Southeast Hills and Delta Swamps and Plains ecological zones. Species totals were similar (27–31) at the other five primary sites (Appendix 1).

The odonate fauna in the study area is dominated by species known to have broad distributions that extend outside the study area (Appendix 1). There have been few comparable studies of odonate diversity and community structure in the southern lowlands and foothills of New Guinea. The total diversity of damselflies reported here (46 species) is similar to that reported from a survey of seven sites in the Kikori basin including Mount Bosavi (37 species) by Polhemus (1995). Total odonate diversity documented during the Project surveys (97 species) is nearly three times that known from the Lakekamu basin approximately 140 km east of the study area (34 species) and more than four times that recorded from the Dark-End Lumber site near Kopi in the lowlands of the Kikori basin (20 species). However, these differences are likely due to the fact that the Lakekamu and Dark-End Lumber studies each covered a much smaller geographic area (the equivalent of one site in the study area) and were sampled much less intensively (Richards et al. 1998, Richards 2000).

Despite these discrepancies in size of the area surveyed and in sampling effort some useful comparisons among these sites can be made. For example, the proportional representation of constituent taxonomic groups (families) at the four sites in the study area and at Lakekamu is very similar (Table 3) and this is reflected in the high level of overlap between species among the sites. Of the 34 species documented at Lakekamu at least 22 (65%) were recorded from the study area, and a similar level of overlap was recorded at Dark-End Lumber with at least 12 of 20 species (60%) recorded there being found during the Project surveys.

Together these results suggest that the odonate fauna of the study area is extremely diverse (more than 95 species) and that:

1. Each principal survey site had a total diversity similar to that found at Lakekamu about 140 km to the east of the study area.

2. Diversity at each site was higher than that documented at Kopi to the west of the study area (but sampling intensity was lower at that site).

3. The odonate fauna in the study area broadly overlaps with that documented at both Lakekamu and Kopi.

None of the species accumulation curves for the eight principal sites reached asymptotes (Figure 8); however, rates of species accumulation had slowed substantially at each site after 4–5 days of sampling indicating that, with further search effort, few additional species were likely to be documented at these sites. Failure to reach an asymptote after one week at remote sites in Papua New Guinea's highly biodiverse rainforest habitats is to be expected.

Table 3. Odonate assemblages in the study area and at Lakekamu about 140 km to the east.

Data are presented as numbers of species and percent of total species in each family.

Family	Study area		Lakekamu	
Damselflies	Species	% of total	Species	% of total
Argiolestidae	5	5.15	1	2.94
Calopterygidae	1	1.03	1	2.94
Chlorocyphidae	1	1.03	1	2.94
Coenagrionidae	18	18.56	3	8.83
Isostictidae	3	3.09	0	0
Lestidae	3	3.09	0	0
Platycnemididae	13	13.40	9	26.47
Platystictidae	2	2.06	2	5.88
Dragonflies				
Aeshnidae	7	7.22	1	2.94
Corduliidae	2	2.06	0	0
Gomphidae	1	1.03	1	2.94
Libellulidae	38	39.17	12	35.29
Macromiidae	1	1.03	2	5.88
Synthemistidae	2	2.06	1	2.94
TOTAL	**97**	**100**	**34**	**100**

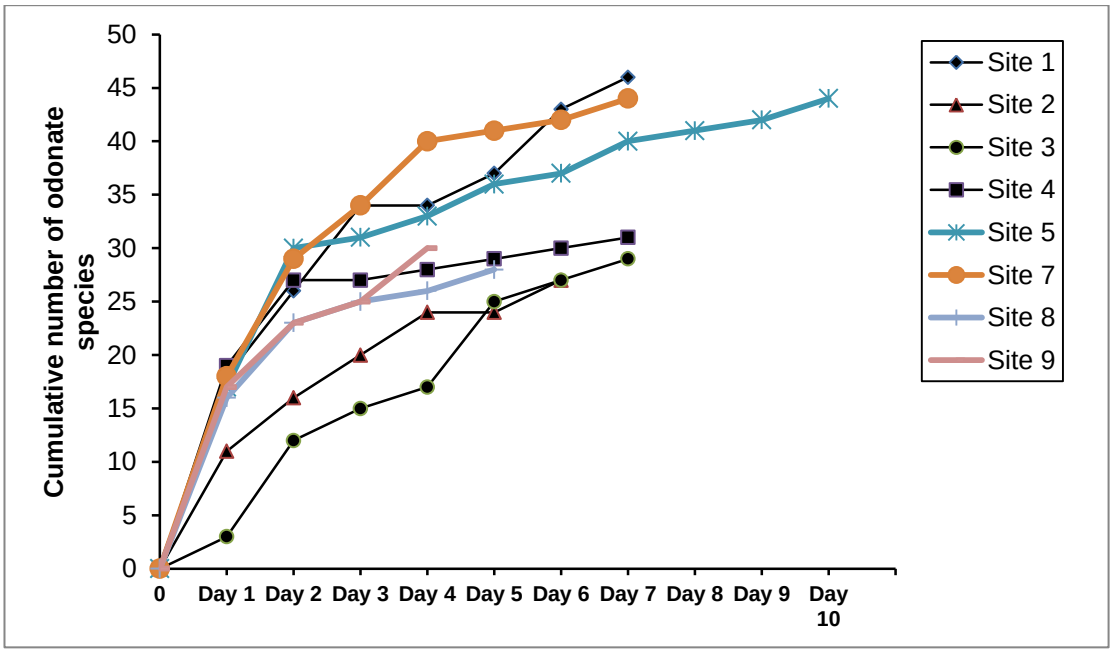

Figure 8. Species accumulation curves for odonates at the eight principal survey sites.

4.2. Conservation listed species known or expected to occur

Species of conservation significance recorded in the study area are listed in Table 4 and summary accounts for each species are provided in the following section. Examples of IUCN listed, new-to-science and restricted-range species are illustrated in Plates 1–4.

4.2.1. IUCN listed species encountered

A comprehensive assessment of the status of most odonate species from PNG has not been undertaken by the IUCN for inclusion in the IUCN Red List (S.J. Richards, unpublished data). However, four species of odonates encountered during the surveys, *Diplacina cyrene*, *Nososticta finisterrae*, *N. nigrifrons* and *Selysioneura rhaphia* are listed as Data Deficient (DD) by the IUCN due to a lack of information on their status and distribution. Hill forest habitats supported all four Data Deficient species, with Sites 1 and 2 in the Middle Purari Hills ecological zone each supporting three species and Site 3 in the Southeast Hills ecological zone and Site 6A in the Middle Purari Hills ecological zone each supporting two species (Table 4). In contrast only two DD species were found in the alluvial forests of the Delta Swamps and Plains ecological zone with Site 4 and Site 5 each supporting one species that was also found in hill forest habitats. All of the Data Deficient species were restricted to clear-flowing streams, and in the alluvial forests at Sites 4 and 5 they were found along streams more reminiscent of those occurring in hill forest habitats; they were not found in swampy forest or around forest pools. No IUCN listed species were encountered in the Southeast Coast or Mangrove ecological zones. No odonates listed as Vulnerable, Endangered or Critically Endangered by the IUCN were encountered during the study and none are known or expected to occur in the study area.

Table 4. Species of conservation significance recorded from the study area.

(No species of conservation significance were encountered in the Mangroves ecological zone and no CITES listed species occur in Papua New Guinea).

