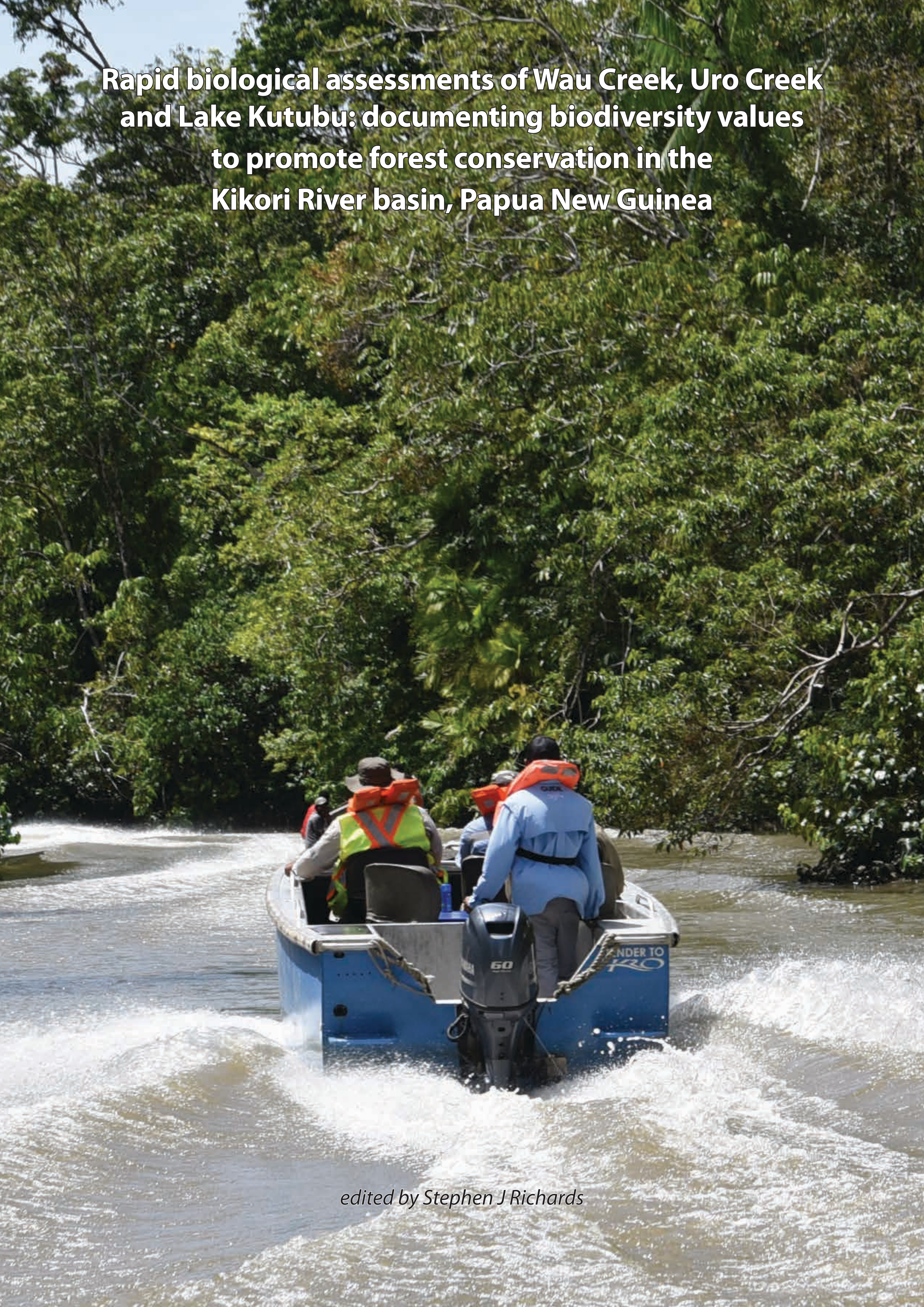
Rapid biological assessments of Wau Creek, Uro Creek and Lake Kutubu: documenting biodiversity values to promote forest conservation in the Kikori River basin, Papua New Guinea



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Cover image: A network of narrow channels penetrates the extensive forests of the Kikori River delta. These forests support an extraordinary and poorly-documented biodiversity, and provide numerous resources for local communities.

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Report Summary

Stephen Richards and Iain Woxvold

The Southern Cassowary is an ecological keystone species, and an important resource for local communities

Background and aims

Best known for its birds-of-paradise, echidnas and tree kangaroos, New Guinea has an exceptionally high biodiversity, and much of its fauna and flora is found nowhere else on Earth. Many species have cultural significance for local communities, and numerous plants and animals that are new to science are being discovered every year. Documenting this biodiversity is critical because knowledge of biodiversity underpins our understanding of the ecosystem services that play a key role in meeting the subsistence, cultural and spiritual needs of local communities.

The Kikori River basin in Gulf, Southern Highlands and Hela Provinces in southern Papua New Guinea (PNG) encompasses large expanses of undisturbed tropical forest extending from sea level to over 3,500 m asl. The basin is extremely rugged, comprising extensive areas of polygonal and doline karst, karst plains and plateaus with karst corridors, and volcanic areas. Spectacular landscape features include Mount Bosavi and the Ramsar-listed Lake Kutubu. In recognition that it is a region of high biodiversity significance, the Kikori basin is the site of the Kikori Integrated Conservation and Development Project (KICDP, now called the Kikori River Program), a World Wide Fund for Nature (WWF) conservation initiative supported initially by Chevron Asiatic Ltd and later by Oil Search Limited.

The Papua New Guinea Liquefied Natural Gas (PNG LNG), which is operated by ExxonMobil PNG Limited, is fully encompassed in the drainage of the Kikori River basin. Studies conducted prior to Project development confirmed the substantial biodiversity values in the Upstream Project Area and these were summarised in ExxonMobil PNG Limited's (EMPNG) Biodiversity Strategy as (i) extensive intact forest, (ii) high floristic diversity, (iii) high faunal diversity, (iv) endemic species, (v) unique assemblages of species, (vi) species of conservation concern, and (vii) biodiversity of importance to local communities for resource use and cultural and spiritual purposes.

As part of its commitment to safeguarding these biodiversity values in the Upstream Project Area, EMPNG has developed a biodiversity offset program that aims to protect forest habitats in different altitudinal zones within the Kikori basin. Three components of this program are: Protected area planning; Enhancing existing protected areas; and Establishing new protected areas. Because a key requirement of PNG's Conservation and Environment Protection Authority (CEPA) for planning and establishing protected areas in Papua New Guinea is an evaluation of their biodiversity values, EMPNG assembled a team of national and international scientists to document the biodiversity of three sites identified as having community support for protected area establishment or enhancement.

This report presents the results of a series of biodiversity surveys conducted during 2017 that aimed to generate data on the biodiversity values of existing or potential community-based protected areas at three sites in the Kikori basin: (Figure 1; Table 1): 1) The Wau Creek proposed Wildlife Management Area (WMA); 2) The Uro Creek catchment, and 3) the Lake Kutubu WMA.