	IUCN Listed	New-to-science (NTS) or Undescribed (UN)	Restricted Range	Middle Purari Hills	Southeast Hills	Delta Swamps and Plains	Southeast Coast	Comments
DAMSELFLIES								
Argiolestidae								
Argiolestes tuberculiferus			X	X				Previously known only from Crater Mountain
Metagrion trigonale			X	X				Previously known only from Kikori basin
Metagrion sp. 1.		**NTS**	X		X			Known only from the study area
Pyrrhargiolestes angulatus			X	X				Crater Mountain WMA, possibly SW Morobe Province
Coenagrionidae								
Papuagrion sp. 1.		**NTS**	X				X	Known only from the study area
Teinobasis buwaldai			X		X			Previously known from Aru Islands
Teinobasis debeauxi			X	X	X			Previously known from Astrolabe Mtns near Port Moresby
Teinobasis sp. 1.		**NTS**	X	X				Known only from the study area
Isostictidae								
Selysioneura rhaphia	**DD**			X	X			Widespread southern New Guinea

	IUCN Listed	New-to-science (NTS) or Undescribed (UN)	Restricted Range	Middle Purari Hills	Southeast Hills	Delta Swamps and Plains	Southeast Coast	Comments
Lestidae								
Indolestes linsleyi			X			X		Previously known from Astrolabe Range near Port Moresby and Digul River
Platycnemididae								
Idiocnemis patriciae			X	X	X			Previously known from Kikori basin, Lakekamu, Fly/Strickland catchments.
Idiocnemis sp. 1.		UN	X	X	X	X	X	Known from study area and Lakekamu
Nososticta chrismulleri			X	X	X	X		Previously known from Fly/Strickland catchments, Western Province
Nososticta finisterrae	DD			X	X	X		Widespread southern New Guinea
Nososticta makrodon			X	X	X	X	X	Previously known from Fly/Strickland catchment, Western Province
Nososticta nigrifrons	DD			X		X		Widespread southern New Guinea
Nososticta paraconifera			X			X		Previously known from Fly/Strickland catchment
Nososticta smilodon			X	X		X		Previously known only from Kikori basin
Nososticta truncata			X	X		X		Previously known from Lakekamu west to Fly
Nososticta sp. 1.		NTS	X			X		Known only from the study area
Rhyacocnemis sp. 1		NTS	X	X	X			Known only from the study area
Platystictidae								
Drepanosticta taurulus			X	X	X			Previously known only from Crater Mountain
DRAGONFLIES								
Aeshnidae								
Agyrtacantha sp. 1.		NTS	X			X		Known only from the study area
Libellulidae								
Bironides sp. 1.		NTS	X		X	X		Known only from the study area
Diplacina cyrene	DD		X	X				Previously known from Vogelkop Peninsula and Misool Island
Synthemistidae								
Palaeosynthemis sp. 1.		NTS	X	X				Known only from the study area
TOTALS	**4**	**9**	**23**	**18**	**12**	**12**	**3**	

Isostictidae

Selysioneura rhaphia is a long, slender damselfly with distinct dark markings on the thorax and very narrow wings. There are few records of this genus from southern mainland New Guinea and the group remains poorly known. However, one species documented in the study area is indistinguishable from *Selysioneura rhaphia*, a damselfly known previously from the Milne Bay islands in eastern PNG (Kalkman 2009c; Kalkman & Orr 2013) and from two sites reaching as far west as the upper Strickland River basin. Despite the large distance from the Milne Bay population, the species from the study area cannot be morphologically distinguished from it and so it is referred to *S. rhaphia*. However further studies of Milne Bay material may reveal the Gulf Province population to be a closely related undescribed species.

This species is restricted to clear-flowing streams and rivers. Within the study area it was found only in hill forest habitats at Sites 1 and 3 in the Middle Purari Hills and Southeast Hills ecological zones. If this species occurs at additional locations between Milne Bay and the Strickland basin then the species has a very broad distribution across southern New Guinea.

All individuals encountered were in closed-canopy forest where they perched hanging on or under leaves in shady positions immediately adjacent to, or overhanging, clear-flowing streams with dense riparian vegetation. Like other members of the genus, this species is closely associated with clear-flowing streams in closed-canopy forest.

The major threatening processes that could affect this species are removal of forest cover and damage to streams and adjacent riparian habitats. Opening the forest canopy will increase insolation resulting in increased temperatures and reduced humidity, while damage to riparian vegetation will directly impact shelter and feeding sites. These impacts would have major impacts on the survival of adults, which require cool shady habitats adjacent to streams. Damage to the stream banks' structure and vegetation, and directly to the stream bed, will also increase turbidity of the stream water through increased erosion, potentially impacting survivorship of the larvae of this species.

Platycnemididae

Nososticta finisterrae is a small, slender, black damselfly with bright blue markings on the thorax and red markings on the terminal abdomen segments. Until recently this species was known only from a small series collected over 100 years ago in Milne Bay, eastern mainland PNG (Kalkman 2009a). However additional material obtained from a number of sites across southern PNG, including the study area, since 1996 is indistinguishable from the Milne Bay taxon so the population of red-tailed *Nososticta* encountered in the study area is here referred to *N. finisterrae*.

This species is restricted to clear-flowing streams and rivers. Within the study area it was found in Hill forest at Sites 1–3 and 6A–B, and in alluvial forest at Site 4. It was not found in swamp forest habitats and at Site 4 was restricted to better drained alluvial forest. Additional localities for the species in PNG's southern watersheds outside of the study area now include the foothills of the Muller Range (Kalkman et al. 2011), and the Lakekamu basin to the east of the study area. The species clearly has a broad distribution across southern New Guinea. The major threatening processes that could affect this species are removal of forest cover and damage to streams and adjacent riparian habitats.

This species occupies a wider range of flowing stream habitats than most *Nososticta* species. During the Project surveys, it was found along streams ranging from very small (< 1 m wide) and in deep shade to large, open-canopy streams and rivers where adults perched on flood debris, rocks, and riparian vegetation in full sun.

The major threatening processes that could affect this species are removal of forest cover and damage to streams and adjacent riparian habitats. Although some populations of this species occur along open, sunny streams and so may be resilient to limited forest disturbance, damage to the stream banks' structure and vegetation, and directly to the stream bed, will increase turbidity of the stream water through increased erosion, potentially impacting survivorship of the larvae.

Nososticta nigrifrons is a small, slender, black damselfly with bright blue markings on the thorax, thin blue rings on the abdomen, and a completely black face. Until recently this species was known only from a single specimen collected over 100 years ago (Kalkman 2009b). However additional material representing this species has been obtained from a number of sites across PNG since 1996.

This species is restricted to clear-flowing streams and rivers. Within the study area it was found only in Hill forest at Sites 1, 2 and 6A in the Middle Purari Hills ecological zone and in alluvial forest at Site 5 in the Delta Swamps and Plains ecological zone. It was not found in swampy habitats within alluvial forest, where it was restricted to better drained areas. Additional localities for the species in PNG's southern watersheds outside of the study area now include the Lakekamu basin about 140 km east of the study area, and the foothills of the Star Mountains near Tabubil (Richards & Theischinger 2013). The species clearly has a broad distribution across southern New Guinea in the foothills of the central cordillera below about 500 m above sea level (asl).

This species occupies more open-canopy habitats than most *Nososticta* species and is frequently found perched on flood debris, rocks, and riparian vegetation in full sun on the banks of large streams and rivers. Therefore, although removal of forest cover and damage to streams and adjacent riparian habitats would directly impact shelter and feeding sites, their impacts on the survival of adults may be less severe than for the other DD species discussed here, which require cool shady habitats adjacent to streams. However, damage to the stream banks' structure and vegetation, and directly to the stream bed, will increase turbidity of the stream water through increased erosion, potentially impacting survivorship of the larvae of this species.

Libellulidae

Diplacina cyrene is a small but moderately robust yellow and black dragonfly previously recorded from two sites at the western extremity of Indonesian New Guinea; one on the Vogelkop Peninsula and the other on Misool island in the Moluccas (Kalkman 2009d). A single individual of this species was captured on a small clear stream in Hill forest at Site 2 in the Middle Purari Hills ecological zone, representing a major range extension and the first record for PNG.

The habitat requirements of this species were unknown prior to the discovery of the study area population. In common with other members of the genus this species is likely to be restricted to clear-flowing streams and rivers. Clear-flowing streams are common in the Middle Purari Hills and suitable habitat is probably widespread there, as well as in the Southeast Hills ecological zone.

The major threatening processes that could affect this species are removal of forest cover and damage to streams and adjacent riparian habitats. Opening the forest canopy will increase insolation resulting in increased temperatures and reduced humidity, while damage to riparian vegetation will directly impact shelter and feeding sites. These impacts would have major impacts on the survival of adults, which require cool shady habitats adjacent to streams. Damage to the stream banks' structure and vegetation, and directly to the stream bed, will also increase turbidity of the stream water through increased erosion, potentially impacting survivorship of the larvae of this species.