Survey dates

20th April–9th May 2017

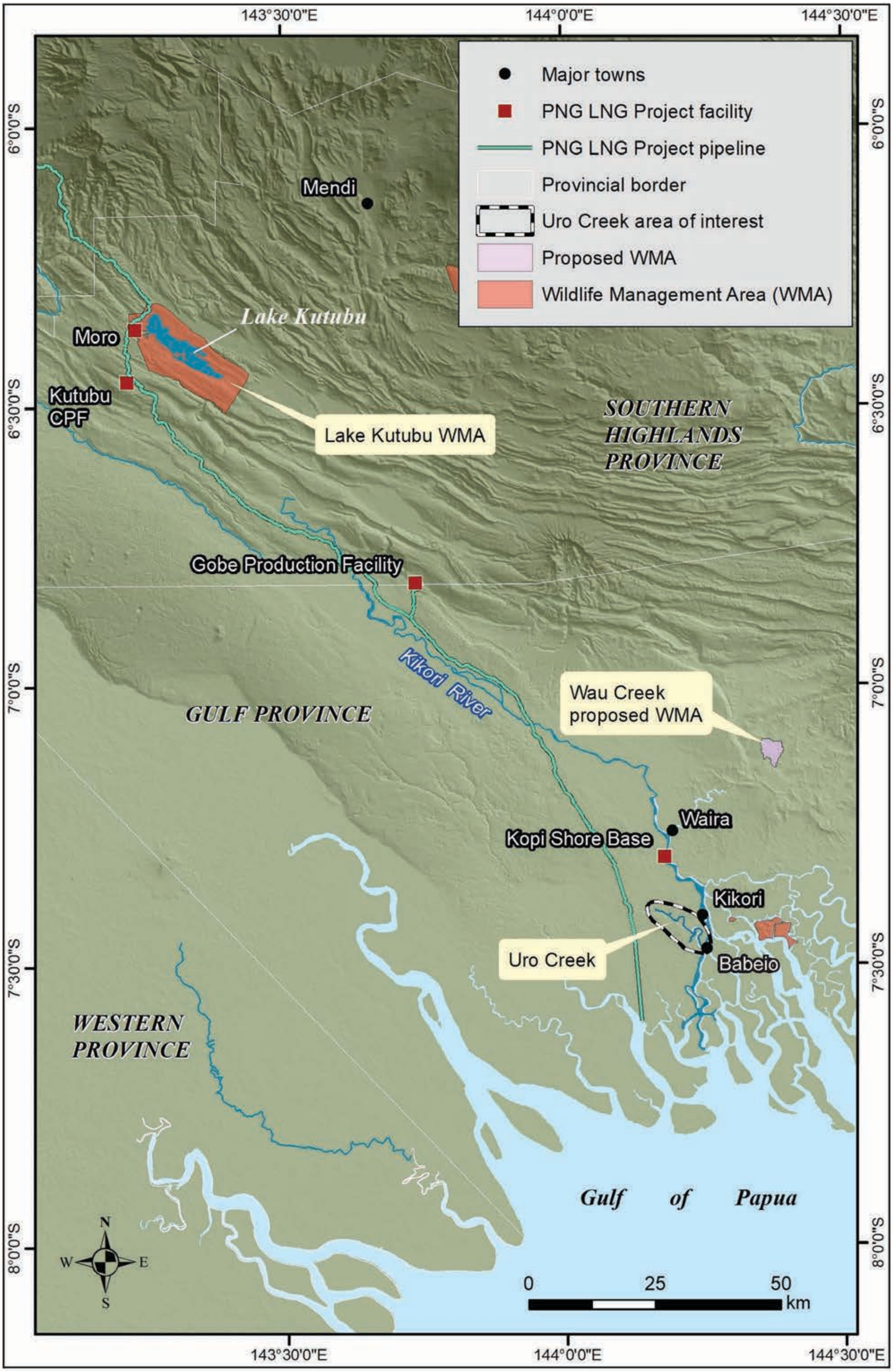

Figure 1. Map of the Kikori basin showing the three survey locations.

Brief descriptions of the survey areas

Wau Creek

The Wau Creek proposed WMA is located approximately 20 km southwest of Mount Duau and 22 km east of the Kikori River at its closest point (Figure 2; Table 1). Centred on Wau Creek and bordered in the south by the Sire River, a tributary of the Sirebi River, the proposed WMA covers 1,605 ha of foothill and alluvial terrain, mostly below 100 m above sea level (asl) with some sites in the northwest reaching over 165 m asl.

Within the proposed WMA, the geology is dominated by recent (Quaternary) alluvium in broad flood zones along the larger watercourses (Sire River, Wau Creek and Rue Creek), with most hill terrain comprising sandstone-dominant Tertiary (Miocene–Pliocene) Era Bed sediments (Pieters 1980). Smaller areas of Pleistocene volcanic deposits characterise high points along its northwest and eastern boundaries.

Climatically, Wau Creek is located in one of Papua New Guinea's wettest areas with annual falls totalling more than five metres (McAlpine et al. 1983; Bryan and Shearman 2008). Rainfall is heavy throughout the year though generally highest during New Guinea's southeast 'trade winds' season of May–October.

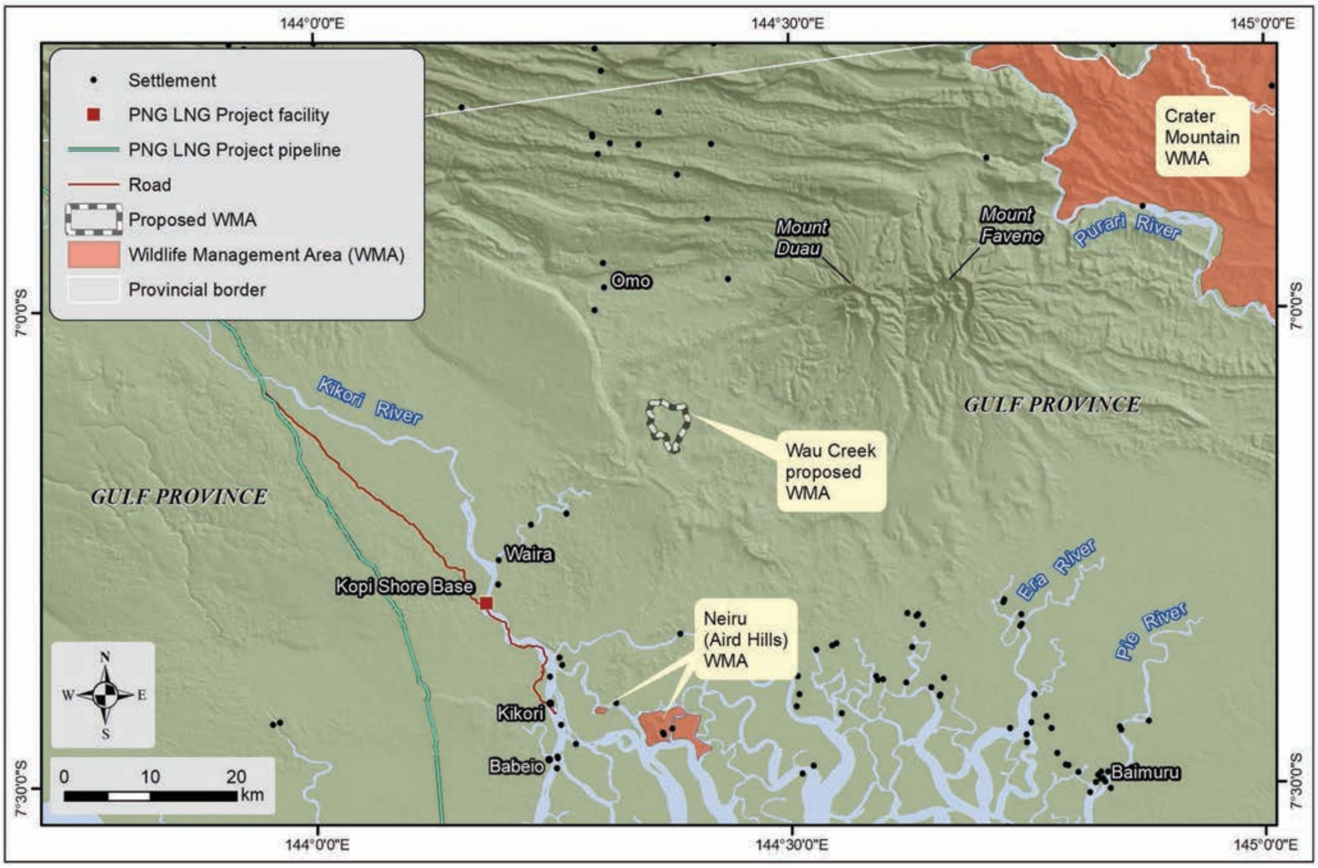

Figure 2. Location of the proposed Wau Creek WMA

Natural vegetation is mapped under the Papua New Guinea Forest Inventory Mapping System (FIMS) (Hammermaster and Saunders 1995) as large crowned alluvial forest (FIMS code Pl—'large to medium crowned low altitude forest on plains and fans') with medium crowned hill forest (FIMS code Hm—'medium crowned low altitude forest on uplands') on more extensive areas of hill terrain near the northern, western and eastern borders of the proposed WMA. Unmapped occurrences of hill terrain were present more locally in areas surveyed close to Wau Creek. Forest structure and floristics change markedly with minor changes in elevation and associated changes in drainage pattern, so that a mosaic of hill and alluvial forest types was observed in surveyed areas.