The restricted-range status of this species is discussed in Section 4.4.

4.3. NEW-TO-SCIENCE AND UNDESCRIBED TAXA

Although the odonate fauna of the study area is dominated by widespread species it also includes nine species that are new-to-science or undescribed (Table 4). Eight of these (89%) are new-to-science species discovered for the first time during the Project surveys that are known only from the study area; while one was previously known from the Lakekamu basin (S.J. Richards, unpublished data). The Middle Purari Hills, Southeast Hills and Delta Swamps and Plains ecological zones each supported four species, and the Southeast Coast ecological zone two species, of the undescribed and new-to-science species. At least one new-to-science species in each of these ecological zones was not shared with another ecological zone. No undescribed or new-to-science species were encountered in the Mangroves ecological zone. All nine new-to-science and undescribed species also qualify as restricted-range species.

Species accounts

DAMSELFLIES

Argiolestidae

Metagrion sp. 1. – NEW-TO-SCIENCE – known only from the study area

A moderately large and robust damselfly with red legs, a pale stripe on the top of the thorax, and wings held flat rather than vertically when at rest. This stream-dwelling species was found only along small streams and seepages, mostly < 5 m wide, at Sites 3 and 7 in the Southeast Hills ecological zone where animals rested adjacent to the streams on leaves and twigs in shade and dappled sunlight. The species was relatively uniformly distributed along the streams at these sites, occurring adjacent to both pool and riffle habitats within the stream bed. However it was absent from sunny areas with little canopy cover, and from streams that were not flowing during the survey.

Although forest streams occur throughout the Middle Purari Hills ecological zone this species was not encountered during intensive surveys there. Rather, the morphologically similar *Metagrion trigonale* was abundant along streams at both sites surveyed in that ecological zone, suggesting that the new species may be excluded by its congener from these habitats. These observations suggest that *Metagrion* sp. 1. may have a limited, and potentially patchy, distribution in the hill forest habitats of the study area. Although it may occur outside the study area, its specific habitat requirements and small known distribution suggest that it will probably qualify for restricted-range status (see Section 4.4. below). The major threatening processes that could affect this species are removal of forest cover and damage to streams and adjacent riparian habitats.

Coenagrionidae

Papuagrion sp. 1. – NEW-TO-SCIENCE – known only from the study area

A large, robust, sombre-colored green to brown-ish black damselfly that is known from just two specimens collected from vegetation in a patchwork of heavily disturbed forest and gardens at Site 8 in the Southeast Coast ecological zone. No other information on habitat requirements is available but the species can persist in modified landscapes suggesting that it may have a relatively broad distribution in the Southeast Coast ecological zone. However, on the basis that it is currently known only from Site 8, and its habitat requirements are poorly known, it qualifies for restricted-range status.

Teinobasis sp. 1. – NEW-TO-SCIENCE – known only from the study area

A moderately large and slender damselfly with strongly contrasting pale blue markings on the thorax, and wings held vertically when at rest. This pool-dwelling species was found in Hill forest along the access road at Site 1 in the Middle Purari Hills ecological zone, where animals rested on leaves and twigs in shade and dappled sunlight adjacent to two small pools that had formed at the forest edge after rain.

Small forest pools were encountered infrequently at the hill forest sites, and this species was not encountered in alluvial or swamp forest habitats in other ecological zones so within the study area it may have a fragmented distribution within the Middle Purari Hills. It is unclear whether suitable habitats also occur within the Southeast Hills ecological zone. Although most *Teinobasis* species are associated with standing or slow-flowing water (Kalkman & Orr 2013), it is difficult to form conclusions about the habitat preferences or likely geographical limits of this new species other than that it is known to occupy small forest pools. On the basis of currently available information it also qualifies for restricted-range status (see Section 4.4. below). The major threatening process that could affect this species is removal of forest cover.

Platycnemididae

Idiocnemis sp. 1. – UNDESCRIBED – known previously from the Lakekamu basin

A small, slender, orange-pink and black damselfly with purple terminal segments; the wings are held vertically when at rest. This stream-dwelling species was found in hill and alluvial forest at Sites 1, 4, 5, 6B, 7 and 8 in the Middle Purari Hills, Southeast Hills, Delta Swamps and Plains and Southeast Coast ecological zones. This species preferred perches on vegetation in dappled sunlight adjacent to shallow, clear streams with rocky, sandy or muddy substrates.

Idiocnemis sp. 1 was patchily distributed along streams at these sites, preferring areas with dense riparian vegetation and extensive canopy cover. It probably has a broad distribution in suitable hill and alluvial forest habitats within the study area, and occurs at least as far east as the Lakekamu basin (Gassman & Richards, unpublished data). However, the species is replaced by a morphologically and ecologically similar *Idiocnemis* species (*I. schorri*) in the Kikori basin to the west of the study area (Gassmann et al. 2016) and qualifies for restricted-range status (see Section 4.4. below). The major threatening processes that could affect this species are removal of forest cover and damage to streams and adjacent riparian habitats.

Nososticta sp. 1. – NEW-TO-SCIENCE – known only from the study area

A slender black damselfly with yellow markings on the thorax and lacking color on the terminal abdominal segments. This species was found only along small streams in a complex of shallow, inter-connected freshwater swamp habitats within Alluvial forest (Po/Fsw) to the west of the fly camp at Site 5 in the Delta Swamps and Plains ecological zone. Animals were perched in dappled sunlight on the leaves of vegetation overhanging shallow stream channels connecting the freshwater swamp habitats.

This species is likely to be widespread where undisturbed alluvial forest containing such swamp habitats remains within the Delta Swamps and Plains ecological zones. However, the species was not found in slow-flowing, swampy habitats in the Southeast Coast ecological zone and it probably qualifies for restricted-range status (see Section 4.4. below). The major threatening processes that could affect this species are removal of forest cover and damage to the small streams within swampy habitats.

Rhyacocnemis sp. 1. – NEW-TO-SCIENCE – known only from the study area

A small, slender, rather nondescript damselfly with crenulated wing tips. This stream-dwelling species is the most unusual odonate encountered during the Project surveys and its generic status is uncertain; it does not closely resemble any other known species. *Rhyacocnemis* sp. 1 was found only in Hill forest at Sites 2 and 3 in the Middle Purari Hills and Southeast Hills ecological zones where animals were perched on the leaves of riparian vegetation along shallow, clear-flowing streams in forest.

This species was uncommon – it was closely associated with streams having dense riparian vegetation and extensive canopy cover. Adults appeared to spend most of their time in the canopy, descending to the streams only briefly to perch in dappled sunlight. Suitable habitat for this species is widespread within the study area but the species' distribution appears to be patchy; for example, it was not encountered in apparently suitable habitats at Sites 1 or 7. The species is not known from outside the study area and qualifies for restricted-range status (see Section 4.4. below). The major threatening processes that could affect this species are removal of forest cover and damage to streams and adjacent riparian habitats.

DRAGONFLIES

Aeshnidae

Agyrtacantha sp. 1. – NEW-TO-SCIENCE – known only from the study area

A large and robust green and black dragonfly found during Phase 2 in alluvial forest at sites 4 and 5 in the Delta Swamps and Plains ecological zone, and in Hill forest at Site 7 where it occurred on the hill

foot at the boundary of hill and alluvial forest. This genus of dragonflies is most active at dusk and dawn, when adults hawk for insects in forest clearings.

Agyrtacantha sp. 1 was not encountered in Hill forest at Sites 1–3, although dusk-flying dragonflies were scarce at all sites during the Phase 1 survey while they were abundant during Phase 2 so this may be a seasonal artefact. It was not encountered in the Lakekamu or Kikori basins (Richards et al. 1998, Richards 2000) and it qualifies for restricted-range status (see Section 4.4. below). The major threatening process that could affect this species is removal of forest cover.

Libellulidae

***Bironides* sp. 1. – NEW-TO-SCIENCE – known only from the study area**

A moderately small, brown and creamy yellow dragonfly that was abundant in hill and alluvial forest at Sites 3, 4 and 7 in the Southeast Hills and Delta Swamps and Plains ecological zones. In addition to perching in the sun on riparian vegetation close to the water's edge, this stream-dwelling species was often found in deep shade up to 20 m into the forest near streams, and occasionally in areas of open but shaded understorey a long distance from water.

Suitable habitat for this species occurs widely in the Southeast Hills and Delta Swamps and Plains ecological zones and the species is probably widespread, particularly along streams and in adjacent alluvial forest in the Delta Swamps and Plains where it was abundant during this survey. However, the species is not known to occur outside the study area and qualifies for restricted-range status (see Section 4.4. below). The major threatening processes that could affect this species are removal of forest cover and damage to streams and adjacent riparian habitats.

Synthemistidae

***Palaeosynthemis* sp. 1. – NEW-TO-SCIENCE – known only from the study area**

A moderately large but extremely slender dragonfly with a distinct yellow spot on the abdomen. Found only in Hill forest at Site 1 in the Middle Purari Hills ecological zone where a single individual was sleeping on vegetation near a small stream at night.

Few comments can be made about the habitat requirements and potential distribution of this species, because it is currently known from a single specimen. However inasmuch as it was not detected at any other sites, and has not been encountered in the Lakekamu or Kikori basins (Richards et al. 1998, Richards 2000) it clearly qualifies for restricted-range status (see Section 4.4. below). The major threatening processes that could affect this species are removal of forest cover and damage to streams and adjacent riparian habitats.

4.4. ENDEMIC AND RESTRICTED-RANGE SPECIES

Fourteen named, restricted-range species were also encountered. Eleven of these are endemic to Papua New Guinea. The Middle Purari Hills supported the highest number of named, restricted-range species (11) while the Delta Swamps and Plains (7 species) and Southeast Hills (5 species) ecological zones also supported numerous restricted-range species (Table 4). One restricted-range species was encountered in the Southeast Coast and none in the Mangrove ecological zones.

Examination of the broad patterns of endemism of odonates encountered during this survey shows that, excluding five species of uncertain identity, more than a third of species (39%) are in the lowest endemism category (Category 1), being widespread and occurring beyond New Guinea and associated islands. However, the second-largest group of species (25%) is in the highest endemism category (Category 5), being endemic to southern mainland New Guinea. It is apparent from Figure 9 that this pattern is relatively consistent across sites in the hill and alluvial forests of Sites 1–7 in the Middle Purari Hills, Southeast Hills and Delta Swamps and Plains ecological zones. However, a different pattern is evident at Sites 8 and 9 in the Southeast Coast ecological zone where the fauna is dominated by widespread species in Category 1, and few (Site 8) or no (Site 9) Category 5 species are present. This pattern reflects the disturbed and more open habitats at these sites that have promoted colonization by widely dispersing libellulid and coenagrionid species in Category 1 (widest distribution) at the expense of restricted-range stream-dwelling species of the forest interior.

Given the large proportion of species in the highest endemism category at Sites 1–7, the proportion of species qualifying as restricted-range (having known ranges < 50,000 km^2) was assessed. Excluding five species of uncertain identity, 23 of the remaining 92 species encountered (25%) during the Project surveys qualify for restricted-range status although three of these, *Indolestes linsleyi*, *Teinobasis buwaldai* and *Diplacina cyrene*, are considered to be marginal. Proportions of restricted-range species were very different for damselflies and dragonflies; just four of the 23 restricted-range species (17%) are dragonflies while 19 (83%) are damselflies. This reflects the dominance of the dragonfly fauna by libellulid species with wide distributions and broad habitat tolerances. In contrast 13 of the 23 restricted-range odonates are stream-dwelling damselflies that require clear-flowing permanent streams in forest for their reproduction and survival.

Proportions of restricted-range species at each site therefore largely reflect the presence and diversity of stream-dwelling habitat specialists. The highest proportions of restricted-range species were encountered in Hill forest at Sites 1 and 2 in the Middle Purari Hills (28–30%) where there was a wide variety of forest stream habitats. The proportion was also high at Site 4 in the alluvial forests of the Delta Swamps and Plains ecological zone (27%). This site had numerous small streams with features typical of streams in Hill forest – being shallow and clear-flowing. Fewer restricted-range species were encountered in the Southeast Hills ecological zone (18% of the fauna at Site 3, 22% at Site 7), and this probably reflects the extremely dry conditions at Site 3 where at the time of the Phase 1 survey most streams were dry after a major El Nino event. Although conditions were wetter during the Phase 2 survey, at Site 7 survey effort was divided between the hill forest and adjacent alluvial forest. Sites 5 and 8 in the alluvial forests of the Delta Swamps and Plains and Southeast Coast ecological zones had just 14 and 11% of the fauna represented by restricted-range species due to limited forest-stream habitats at those sites, and no restricted-range species were encountered in the heavily disturbed coastal habitats of Site 9.

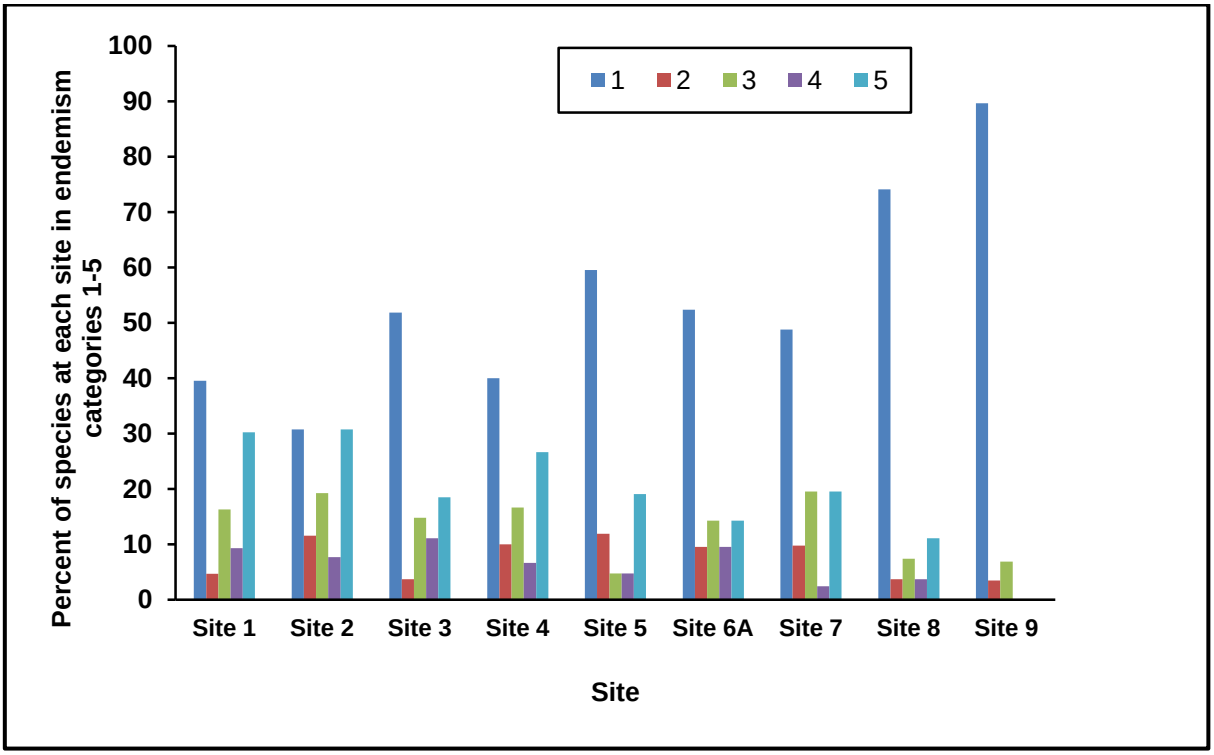

Figure 9. Proportion of odonate species in each endemism category at each site.

See Table 2 for explanation of endemism codes.