Commercial forestry is the largest industrial land use activity undertaken in the lower Kikori basin. The proposed WMA is located within the Kikori Block 2 logging concession and approximately 15 km northeast of the currently active Sirebi Logging Camp. Much of the forest within the proposed WMA has been logged, most recently in 1995 according to local informants. Logging tracks are evident in recent satellite imagery and an earlier road network is visible on the 1970s 1:100,000 Kikori (no. 7783) topographic mapsheet. In many surveyed areas the forest structure and floristics had been severely altered. However, in some areas near the research station large, non-commercial trees had been left standing so that patches of forest retained an open, multi-layered understorey structure characteristic of more mature forest.

The initial impetus for establishment of a WMA at Wau Creek was recognition that the area supports a significant nesting population of the IUCN-Endangered Pig-nosed Turtle (*Carettochelys insculpta*), and a desire by the local landowner Frank John and his family to conserve this species. A small research station has been established within the proposed WMA to support long-term research on this species and other biodiversity.

Uro Creek

Uro Creek flows east into the lower Kikori River at the head of the Kikori delta (Figure 3). The Uro Creek catchment covers more than 110 km^2 and spans a variety of landforms. The west and centre of the catchment are dominated by karst foothills of the Darai limestone formation (Pieters 1980; Bryan and Shearman 2008). The limestone terrain extends furthest downstream south of Uro Creek, following the Veiru anticline to Ako Creek approximately 3 km from the Kikori River. The Veiru anticline is the catchment's major topographic feature, attaining heights of more than 140 m asl in the rugged karst hills in the centre of the catchment. Elsewhere, Pleistocene non-calcareous sediments form low hills flanking the catchment near the Kikori River, and levee plains bordering the navigable sections of Uro Creek and its main tributaries. The levee plains lie as low as 10–15 m asl and are subject to regular flooding and tidal influence.

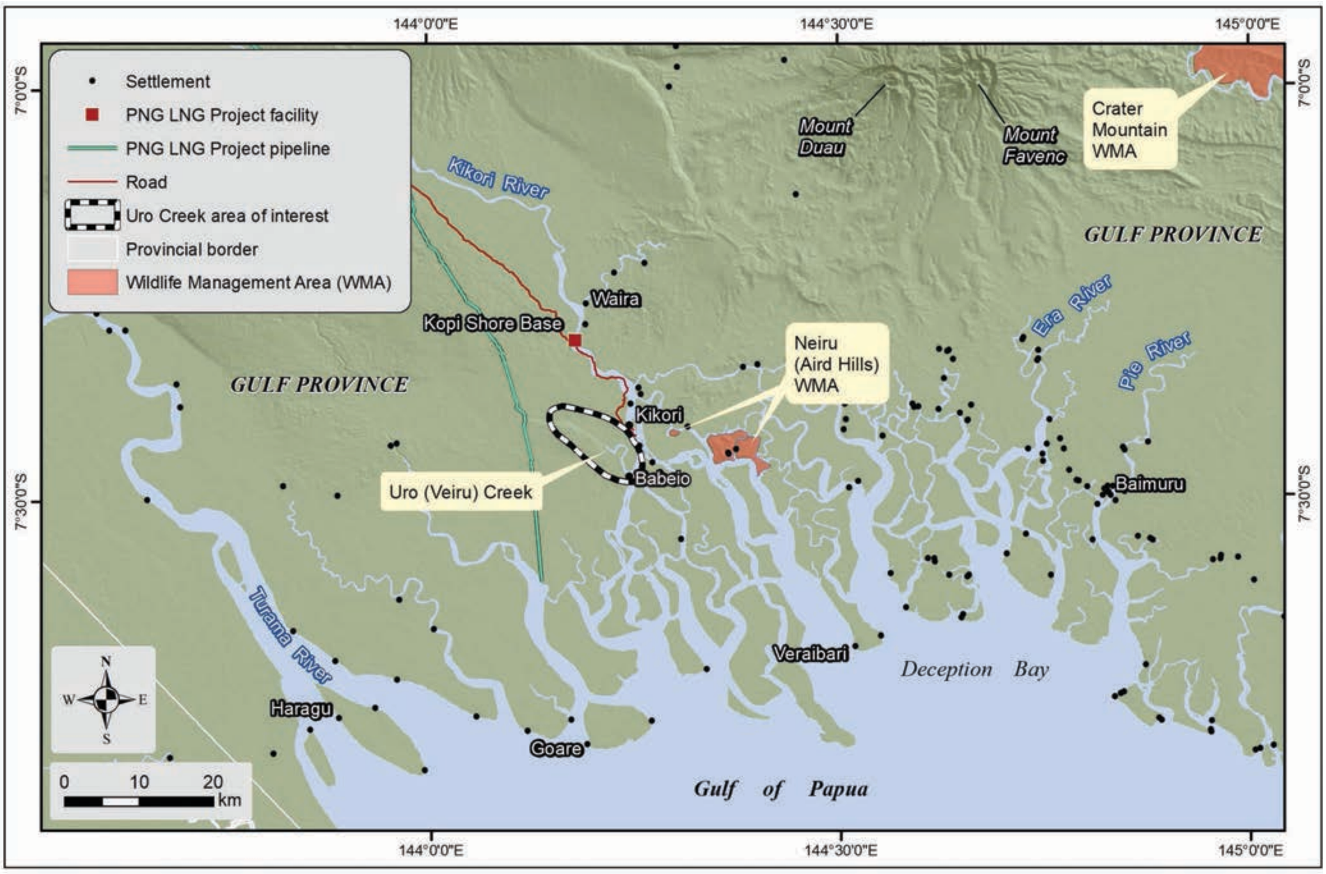

Figure 3. Location of the Uro Creek survey area.

The variable terrain, substrate and flooding regimes in turn support a variety of vegetation types. The Papua New Guinea FIMS dataset identifies five major vegetation types, occurring alone or in complex form, within the Uro Creek catchment (Hammermaster and Saunders 1995):

- Hill forest ('low altitude forest on uplands')—predominantly complexes of medium and small crowned forest (FIMS code Hm/Hs), on limestone and sedimentary hill terrain.
- Small crowned alluvial forest (FIMS code Ps)—on low-lying limestone platforms in the catchment's north.
- Swamp forest (FIMS code Fsw)—alone on low-lying sediments (limestone and non-calcareous), and as a subordinate component in complexes with hill forest (FIMS codes Hm/Hs/Fsw, Hs/Fsw).
- Freshwater Swamp woodland (FIMS code Wsw) with sago (*Metroxylon sagu*) and pandanus (*Pandanus* spp.), and Mangrove (FIMS code M)—in complex form (Wsw/M) across all levee plains.

The Uro Creek catchment is located within the Turama Block 1 logging concession. Approximately one third of the catchment has been logged in the outer west, north and south of the catchment, with logging roads evident in recent satellite imagery. Based on the FIMS mapping, much of the hill forest and parts of the small crowned alluvial forest formations have been harvested.

At a more local scale, forest at numerous arable sites along the navigable waterways had been converted to gardens or was regenerating after prior cultivation. The only permanent settlement is Babeio village at the Uro Creek–Kikori River confluence and landowners based at Babeio village travel by boat to these temporary camps. Some sites in the northwest, such as Veimake and Veimei camp, can be reached on foot by road from Kikori Station.