Restricted-range species known only from the study area

Eight odonate species – *Metagrion* sp. 1, *Nososticta* sp. 1, *Papuagrion* sp. 1, *Teinobasis* sp. 1, *Rhyacocnemis* sp. 1, *Agyrtacantha* sp. 1, *Bironides* sp. 1 and *Palaeosynthemis* sp. 1 – that were documented during this survey are currently known only from the study area. All of them are new-to-science species discovered for the first time during the Project surveys. Short accounts for each species are presented in Section 4.3. Given that past surveys did not locate these species in suitable lowland habitat in other parts of Gulf Province to the east and west of the study area (Lakekamu and Kikori basins respectively), or in higher elevation hill forest in the Crater Mountain WMA, currently available data suggest that these species may occupy a very restricted geographic range in the order of less than 10,000–15,000 km^2.

Undescribed restricted-range species previously known from outside the study area

One odonate species documented during the Project surveys is undescribed and has a restricted range that extends outside of the study area. Idiocnemis sp. 1. is known from the study area and the Lakekamu basin about 140 km to the east. Given that this species is replaced to the west by an ecologically and morphologically similar congener, and was not encountered in the higher elevation hill forest in the Crater Mountain WMA, currently available data suggest that it may occupy a very restricted geographic range2 in the order of less than 15,000–20,000 km2.

IUCN listed restricted-range species previously known from outside the study area

One odonate species, *Diplacina cyrene*, that is listed by the IUCN as Data Deficient was previously known only from two records at two Indonesian localities more than 1,400 km west-northwest of the study area, one on the Vogelkop Peninsula in West Papua Province and the other on Misool Island in the Moluccas (Kalkman 2009d). No information on the species' habitat requirements was previously known but the single individual of this species that was captured at Site 2 was perched on vegetation adjacent to a small clear stream, and this is typical for members of the genus. However, given the paucity of information on the species' habitat requirements it is difficult to determine whether it is likely to be widespread between the Moluccas and the Purari basin or whether the distribution is likely to be fragmented. Given that past surveys did not locate this species in suitable habitat to the west of the study area in the Kikori basin it may have a fragmented distribution and is tentatively considered to occupy a geographic range in the order of less than 50,000 km^2.

Other restricted-range species documented during this survey

Thirteen additional odonate species with known ranges of less than 50,000 km^2 were documented during this survey. Accounts for each of these species are presented below.

Argiolestidae

Argiolestes tuberculiferus

A moderately large and robust damselfly with a distinct pale zig-zag pattern on the side of the thorax. This species is a 'flatwing' that perches with its wings held horizontally when at rest. Prior to the documentation of a single specimen adjacent to a small forest stream in Hill forest at Site 1 in the Middle Purari Hills ecological zone, it was known only from the type locality at an elevation of about 900 m asl in the Crater Mountain WMA to the north of the study area. This species is a habitat specialist requiring cool, clear streams in hilly terrain where canopy cover remains intact. Given that past surveys did not locate this species in suitable hilly lowland habitat to the east (Lakekamu basin) and to the west (Kikori basin) of the study area it is calculated to occupy a restricted range in the order of less than 15,000 km^2 (hill forest below 1,000 m asl from the eastern Kikori basin east to the Kerema/Kukukuku lobe area). The major threatening processes that could affect this species are removal of forest cover and damage to streams and adjacent riparian habitats.

[2] Calculated as a conservative maximum: all areas below 750 m asl and excluding marine tidally influenced mangrove habitats between the Sirebi River (Kikori Basin, Gulf Province) and Hall Sound (Central Province). The actual area of occurrence may be smaller if this species occurs at lower elevations and/or does not occupy non-forest freshwater swamp habitats.

Metagrion trigonale

A moderately large and robust damselfly with orange legs, a curved yellowish stripe on the top of the thorax, and having abdominal segment nine distinctly paler than the remaining segments. This species is a 'flatwing' that perches with its wings held horizontally when at rest. Prior to the documentation of *M. trigonale* at Sites 1 and 2 in the Middle Purari Hills ecological zone, it was known only from the type locality in the lower Kikori basin where its habitat was described as '*primary forest at the base of a low, heavily forested ridge drained by several small, clear and heavily shaded streams*' (Theischinger & Richards 2008). This species was always found in similar habitats during the Project surveys suggesting that it is a habitat specialist requiring cool, clear streams in hilly terrain where canopy cover remains intact. Given that past surveys did not locate this species in suitable hilly lowland habitat to the east of the study area (Lakekamu basin), or in higher elevation hill forest in the Crater Mountain WMA, currently available data suggest that this species may occupy a very restricted geographic range[3] in the order of less than 15,000–20,000 km^2. The major threatening processes that could affect this species are removal of forest cover and damage to streams and adjacent riparian habitats.

Pyrrhargiolestes angulatus

A moderately large and robust damselfly with bright red legs, contrasting red-and-black colors on the body, and wings held flat rather than vertically when at rest. This stream-dwelling species was found only along a tributary of Boa Creek at Site 1 and on a steep stream at Site 6D in the Middle Purari Hills ecological zone, where animals rested adjacent to the stream on leaves and twigs in shade and dappled sunlight. The species was not uniformly distributed along the stream – it was absent from sandy stretches, and from sunny areas with little canopy cover. Preferred habitats were rocky stretches with small riffles where the stream was c. 5 m wide, and the highest densities were observed in extremely humid places where water was seeping down the stream banks and dripping into the stream channel.

Although forest streams occur throughout the two hill zones, this species appears to have specific habitat preferences and, despite intensive surveys at a wide variety of streams at Sites 2–3 and 7 it was not encountered there. These observations suggest that this species may have a limited, and potentially patchy, distribution along hill forest streams of the study area. This species occurs outside the study area only in the Crater Mountain WMA at around 1,500 m asl, and possibly in adjacent Morobe Province (Michalski 2012). Considering its specific habitat requirements an estimate of distribution incorporating foothills up to 1,600 m asl in the area east of the eastern Kikori basin, to the northern Lakekamu hills and north to the slopes of the central cordillera in Morobe and northeastern Eastern Highlands Province, suggest a restricted range of <c. 35,000 km^2. The major threatening processes that could affect this species are removal of forest cover and damage to streams and adjacent riparian habitats.

Coenagrionidae

Teinobasis buwaldai

A moderately large and sombre-colored black and pale blue damselfly with inferior male appendages distinctly longer than the superior appendages. It was found only along two shallow streams in Hill forest at Site 7 in the Southeast Hills ecological zone near the boundary with the Delta Swamps and Plains ecological zone. This poorly-documented species was previously known only from the Aru Islands (Indonesia) and its presence at Site 7 represents a major range extension. Its habitat requirements are poorly known but small, shallow streams are likely to be widespread in the Southeast Hills and Middle Purari Hills ecological zones. This species was not detected at Site 3, and at sites in the Middle Purari Hills, suggesting that it may prefer streams where they emerge from the foothills onto the Delta Swamps and Plains.

Given the paucity of information on the species' habitat requirements it is difficult to determine whether it is likely to be widespread between the Aru Islands and the Purari basin or whether the distribution is likely to be fragmented. If this species is continuously distributed on the southern hill

[3] A conservative maximum: all areas of hilly terrain below 750 m asl between the Darai Plateau (Kikori Basin, western Gulf Province) and Kerema and the Kukukuku Lobe (eastern Gulf Province).

slopes of the central cordillera between the Aru Islands and the Purari basin then its range will exceed 50,000 km^2. However, given that past surveys did not locate this species in suitable habitat to the west of the study area in the Kikori, Hegigio, Strickland, Fly and Ok Tedi drainages it may have a fragmented distribution and is tentatively considered to occupy a geographic range in the order of less than 50,000 km^2. The major threatening processes that could affect this species are removal of forest cover and damage to streams and adjacent riparian habitats.

Teinobasis debeauxi

An extremely slender, orange and black damselfly that perches with its narrow wings held vertically when at rest. Prior to the documentation of *T. debeauxi* at Sites 1–3 in the Purari Middle Hills and Southeast Hills ecological zones it was known only from the Astrolabe Range near Port Moresby. There is little information about its habitat requirements; in the study area, it was found in shaded understorey vegetation, often a long distance from water. It was not found in alluvial forest. Given that past surveys did not locate this species in suitable hilly lowland habitat to the west of the study area in the Kikori basin, or in higher elevation hill forest in the Crater Mountain WMA, currently available data suggest that this species may occupy a restricted geographic range[4] in the order of less than 15,000–20,000 km^2 between the Astrolabe Range and the Purari basin. The major threatening process that could affect this species is removal of forest cover.