Climatically, Uro Creek is located in one of Papua New Guinea's wettest areas with annual falls totalling more than five metres (McAlpine et al. 1983; Bryan and Shearman 2008). Rainfall is heavy throughout the year though generally highest during New Guinea's southeast 'trade winds' season of May–October.

Lake Kutubu

The Lake Kutubu WMA in Southern Highlands Province (Figure 4) covers approximately 24,057 ha of the lake and surrounding forested hill and lower montane slopes, from about 810 m to above 1,380 m asl at Mount Kemenagi less than two kilometres from the southern lake shore. Located in the Kikori-Lake Kutubu Karst Area of the Southern Fold Mountains, the geology is characterised by Tertiary limestones and Pleistocene volcanic deposits forming a northwest-trending series of ridges, plateaux and valleys (Löffler 1977; Bryan and Shearman 2008). Recent (Quaternary) alluvial deposits are located at each end of the 19 km-long lake. Three major vegetation groupings are mapped under the Papua New Guinea FIMS dataset (Hammermaster and Saunders 1995):

- Wooded freshwater swamps—dominated by complexes of Sago (*Metroxylon sagu*)/*Pandanus* swamp woodland and mixed swamp forest (FIMS type (Wsw/Fsw) on flood-prone alluvium at each end of the lake.
- Hill forest—medium crowned forest (FIMS type Hm) on mountain slopes below 1,000 m asl, with *Nothofagus* (sometimes called *Trisyngyne*) mapped present (FIMS type Hm.N) on most upper slopes more than a few hundred metres from the lake shore.
- Lower montane forest—on all terrain above 1,000 m asl, alone or in complex form as structural variants (small/very small crowned) with or without *Nothofagus* prominent in the canopy (FIMS types L, LN, LsN/L, LsN/LN).

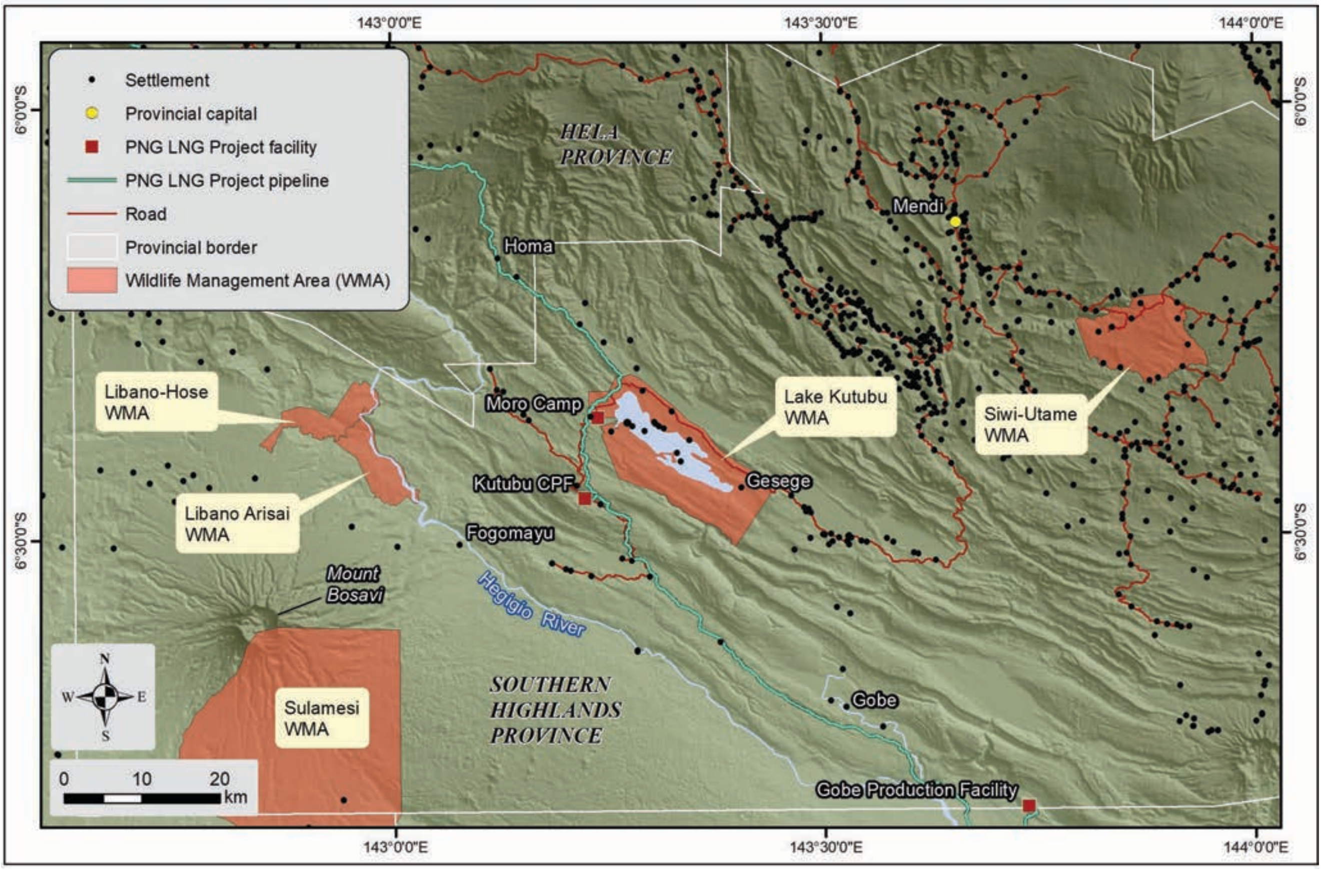

Figure 4. Location of the Lake Kutubu WMA.

Vegetation is predominantly intact except in areas cleared for development of oil and gas infrastructure and around local settlements. Local resident settlements are presently concentrated along the margins of the lake and at a few sites along road routes. Secondary forest in regenerating garden sites and natural forest degraded by local resource extraction is present in areas around settlements and along some road routes.

Table 1. Major survey sites at the three locations surveyed.

	Latitude	Longitude	Altitude m (asl)
Wau Creek			
Research station*	-7.1219	144.3739	20
Uro Creek			
A'oo Cave	-7.4634	144.2387	39
Eimu Camp	-7.4439	144.2239	25
Tipiowo	-7.4616	144.2403	20
Veimake Camp	-7.4074	144.2088	15
Veimei	-7.4089	144.1899	25
Babeio Village	-7.4706	144.2529	11
Lake Kutubu			
KP87*	-6.3250	143.263	838
*most studies were conducted within a radius of 1 km of these coordinates. Additional locations are described and mapped in individual chapters			

Major results

Between 330 and 510 animal and plant species were documented at each of the three locations targeted during these surveys, including a total of approximately 43 species that were previously unknown to science (new species) or that were known but have yet to be scientifically named (undescribed). Numerous species listed in a threat category higher than Least Concern by the IUCN or Protected under PNG law were also encountered. A summary of the major results for each area surveyed is presented below and the total numbers of species documented at each of the three primary survey locations are presented in Tables 2–4.

Wau Creek

Flora

The Wau Creek proposed WMA is floristically rich and the rapid taxonomic inventory conducted there documented over 160 species of vascular plants, collected 59 species vouchers and recorded 94 morpho-species from a plot survey. Noteworthy records include local endemics, new distributional records for poorly-known species, rare taxa of conservation value, four species possibly new to science, and plants of value to local communities.