Lestidae

Indolestes linsleyi

A moderately slender, grey and black damselfly with unusually shaped wings, that hangs vertically when at rest. Prior to its documentation at Site 5 in the Delta Swamps and Plains ecological zone, it was known only from the Astrolabe Range near Port Moresby and from a single female from the Digul River. There is little information about its habitat requirements; in the study area, it was found in shaded understorey vegetation in a complex of shallow, inter-connected freshwater swamp habitats to the west of camp in alluvial forest. Past surveys failed to locate this species in apparently suitable habitat in the Lakekamu, Kikori, Strickland and Fly River basins, nor was it encountered in higher elevation hill forest in the Crater Mountain WMA. Currently available data suggests that this species, which is now known from three widely disjunct sites, may have an extremely patchy range that is in the order of less than 50,000 km^2 between the Astrolabe Range and the Digul River. However, if it is shown to have a more uniform distribution in the lowland forests of southern New Guinea then its range will exceed 50,000 km^2. The major threatening process that could affect this species is removal of forest cover.

Platycnemididae

Idiocnemis patriciae

A small, slender, red-brown damselfly with a short pale stripe along the side of the thorax. Documentation of this species at Sites 1 and 7 in the Middle Purari Hills and Southeast Hills ecological zones fills a gap in its known distribution; previously the species was known from the Lakekamu basin to the east and from the Kikori basin and several sites extending nearly to Tabubil in Western Province. Given that past surveys did not locate this species in higher elevation hill forest in the Crater Mountain WMA, and that it is replaced by the similar species *I. australis* in the Fly River headwaters at Tabubil (Richards & Theischinger 2013), currently available data suggest that this species may occupy a restricted geographic range[5] in the order of less than 50,000 km^2 in hilly forest between Lakekamu and the Fly River headwaters. The major threatening processes that could affect this species are removal of forest cover and damage to streams and adjacent riparian habitats.

Nososticta chrismulleri

A slender black damselfly with extensive blue markings on the thorax and a distinct blue ring on abdominal segment 8. This stream-dwelling species was found at Sites 1, 2, 4, 5, 6A and 7 in the

[4] A conservative maximum: all areas of hilly terrain below 750 m asl from the study area (east to Astrolabe Range, Central Province).
[5] Estimated from areas of hilly terrain below 750 m asl between the Fly River (Western Province) and Hall Sound (western Central Province).

Middle Purari Hills, Southeast Hills and Delta Swamps and Plains ecological zones. Animals were perched among flood debris and on the leaves of riparian vegetation on the banks of shallow, clear-flowing streams in hill and alluvial forest.

Nososticta chrismulleri was abundant along both small (< 1 m) and larger (>~3–4 m wide) streams with substrates ranging from rock to sand and mud. Females were also observed in large sun patches away from water. This species is likely to be widespread where undisturbed forest containing numerous such streams remains within these ecological zones. It was not found in swamp forest habitats.

This species is currently known only from the study area and from hill and alluvial forest types in PNG's high rainfall band (above c. 4,000 mm per annum; Bryan & Shearman 2008) between the Ok Tedi and Fly Rivers in the west and Kerema and the Kukukuku Lobe in the east. Past surveys have failed to locate this species in suitable lowland habitat in other parts of Gulf Province to the east of the study area (Lakekamu basin) or in higher elevation hill forest in the Crater Mountain WMA. Currently available data suggest that this species may occupy a restricted geographic range in the order of less than 50,000 km^2 in hilly forest between the Purari and Vailala basins and the Fly River headwaters. The major threatening processes that could affect this species are removal of forest cover and damage to streams and adjacent riparian habitats.

Nososticta makrodon

A slender black damselfly with orange patches on the thorax, white terminal appendages and no color on the abdominal segments. This stream-dwelling species was found at Sites 1, 4, 7 and 8 in the Middle Purari Hills, Southeast Hills, Delta Swamps and Plains and Southeast Coast ecological zones. It preferred perches on vegetation in sunlight adjacent to shallow, clear streams with rocky, sandy or muddy substrates.

Nososticta makrodon is most abundant in larger streams (>~3–4 m across) with a more open canopy that allowed large patches of sunlight to reach the water surface, but also occurred along smaller streams where sunlight penetrated to the forest floor. It was also observed in large sun patches away from water. This species is likely to be widespread where undisturbed forest or forest patches within disturbed landscapes containing numerous such streams remain within the Middle Purari Hills, Southeast Hills, Delta Swamps and Plains and Southeast Coast ecological zones.

This species is currently known only from the study area and from hill and alluvial forest types in PNG's high rainfall band (above c. 4,000 mm per annum; Bryan and Shearman 2008) between the Ok Tedi and Fly Rivers in the west and Kerema and the Kukukuku Lobe in the east. Past surveys have failed to locate this species in suitable lowland habitat in other parts of Gulf Province to the east of the study area (Lakekamu basin) or in higher elevation hill forest in the Crater Mountain WMA. Currently available data suggest that this species may occupy a restricted geographic range in the order of less than 50,000 km^2 in hilly forest between the Purari basin and the Fly River headwaters. The major threatening processes that could affect this species are removal of forest cover and damage to streams and adjacent riparian habitats.

Nososticta paraconifera

A slender black damselfly with extensive blue markings on the thorax but lacking color on any of the terminal abdominal segments. This stream-dwelling species was found only in alluvial forest at Site 4 in the Delta Swamps and Plains ecological zone. Animals were perched on the leaves of riparian vegetation on the banks of shallow streams in forest.

Nososticta paraconifera was moderately common along small (< 3 m) clear streams with sandy and muddy substrates. This species is likely to be widespread where undisturbed forest containing numerous such streams remains within the Delta Swamps and Plains ecological zone. It is currently known only from the study area and from hill and alluvial forest types in PNG's high rainfall band (above c. 4,000 mm per annum; Bryan and Shearman 2008) between the Ok Tedi and Fly Rivers in Western Province and Kerema and the Kukukuku Lobe in the east. Past surveys have failed to locate this species in suitable lowland habitat in other parts of Gulf Province to the east of the study area (Lakekamu basin) or in higher elevation hill forest in the Crater Mountain WMA. Currently available data suggest that this species may occupy a restricted geographic range in the order of less than

50,000 km^2 in hill and alluvial forest between the Purari basin and the Fly River headwaters. The major threatening processes that could affect this species are removal of forest cover and damage to streams and adjacent riparian habitats.

Nososticta smilodon

A small, slender, black and blue damselfly with bright orange 'flag-shaped' terminal appendages. Prior to the documentation of this species at Sites 2 and 4 in the Middle Purari Hills and Delta Swamps and Plains ecological zones, it was known only from the type locality in the lower Kikori basin where it occurred in '*dappled sunny patches during the morning and middle of the day*' in *'primary forest at the base of a low, heavily forested ridge drained by several small, clear and heavily shaded streams*' (Theischinger & Richards 2006a). This species was found in similar habitats during the Project surveys but also occurred along low-gradient, slow-flowing streams in flat alluvial forest. Given that past surveys did not locate this species in suitable lowland habitat to the east of the study area in the Lakekamu basin, and its replacement by a similar species in equivalent habitats to the west of the Kikori basin (Richards, unpublished data), currently available data suggest that this species may occupy a very restricted geographic range[6] in the order of less than 15,000–20,000 km^2. The major threatening processes that could affect this species are removal of forest cover and damage to streams and adjacent riparian habitats.