Butterflies

One hundred and nine butterfly species were recorded in the Wau Creek proposed WMA. Two species, *Kobrona* sp. and *Cephrenes* sp. (both Hesperiidae), appear to be new to science and one species of *Perpheres* (Lycaenidae) was previously known only from two specimens taken in Central Province and remains undescribed. Fifteen species were recorded from Gulf Province for the first time and the previously unknown life histories of five butterfly species were also documented for the first time. The Protected Goliath Birdwing Butterfly (*Ornithoptera goliath*) was observed once, flying high above the canopy and the IUCN Endangered *O. meridionalis* was also recorded in small numbers, especially along the main channel of Wau Creek. Together with the Common Birdwing (*O. priamus*), these butterflies are reared for sale as specimens by some local communities elsewhere in PNG and a sustainable farming program may be an option in the Wau Creek area. Wau Creek retains considerable biodiversity values, supporting a diverse butterfly fauna that includes new, poorly known and conservation significant species.

Dragonflies

Forty-six species of odonates were encountered in the Wau Creek proposed WMA, including 23 species of damselflies (Zygoptera) and 23 species of dragonflies (Anisoptera). Another six species are known from the adjacent Dark End Lumber site, bringing the total number of species from this small area to 52. Two species from Wau Creek (one in the libellulid genus *Nannophlebia* and one in the platycnemidid genus *Nososticta*) are new to science and at least two additional species (in the genera *Bironides* and *Idiocnemis*) are undescribed, but they were each previously known from other sites in south-central PNG. All four of these species were associated with clear-flowing streams in forest. Two species in the taxonomically difficult coenagrionid genus *Teinobasis* may also be new to science but additional studies are required before this can be confirmed. Two species, the damselfly *Nososticta nigrifrons* and the dragonfly *Nannophya paulsoni* are listed as Data Deficient by the IUCN. The diversity of odonates documented at Wau Creek is among the highest reported for any site in New Guinea, and reflects the wide range of high-quality aquatic habitat types available for dragonflies and damselflies there.

Frogs and reptiles

Fifty-one species of herpetofauna were encountered at Wau Creek including 23 frogs and 28 reptiles. Five species of frogs are undescribed and one species of treefrog, *Litoria richardsi*, is classified as Data Deficient by the IUCN owing to its poorly-known distribution and habitat requirements. Two species of large freshwater turtles, The Pig-nosed Turtle (*Carettochelys insculpta*) is classified as Endangered by the IUCN, and the New Guinea Giant Softshell Turtle (*Pelochelys bibroni*) as Vulnerable owing to unsustainable harvesting over at least some of their range. The forests at Wau Creek support a high diversity of frog and reptile species, and the freshwater streams there provide significant habitat for nesting Pig-nosed Turtles. Ongoing protection of these important nesting sites will help to ensure the long-term future of this iconic species in the Kikori basin.

Birds

Birds were surveyed at the Wau Creek proposed WMA in two phases during November– December 2016 and April–May 2017. Survey methods included active searches, camera trapping, mist netting and automated sound recording. The results of bird surveys conducted by Jared Diamond and David Bishop at 'Dark End Lumber' on the Sire River in October 1999 are combined with those of the present study. One hundred and thirty-five bird species have been recorded. Twenty birds from 13 species were mist netted or otherwise captured and 12 bird species were photographed by camera trap. Fourteen conservation listed species were recorded, including three birds listed by the IUCN as Vulnerable (Papuan Eagle (*Harpyopsis novaeguineae*), Scheepmaker's Crowned Pigeon (*Goura scheepmakeri*), Pesquet's Parrot (*Psittrichas fulgidus*)) and 14 species that are Protected under Papua New Guinean law. Camera trap records of Scheepmaker's Crowned Pigeon extend the known geographic range of this restricted-range species west from the Purari basin.

Mammals

The survey of mammals in the Wau Creek proposed WMA was conducted between 22 and 26 April 2017. Non-volant (non-flying) species were sampled using live trapping with Elliott box traps, camera trapping, and spotlighting searches at night. Bats were surveyed by trapping with harp traps and mist nets, and by recording their echolocation calls with electronic bat detectors. The survey resulted in the detection of 11 native non-volant mammal species in 10 genera from four marsupial families (Peroryctidae—1 sp., Macropodidae—1 sp., Phalangeridae—1 sp. and Pseudocheiridae—1 sp.), and one rodent family (Muridae—7 spp.). The most significant non-volant mammal species encountered was the Grey Dorcopsis (*Dorcopsis luctuosa*), which is listed by the IUCN as Vulnerable because of a declining population size from over-hunting. A total of 22 bat species was detected on the survey, none of which are conservation listed by the IUCN. Although the taxonomy of many bat species remains unresolved, it appears that up to eight of the species detected at Wau Creek may be undescribed. The detection of 33 mammal species over a four-night period is indicative of a diverse and intact mammal assemblage that is worthy of conservation.

Table 2. Total number of species documented during the 2017 Kikori basin survey at Wau Creek, number estimated to be new to science or undescribed, and the number of species listed by the IUCN with a threat classification greater than Least Concern.

Wau Creek	Plants	Butterflies	Dragonflies	Frogs & reptiles	Birds	Mammals	TOTALS
Total species	160	109	46	51	110	33	509
New & undescribed species	4	3	4	5	0	8	24
IUCN conservation listed species	4	1	2	3	2	1	13

Uro Creek

Flora

The Uro Creek catchment is floristically rich and this rapid taxonomic inventory documented over 95 morpho-species of vascular plants, and collected 64 specimen vouchers. The flora is dominated by species typical of New Guinea lowland alluvial forests, especially swamp and riverine species. Noteworthy records include local endemics, new distributional records for poorly-known species including at least one new record for PNG, two species classified as Vulnerable by the IUCN, and plants of value to local communities.

Butterflies

One hundred and seventeen butterfly species were documented at Uro Creek. One species of *Perpheres* (Lycaenidae) is undescribed and 20 species were recorded from Gulf Province for the first time. The previously unknown life histories of six butterfly species were also documented. The IUCN Endangered Southern Tailed Birdwing Butterfly (*Ornithoptera meridionalis*) was observed at Tipiowo and Veimake. Together with the Common Birdwing (*O. priamus*), these butterflies are reared by some local communities elsewhere in PNG as a source of income and a sustainable ranching program could be viable in the Uro Creek area. Uro Creek has considerable biodiversity values, with a diverse butterfly fauna that includes poorly known and conservation significant species.

Dragonflies

Twenty five species of odonates were encountered in the Uro Creek catchment, including 10 species of damselflies (Zygoptera) and 15 species of dragonflies (Anisoptera). Three species, including one in the argiolestid genus *Metagrion*, one in the coenagrionid genus *Pseudagrion* and one in the platycnemidid genus *Idiocnemis*, are undescribed. These species were previously known from several other sites in Gulf Province but were unnamed. All are associated with clear-flowing streams in forest. Although less diverse than the odonate community at Wau Creek, the Uro Creek area provides important habitat for a moderately diverse and poorly known fauna that includes several undescribed species. Small streams isolated from the tidal influence of the main Uro Creek channel are particularly important habitats for this odonate assemblage.

Frogs and reptiles

Twenty-seven species of native herpetofauna were encountered in the Uro Creek catchment, including 14 frogs and 13 reptiles. The introduced Cane Toad (*Rhinella marina*) was also encountered in cleared areas along Uro Creek. At least one, and probably two, species of frogs are undescribed and one species of treefrog, *Litoria sauroni*, is classified as Data Deficient by the IUCN owing to its poorly-known distribution and habitat requirements. The IUCN-Endangered Pig-nosed Turtle (*Carettochelys insculpta*), was observed on several occasions and the IUCN-Vulnerable New Guinea Giant Softshell Turtle (*Pelochelys bibroni*) is known to occur in the local waterways although it was not encountered during this survey. The moderately diverse herpetofauna documented during this survey included mangrove, freshwater, and terrestrial species. This high ecological diversity among species has been generated by the complex of different, interconnected ecosystems within the catchment. Any moves to establish a community-based protected area within the catchment should strive to capture as many of these inter-connected forest and swamp ecosystems as possible.

Birds

Birds were surveyed at Uro Creek during 27 April–3 May 2017 using active searches, camera trapping, mist netting and automated sound recording. The results of bird surveys conducted at Uro Creek by Ian Burrows in October 1995 are combined with those of the present study to produce a total of 126 bird species for the catchment. Twelve conservation listed species have been recorded, including two birds listed by the IUCN as Vulnerable (Pesquet's Parrot (*Psittrichas fulgidus*)) or Near Threatened (Sclater's Crowned Pigeon (*Goura sclaterii*)) and 12 species that are Protected under Papua New Guinean law. Local records of Sclater's Crowned Pigeon extend the known geographic range of this IUCN listed species. The Uro Creek catchment supports an ecologically diverse ecosystem-complex that includes a variety of well-connected forest types. The forest bird community is therefore both species rich and displays a high level of beta diversity.

Mammals

The mammal survey in the Uro Creek catchment between 28 April and 3 May 2017 used a range of field techniques including live trapping with Elliott box traps, camera trapping, spotlighting searches at night, harp traps, mist nets and electronic bat detectors. The survey detected nine native non-volant mammal species in eight genera from three marsupial families (Peroryctidae—1 sp., Macropodidae—2 spp., Phalangeridae—1 sp.), and one rodent family (Muridae—5 spp.). In addition, one non-native species, the Pig (*Sus scrofa*), was detected. Additional trapping in Babeio village also detected the Black Rat (*Rattus rattus*), which is an introduced pest species. The most significant non-volant mammal species encountered were the Goodfellow's Tree Kangaroo (*Dendrolagus goodfellowi*; IUCN Endangered) and the Grey Dorcopsis (*Dorcopsis luctuosa*; IUCN Vulnerable). A total of 25 bat species was also detected on the survey one of which, *Rhinolophus mcintyrei*, is listed as Data Deficient by the IUCN. Although the taxonomy of many bat species remains unresolved, it appears that up to eight of the species detected at Wau Creek may be undescribed. The detection of 34 native mammal species over a five-night period is indicative of a diverse and intact mammal assemblage that is worthy of conservation, and numerous additional species are expected to occur within the catchment.

Table 3. Total number of species documented during the 2017 Kikori basin survey at Uro Creek, number estimated to be new to science or undescribed, and the number of species listed by the IUCN with a threat classification greater than Least Concern

Uro Creek	Plants	Butterflies	Dragonflies	Frogs & reptiles	Birds	Mammals	TOTALS
Total species	95	117	25	27	116	34	414
New & undescribed species	0	1	3	1+	0	8	13
IUCN threatened species	4	1	0	2	2	2	11

Lake Kutubu

Flora

The forests within the Lake Kutubu WMA are floristically rich, with approximately 70 species documented in just two days including two new or undescribed species. A number of other noteworthy plants were detected, including species with limited known distributions. Although the forest interior gives the impression of a montane forest, with a prevalence of mosses and other epiphytes, the tree flora is dominated by common lowland rainforest species and few upper montane taxa are present.

Butterflies

Fifty butterfly species were recorded at Lake Kutubu during this survey. Three additional, conservation significant birdwing butterflies, the PNG-Protected Butterfly of Paradise (*Ornithoptera paradisea*), the PNG-Protected Goliath Birdwing (*Ornithoptera goliath*) and the IUCN Endangered, PNG-Protected Southern Tailed Birdwing (*Ornithoptera meridionalis*) (Papilionidae), have been recorded previously at Lake Kutubu, as well as two other Birdwing species, the Common Green Birdwing (*Ornithoptera priamus*), and the Oblong-spotted Birdwing (*Troides oblongomaculatus*). Six species were recorded from Southern Highlands Province for the first time. One of those, *Mycalesis biformis* (Nymphalidae), was only very recently recorded from PNG for the first time. The Lake Kutubu WMA is a particularly important site for butterflies because five Birdwing species are known to occur there. It was considered as one of five potential reserves in PNG for the PNG-Protected Butterfly of Paradise (*Ornithoptera paradise*), and for the IUCN-Endangered Southern Tailed Birdwing (*Ornithoptera meridionalis*).

Dragonflies

Twenty-nine species of odonates were encountered in the Lake Kutubu WMA, including 14 species of damselflies (Zygoptera) and 15 species of dragonflies (Anisoptera). Two species, one in the argiolestid genus *Wahnesia* and one in the platystictid genus *Drepanosticta*, are new to science. They were discovered for the first time during this survey and are currently known only from forest adjacent to Lake Kutubu. One additional species in the coenagrionid genus

Pseudagrion is undescribed, but was previously known from other sites in south-central PNG and was also collected at Uro Creek during the 2017 surveys. All three of these species are associated with clear-flowing streams in forest. One species, the platycnemidid damselfly *Nososticta finisterrae*, that was found along small streams near the lake is listed as Data Deficient by the IUCN and another, *N. conifera*, was previously known only from the Lakekamu Basin ~390 km to the southeast. These results indicate that the Lake Kutubu WMA is an important site for new and poorly-known odonate species, and additional species are expected to occur there.

Frogs and reptiles

Twenty-six species of herpetofauna were encountered at Lake Kutubu including 19 frogs and 7 reptiles. Ten species of frogs (52.6%) are undescribed and one of these represents a new genus that is currently known only from the Lake Kutubu-Agogo Range area. The extremely high proportion of undescribed frogs encountered during the survey reflects the incomplete state of knowledge about frogs in the central mountains of PNG. The forests of the Lake Kutubu WMA support important populations of a number of frog species that are undescribed or have small known distributions.

Birds

Birds were surveyed at the Lake Kutubu WMA during 6–18 May 2017. Survey methods included active searches, camera trapping, mist netting and automated sound recording. The results of prior bird surveys conducted in the area are combined with those of the present study. Two hundred and sixteen bird species have been recorded within and immediately adjacent to the WMA, including 127 species during the 2017 surveys. Eighteen conservation listed species have been recorded, including seven species listed by the IUCN as Vulnerable (Papuan Eagle (*Harpyopsis novaeguineae*), Pesquet's Parrot (*Psittrichas fulgidus*)) or Near Threatened (Gurney's Eagle (*Aquila gurneyi*), Grey-tailed Tattler (*Tringa brevipes*), Red-necked Stint (*Calidris ruficollis*), Striated Lorikeet (*Charmosyna multistriata*), Banded Yellow Robin (*Poecilodryas placens*)) and 13 species that are Protected under Papua New Guinean law. Three restricted-range bird species are confirmed present— Striated Lorikeet, Greater Melampitta (*Megalampitta gigantea*) and Banded Yellow Robin. The Lake Kutubu WMA supports an ecologically diverse ecosystem-complex that includes a variety of well-connected forest and wetland types. The forest bird community is species rich and includes species typically representative of lowland, hill and montane forest environments.

Mammals

This survey documented the mammal fauna of the Lake Kutubu WMA in both regrowth and primary forest. The survey was conducted between 6 and 9 May 2017 using a range of field techniques including live trapping with Elliott box traps, camera trapping, spotlighting searches at night, harp traps, mist nets and electronic bat detectors. Six native non-volant mammal species in six genera from two marsupial families (Peroryctidae—1 sp., Macropodidae—1 sp.), and one rodent family (Muridae—4 spp.) were detected. The most significant non-volant mammal species encountered was the Small Dorcopsis (*Dorcopsulus vanheurni*), which is listed by the IUCN as Near Threatened because of a declining population size from over-hunting. Pigs (*Sus scrofa*) and dogs (*Canis familiaris*) were also detected on camera traps. A total of 22 bat species was detected, one of which, the horseshoe bat *Rhinolophus mcintyrei*, is listed as Data Deficient. Although the taxonomy of many bat species remains unresolved, it appears that up to eight of the species detected at Wau Creek may be undescribed. The Lake Kutubu WMA features the largest mid-altitude lake in Oceania, and protects remarkable mid-altitude forest habitats that accommodate some of New Guinea's largest mammals.