Nososticta truncata

A small, slender, black and blue damselfly with white terminal appendages. Documentation of this species at Sites 1, 2 and 4 in the Middle Purari Hills and Delta Swamps and Plains ecological zones fills a gap in its known distribution; previously the species was known from the Lakekamu basin to the east and from several sites extending nearly to Tabubil in Western Province. It is a stream-dwelling species found only along small, clear streams with sandy or rocky substrates. Given this reliance on clear-flowing streams it is unclear how far into the Delta Swamps and Plains its distribution is likely to extend. Given that past surveys did not locate this species in the Kikori basin and in higher elevation hill forest in the Crater Mountain WMA suggests that *N. truncata* may occupy a restricted and patchy geographic range[7] in the order of less than 50,000 km^2 in hill and alluvial forest between Lakekamu and the Fly River headwaters. The major threatening processes that could affect this species are removal of forest cover and damage to streams and adjacent riparian habitats.

Platystictidae

Drepanosticta taurulus

A moderately large, dark damselfly with small pale patches on the thorax and bright blue terminal abdominal segments. This species was described from a single specimen collected at Herowana (~1,400 m asl) in the Crater Mountain WMA (Theischinger & Richards 2005). This species was common along small streams in closed-canopy forest at Sites 1-3 in the Middle Purari Hills and Southeast Hills ecological zones. It is a habitat specialist that was restricted to deeply-shaded sections of clear, rocky streams where they perched among dense foliage or under overhanging stream banks. They were never found in open, sunny areas.

Forest streams occur throughout the two hill zones, and it is probably widespread there. However, considering its specific habitat requirements an estimate of distribution incorporating foothills up to 1,600 m asl in the area east of the eastern Kikori basin, to the northern Lakekamu hills and north to the slopes of the central cordillera in Morobe and northeastern Eastern Highlands Province, suggests a restricted range of <c. 35,000 km^2. The major threatening processes that could affect this species are removal of forest cover and damage to streams and adjacent riparian habitats.

[6] A conservative maximum: all areas below 750 m asl and excluding marine tidally influenced mangrove habitats between the Darai Plateau and Kerema and the Kukukuku Lobe. The actual area of occurrence may be smaller if this species occurs at lower elevations and/or does not occupy non-forest freshwater swamp habitats.

[7] Estimated from areas of hilly and alluvial terrain excluding freshwater swamp habitats below 750 m asl between the Fly River (Western Province) and Hall Sound (western Central Province).

Other restricted-range species not documented during this survey that might occur in the study area

Five species of damselflies with restricted-ranges that were not encountered during the Project surveys may occur within the study area. They are *Nososticta acudens* and *Papuagrion nigripedum* which are currently known only from the Kikori basin to the west; and *Metagrion indentatum*, *Nososticta acuminata* and *N. conifer* that are each known only from the Lakekamu basin to the east (Theischinger & Richards 2006a–c, Michalski et al. 2012). Inasmuch as these species are each currently known only from a single locality, and that those known from Lakekamu were not encountered in similar habitats in the Kikori basin and vice versa, currently available data suggest that each species may occupy a very restricted geographic range in the order of less than 10,000–20,000 km^2. With the exception of *Papuagrion nigripedum*, which occurs in the forest understorey, each of these species is associated closely with small clear streams in forest (Theischinger & Richards 2006a–c, S.J. Richards, unpublished data).

4.5. OTHER SIGNIFICANT SPECIES

No other significant odonate species were encountered.

4.6. INVASIVE ALIEN SPECIES

No invasive alien species of odonates were encountered and none are known to occur in PNG.

4.7. IMPORTANT HABITATS

The hill and alluvial forests of the study area provide a wide variety of aquatic microhabitats that support a rich odonate fauna including many new-to-science and restricted-range species Examples of habitats are illustrated in Plates 5 and 6. To maintain this odonate diversity it is important that as much of this mosaic of lowland and foothill forest habitats is retained as possible. However, within this matrix are several features that appear to be focal habitats for a number of taxa.

There are two broad ecological groups of odonate species in the study area with contrasting ecologies and life histories. One group consists of species reliant on small, clear forest streams for their reproduction and survival. The second group includes species that breed in pools and swamps, and this group dominated where few flowing streams were present, including both sites in the Southeast Coast ecological zone. These species tend to have broad habitat tolerances, wide distributions and good dispersal abilities.

4.7.1. Streams

Clear streams occur throughout the hill forests of the Middle Purari Hills and Southeast Hills ecological zones and, to a lesser extent, in the alluvial forests of the Delta Swamps and Plains ecological zone. These streams and the dense riparian vegetation along their banks provide habitat for distinct assemblages of damselflies that rely on clear streams for successful reproduction and they are considered to be particularly important habitats in the Middle Purari Hills where they support a diverse assemblage of new-to-science and restricted-range species.

Differences among stream assemblages within both the hill forests and alluvial forests suggest that stream morphology and the structure and density of riparian vegetation associated with streams is a crucial factor determining the species of odonates that are able to persist along them. For example, assemblages were different along streams retaining dense overhanging riparian vegetation from those along more open streams, and changes in riparian vegetation and canopy cover along different sections of the same stream also influenced assemblage structure with some genera, e.g. *Drepanosticta* and *Pyrrhargiolestes*, preferring smaller shaded streams with complex understorey riparian vegetation while other species, e.g. *Huonia* spp. and *Nososticta* spp., preferred streams with open understoreys and canopy gaps that allowed large sun patches to penetrate to the creek bed.

Korkeamäki and Suhonen (2002) found that extinction risk of odonate populations in Finland was lower in widely distributed habitat generalist species than in lotic (stream) specialist species and that local extinction within species was more common in small dynamic upstream reaches than in larger stable downstream habitats. Given that many of the stream-dwelling, restricted-range species were

found predominantly in cool, shady stream habitats with extensive canopy cover and dense riparian vegetation, these are identified as important habitats for maintaining the biodiversity values of odonates in the study area.

4.7.2. Forest pools

Small, shaded pools in Hill forest are the only known habitat of *Teinobasis* sp. 1, a new-to-science species that is known only from the Middle Purari Hills ecological zone.

4.8. CONSERVATION VALUE OF THE STUDY AREA

Given the high levels of overlap of odonate species with the Lakekamu basin to the east, and the Kikori basin to the west, the major biodiversity values of the odonates in the study area are:

1) That it represents a diverse faunal assemblage typical of and contiguous with adjacent areas along the southern foothills and lowland plains of mainland New Guinea.

2) That it contains at least eight species that are new-to-science that are so far not known outside of the study area.

3) That it contains an additional 14 restricted-range species and one undescribed species, most of which are habitat specialists requiring clear-flowing forest streams for their reproduction and survival.

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Appendix 1. Odonate species documented at 11 sites in the study area, their IUCN status, endemism code and restricted-range status. No odonates are Protected under PNG law or listed under CITES Appendix I or II, and none were observed at Site 8M in coastal mangrove habitats so this site is not included. An '?' is presented where poorly-resolved taxonomic status prevents assessment of a species' endemism and restricted-range status.

Species	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6A	Site 6B	Site 6D	Site 7	Site 8	Site 9	IUCN Status	Endemism*	Restricted-range?
DAMSELFLIES														
Argiolestidae														
Argiolestes tuberculiferus	X											NE	5	Yes
Metagrion trigonale	X	X										NE	5	Yes
Metagrion sp. 1			X						X			NE	5	Yes
Phyrrargiolestes angulatus	X							X				NE	5	Yes
Podopteryx selysi				X								NE	1	No
Calopterygidae														
Neurobasis australis	X	X		X	X	X						NE	2	No
Chlorocyphidae														
Rhinocypha tincta semitincta	X	X	X	X	X	X			X	X		NE	5	No
Coenagrionidae														
Agriocnemis femina	X		X	X	X	X			X	X	X	LC	1	No
Archibasis crucigera					X				X			LC	2	No
Argiocnemis rubescens				X	X				X	X	X	LC	1	No
Ceriagrion aeruginosum					X				X	X		LC	1	No
Ischnura heterosticta											X	NE	1	No
Ischnura pruinescens					X							NE	1	No
Papuagrion magnanimum		X										NE	3	No
Papuagrion occipitale					X			X	X		X	NE	3	No