Table 4. Total number of species documented during the 2017 Kikori basin survey at Lake Kutubu, number estimated to be new to science or undescribed, and the number of species listed by the IUCN with a threat classification greater than Least Concern.

Lake Kutubu	Plants	Butterflies	Dragonflies	Frogs & reptiles	Birds	Mammals	TOTALS
Total species	~70*	50*	29	26	127	28	330
New & undescribed species	2	0	3	10	0	8	23
IUCN conservation listed species	0	1	1	0	4	1	7
*Survey effort at Lake Kutubu was much lower than at the other two sites							

Overall conclusions and recommendations

The three areas targeted during the 2017 surveys represent a range of different habitats and species assemblages at low to middle elevations within the Kikori River basin; from the foothill and lowland alluvial forests at Wau Creek to the swamp forests of the Uro Creek catchment and mossy hill and lower montane forests of Lake Kutubu. They also represent different stages of community-based protected area development and management, from initial expressions of interest at Babeio (Uro Creek) to advanced stages of planning for a WMA at Wau Creek, and a gazetted WMA at the Ramsar-listed Lake Kutubu.

Each of these areas retains significant biodiversity values, harbouring undescribed and poorly known flora and fauna, conservation-significant species, and plants and animals of cultural value to local communities. They provide hope for the long-term future of this significant biodiversity in the face of increasing pressure from logging and other extractive industries.

Specific taxon-related recommendations are presented in individual chapters and some overall conclusions and recommendations are listed here.

- The Kikori basin is recognised as one of the world's most biologically diverse and endemically rich terrestrial regions;

- In order to ensure the long-term survival of this globally significant biodiversity, future logging within both proposed and existing community-based protected areas should be prevented;

- For protected areas under consideration, effort should be made to include the largest possible extent of unlogged forest, and the maximum representation of different forest ecosystems, when determining protected area boundaries;

- To ensure their long-term sustainability, community-led comprehensive management plans should be developed for proposed protected areas. These should include strategies to minimise the impacts of hunting and feral animals (including hunting dogs and feral dogs) on biodiversity values.

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Plate 1

A. Extensive lowland forest in the Kikori River basin

B. Hanging a butterfly bait trap at Wau Creek

C. Dragonfly team at Wau Creek

D. Rearing butterfly larvae at Wau Creek research station

E. Babeio community meeting

F. Babeio community meeting

Plate 2

A. Enock Kale examining Tree kangaroo skins at Babeio Village

B. Iain Woxvold photographing Crowned Pigeon at Uro Creek

C. A giant fig tree at Lake Kutubu

D. Kyle Armstrong with bat detectors at Lake Kutubu

E. Anita Mosby assisting with flora survey at Lake Kutubu

F. Iain Woxvold and Leo Legra documenting birds from the forest edge

Section 1. Wau Creek

Nest of Pig-nosed Turtle at the Wau Creek proposed Wildlife Management Area.

The 2017 Wau Creek biodiversity survey team.

The Wau Creek research station.

Frank John and family at the research station with map of the proposed WMA.

Forest interior adjacent to the Wau Creek research station.

Access to Wau Creek research station in dry weather.

Access to Wau Creek research station following heavy rain.

Chapter 1.1. Flora of the Wau Creek proposed Wildlife Management Area, Gulf Province, Papua New Guinea

Osia Gideon

Forest interior adjacent to the research station at Wau Creek

Summary
This report describes the broad vegetation types and floristics of the Wau Creek area based on a survey carried out to support its gazettal as a Wildlife Management Area (WMA). The proposed WMA is located in the upper reaches of Wau Creek, one of several tributaries of the Sirebi River which flows into the Kikori River.

Based on the PNG Forest Inventory Mapping System (FIMS) the vegetation at Wau Creek is lowland rainforest of two broad types containing patches of swamp forest. Plant communities were ground-truthed against the FIMS classification and they are described here in some detail.

The flora of the area is dominated by species typical of lowland alluvial forests in New Guinea, with a few representative hill species and some swamp and riverine species also present. The area falls within the Sirebi Lowlands bioregion. The Wau Creek proposed WMA is floristically rich and the rapid taxonomic inventory reported here documented 169 species of vascular plants, collected 59 vouchers and recorded 94 morpho-species from a plot survey. Noteworthy records include local endemics, new distributional records for poorly-known species, rare taxa of conservation value, four species possibly new to science, and plants of value to local communities. Higher risk IUCN listed species sighted or known to occur in the area are listed and a preliminary species list for the area is provided.

Introduction
Considering its significance as a global centre of plant diversity, the flora of New Guinea (also true for the broader Papuasian region) remains poorly known (Gideon 2015 and references therein). Using the 'collecting density index' or CDI (herbarium collections/100 km^2) as a measure of how well a flora is known, areas with 50–100 specimens/100 km^2 are generally considered to be well collected. On that basis most of New Guinea remains poorly collected (Stevens 1989). In 1950 the CDI for New Guinea was 12 (slightly higher in PNG), by 1972 it had risen to 26 (much higher in PNG) and in 1989 it stood at 46, but the lack of botanical activity in the rest of Papuasia means the regional CDI was closer to 30 (Frodin 1990). The 'ideal' CDI for any area is around 100, but at the present rate of collecting in New Guinea it will take many years to reach this level and as a result Prance and Campbell (1988) have identified New Guinea as a world priority for future botanical work.

Botanical exploration within New Guinea has been very uneven, and Takeuchi (2007) reported that sampling intensity of the island's flora was 300% higher in PNG than in the Indonesian Provinces and the holdings of the PNG National Herbarium stood at about 400,000 specimens compared to the modest 30,000 in Indonesian Papua Province (currently Papua and West Papua). There has also been considerable spatial variation in survey effort within PNG (Takeuchi and Golman 2001). At the time of their publication, almost half of the National Herbarium collections came from the Momase region, of which 28% came from Morobe Province where the National Herbarium is located. The provinces that were (and remain) grossly under-represented included Gulf, Northern, New Ireland, East New Britain, Manus, and Enga. Takeuchi and Golman (2001) argued that these provinces should be targeted in future botanical explorations to fill the gaps. The knowledge of New Guinea's flora remains so poor that new species continue to be discovered and described, and many species are known only from one or very few specimens. Basic data such as species distributions, population variations and rarity are known only for a very few species.

The southern karst region has often been identified as one of the areas' most in need of botanical exploration (Prance 1977; Stevens 1989; Johns 1993), and the Kikori basin and adjacent uplands was identified as the largest of 16 biodiversity unknowns in PNG by Sekhran and Miller (1995). The oil and gas projects in the region have commissioned a number of biodiversity surveys as part of their Environmental Impact Statements (EIS) and these surveys have made major contributions to the present state of biodiversity knowledge for the area. Data from these surveys supplement the series of studies carried out by WWF and its collaborators, and together provide major contributions to the biodiversity knowledge of the region. All of these studies were carried out by reputable scientists with PNG experience.

Botanical surveys in upland areas of the Kikori basin were carried out mostly by Wayne Takeuchi, who spent over 20 years collecting and studying the flora of New Guinea, mostly in PNG but also in the western half of the island. Other botanists that have contributed to knowledge of the flora in the Kikori basin include Lawong Balun (Unitech), Olo Gebia (WWF), Pius Piskaut (UPNG), the orchid specialists Mark Clements (Australian National Herbarium, Canberra) and Wayne Harris (Queensland Herbarium, Brisbane), and palm specialists William Baker and Kathleen King of the Royal Botanic Gardens, Kew (United Kingdom), and Roy Banka from the PNG Forest Research Institute. Most produced reports for WWF documenting their important discoveries (Baker 1997; Balun and Gebia 1998; Baker et al. 2000; Gebia and Balun 2000; Harris 2003).