Species	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6A	Site 6B	Site 6D	Site 7	Site 8	Site 9	IUCN Status	Endemism*	Restricted-range?
Papuagrion sp. 1										X		NE	5	Yes
Pseudagrion fumipennis	X	X		X		X			X			NE	3	No
Pseudagrion farinicolle?	X		X		X				X			NE	?	?
Teinobasis buwaldai									X			NE	3	Yes
Teinobasis debeauxi	X	X	X									NE	5	Yes
Teinobasis pulverulenta					X							NE	5	No
Teinobasis rufithorax					X				X	X	X	NE	1	No
Teinobasis sp. 1	X											NE	5	Yes
Teinobasis sp.				X	X				X	X	X	NE	?	?
Xiphiagrion truncatum	X				X	X						NE	4	No
Isostictidae														
Selysioneura phasma	X			X								NE	3	No
Selysioneura rhaphia	X		X									DD	3	No
Tanymecosticta fissicollis									X			LC	3	No
Lestidae														
Indolestes linsleyi					X							NE	5	Yes
Lestes concinnus											X	LC	1	No
Lestes praemorsus	X											LC	1	No
Platycnemididae														
Idiocnemis patriciae	X								X			NE	5	Yes
Idiocnemis sp. 1	X			X	X		X		X	X		NE	5	Yes
Nososticta chrismulleri	X	X		X	X	X			X			NE	5	Yes
Nososticta finisterrae	X	X	X	X		X	X					DD	3	No
Nososticta makrodon	X			X					X	X		NE	5	Yes
Nososticta marina									X			NE	3	No
Nososticta nigrifrons	X	X			X	X						DD	5	No
Nososticta paraconifera				X								NE	5	Yes

Species	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6A	Site 6B	Site 6D	Site 7	Site 8	Site 9	IUCN Status	Endemism*	Restricted-range?
Nososticta rosea rosea	X	X		X			X		X	X		NE	3	No
Nososticta smilodon		X		X								NE	5	Yes
Nososticta truncata	X	X		X	X	X			X			NE	5	Yes
Nososticta sp. 1					X							NE	5	Yes
Rhyacocnemis sp. 1		X	X									NE	5	Yes
Platystictidae														
Drepanosticta dendrolagina	X	X	X	X					X			NE	4	No
Drepanosticta taurulus	X	X	X									NE	5	Yes
DRAGONFLIES														
Aeshnidae														
Agyrtacantha dirupta					X				X		X	NE	1	No
Agyrtacantha tumidula					X				X			NE	2	No
Agyrtacantha sp. 1				X	X				X			NE	5	Yes
Anax guttatus	X		X			X					X	NE	1	No
Gynacantha kirbyi			X		X				X		X	NE	1	No
Gynacantha mocsaryi					X		X		X	X	X	NE	1	No
Gynacantha rosenbergi					X						X	NE	1	No
Corduliidae														
Hemicordulia silvarum	X	X						X				NE	4	No
Metaphya tillyardi		X										LC	1	No
Gomphidae														
Ictinogomphus lieftincki	X								X			NE	3	No
Libellulidae														
Agrionoptera insignis				X	X				X	X	X	LC	1	No
Agrionoptera longitudinalis	X	X	X	X	X				X	X	X	LC	1	No
Bironides sp. 1			X	X					X			NE	5	Yes
Brachydiplax duivenbodei					X				X	X		LC	1	No

Species	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6A	Site 6B	Site 6D	Site 7	Site 8	Site 9	IUCN Status	Endemism*	Restricted-range?
Camacinia gigantea			X									LC	1	No
Camacinia othello										X		LC	1	No
Diplacina cyrene		X										DD	3	Yes
Diplacina antigone	X		X		X	X				X		NE	4	No
Diplacina phoebe			X	X								NE	?	No
Diplacodes haematodes	X								X			NE	1	No
Diplacodes trivialis	X				X	X					X	LC	1	No
Huonia epinephela			X									NE	3	No
Hydrobasileus brevistylus					X							NE	1	No
Lathrecista asiatica											X	LC	1	No
Nannophlebia axiogasta?			X						X			NE	?	?
Nesoxenia mysis					X				X	X		NE	1	No
Neurothemis decora	X		X	X	X	X			X	X	X	NE	3	No
Neurothemis oligoneura											X	NE	1	No
Neurothemis ramburi	X	X	X	X		X			X		X	LC	1	No
Neurothemis stigmatizans	X			X	X	X			X	X	X	NE	1	No
Orthetrum glaucum	X	X						X				LC	1	No
Orthetrum sabina						X				X		LC	1	No
Orthetrum serapia	X	X	X	X	X	X		X	X	X	X	LC	1	No
Orthetrum villosovittatum	X	X	X	X	X	X			X	X		NE	1	No
Pantala flavescens	X		X	X	X	X		X	X	X	X	LC	1	No
Protorthemis coronata		X		X	X				X		X	NE	2	No
Rhodothemis lieftincki					X						X	NE	1	No
Rhyothemis phyllis	X		X							X	X	LC	1	No
Rhyothemis princeps	X				X							LC	1	No
Rhyothemis regia	X											NE	1	No
Rhyothemis resplendens	X	X	X	X						X		NE	1	No

Species	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6A	Site 6B	Site 6D	Site 7	Site 8	Site 9	IUCN Status	Endemism*	Restricted-range?
Tetrathemis irregularis			X	X	X				X	X	X	LC	1	No
Tholymis tillarga					X				X		X	LC	1	No
Tramea eurybia	X		X			X						NE	1	No
Tramea loewi											X	LC	1	No
Tramea transmarina						X				X	X	LC	1	No
Zyxomma multinervorum		X	X		X				X	X		LC	1	No
Zyxomma petiolatum					X						X	LC	1	No
Macromiidae														
Macromia sp.	X											NE	?	?
Synthemistidae														
Palaeosynthemis sp. 1	X											NE	5	Yes
Palaeosynthemis sp.	X	X	X									NE	?	?
Total = 97	**46**	**27**	**30**	**31**	**44**	**21**	**4**	**6**	**44**	**28**	**30**			

*See Table 2 for explanation of endemism codes

Plate 1. Conservation significant and New-to-science odonate species

Family Platycnemididae. *Nososticta nigrifrons*.
IUCN Data Deficient

Family Libellulidae. *Diplacina cyrene*.
IUCN Data Deficient

Family Argiolestidae. *Metagrion* sp. 1.
New-to-science

Family Coenagrionidae. *Papuagrion* sp. 1.
New-to-science

Family Coenagrionidae. *Teinobasis* sp. 1.
New-to-science

Family Platycnemididae. *Idiocnemis* sp. 1.
New-to-science

Family Argiolestidae. *Argiolestes tuberculiferus.*
Restricted range

Family Platycnemididae. *Nososticta finisterrae.*
Data deficient

Family Isostictidae. *Selysioneura rhaphia.*
Data deficient

Plate 2. New-to-science odonate species

Family Platycnemididae. *Nososticta* sp. 1.
New-to-science

Family Platycnemididae. *Rhyacocnemis* sp. 1.
New-to-science

Family Aeshnidae. *Agyrtacantha* sp. 1.
New-to-science

Family Libellulidae. *Bironides* sp. 1.
New-to-science

Family Synthemistidae. *Palaeosynthemis* sp. 1.
New-to-science

Plate 3. Restricted-range odonate species

Family Argiolestidae. *Metagrion trigonale.*
Restricted-range

Family Argiolestidae. *Pyrrhargiolestes angulatus.*
Restricted-range

Family Coenagrionidae. *Teinobasis buwaldai.*
Restricted-range

Family Platycnemididae. *Idiocnemis patriciae.*
Restricted-range

Family Lestidae. *Indolestes linsleyi.*
Restricted-range

Plate 4. Restricted-range odonate species

Family Platycnemididae. *Nososticta chrismulleri*.
Restricted-range

Family Platycnemididae. *Nososticta makrodon*.
Restricted-range

Family Platycnemididae. *Nososticta paraconifera*.
Restricted-range

Family Platycnemididae. *Nososticta smilodon*.
Restricted-range

Family Platycnemididae. *Nososticta truncata*.
Restricted-range

Family Platystictidae. *Drepanosticta taurulus*.
Restricted-range

Plate 5. Habitat examples

Camp and forest at Site 4

Forest interior at site 4

Plate 6. Habitat examples

Forest Stream at Site 1

Pool at forest edge at Site 1