The Kikori River basin is recognised as one of the most important areas of forest and wetlands biodiversity in the Asia/Pacific region (WWF 2015). It is huge, extremely diverse and heterogeneous, and it ranges from sea level to peaks reaching over 3,000 m asl. The area encompasses diverse geologies, geomorphologies, soils and habitats, with great heterogeneity in biodiversity composition. Within the basin is the exceptional Ramsar site of Lake Kutubu, and furthermore, the Kikori River basin and the Great Papuan Plateau has been proposed by the PNG Government (Conservation and Environmental Protection Authority or CEPA) as a possible UNESCO World Heritage site (https://whc.unesco.org/en/tentativelists/5060/). Even though Lake Kutubu is a Ramsar listed wetland, to date it has no specific wetland management plan and it is currently managed as a WMA. Formally gazetted conservation areas in the Kikori basin include the Lake Kutubu WMA and Neiru/Aird Hills WMA. WWF has produced a useful Kikori River Basin Conservation Blueprint (WWF 2015), which the local communities and PNG Government are encouraged to use to plan for development and biodiversity conservation in the area.

During the 1990s WWF implemented the Kikori Integrated Conservation and Development Project (KICDP) with the support of oil and gas projects. The KICDP area of focus encompassed the entire drainage of the Kikori River, extending over 300 km from the high mountain peaks of Hela and Southern Highlands Provinces to the coast in Gulf Province. In addition to the surveys described above the KICDP also raised community awareness on the negative impacts of industrial-scale logging, assisted Lake Kutubu communities to develop a community-driven fish management strategy, assisted with the establishment of WMAs and assisted community groups to establish eco-enterprises.

The aims of this study were to characterise the terrestrial vegetation communities (type and condition) of Wau Creek, document species of conservation and cultural significance, especially species that are rare, threatened (i.e. nationally protected or IUCN-listed), endemic or undescribed and note the presence and location of invasive plant species, especially species known to be a major threat to natural ecosystems.

Methods

Survey Site

The Wau Creek proposed WMA is located on Wau Creek, a tributary of the Sire River which flows into the Sirebi River and ultimately into the Kikori River. Wau Creek and other tributaries drain the western and southern slopes of Mt. Duau. This is a lowland region consisting of mixed sedimentary hills and alluviums. The vegetation is typical lowland rainforest with a few swamp pockets, but mangroves are absent. Parts of the proposed WMA were logged about nine years ago. The forest is within the Kikori Block 2 forest concession, currently under Forest Management Agreement (FMA). The FMA has a gross area of 486,634 ha, and it is due to expire in May 2045.

Flora surveys were carried out within a radius of approximately 500 m of the Wau Creek research station, but boat-based 'drift' surveys extended up to 3.5 km upstream along the Sire River from the junction with Wau Creek (Figure 1), covering altitudes of approximately 20–24 m asl.

Floristic survey methods

The floristic survey was conducted following the rapid-assessment method developed by Conservation International for their Rapid Assessment Program (RAP), which has since been adopted by most floristic surveys in PNG (Mack 1998; Beehler and Alonso 2001; Takeuchi 2008). Descriptions of plant communities follow the PNG Forest Inventory Mapping System (FIMS).

The botanical survey was conducted by the author plus several local assistants and consisted primarily of opportunistic collecting of vascular plants in flower and/or fruit, recording presence of species using a notebook and camera, and plot studies. Two 50 X 20 m (0.1 ha) plots were established to obtain a more quantitative estimate of species alpha diversity and forest structure. These plots were established in forest near the research station (at 7.12104°S, 144.37401°E).

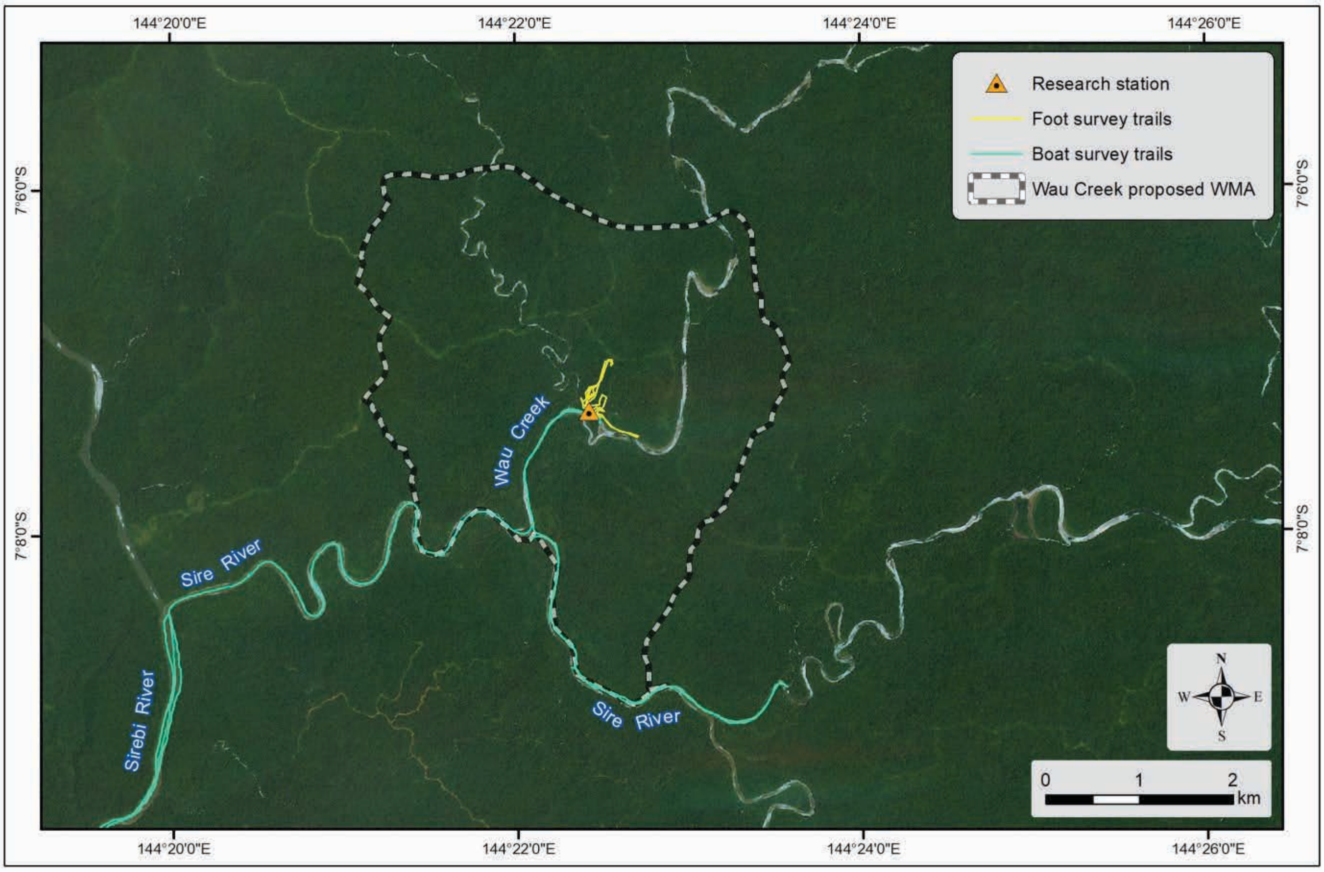

Figure 1. Flora sampling trails and river drift routes along Wau Creek and the Sire River.

Opportunistic botanical collecting was mostly conducted along a series of pre-established forest trails radiating from the research station (Figure 1). A total of three days were spent collecting along these trails, as well as conducting plot studies. One of the most productive methods for encountering interesting plants was the 'river drift' method, where two half-days were spent drifting slowly along Wau Creek and Sire River collecting and studying flowering and fruiting plants that were more easily observed from the boat than when trekking through dense forest.

Botanical collecting focused on fertile (flowering and/or fruiting) taxa considered significant for one reason or another. These included potentially new or rare species, range extensions, unidentified species, and other species of taxonomic interest. Vouchers were retained primarily for further identification in the herbarium. Unfortunately, vouchers from larger trees could not be made because their flowers and fruit were mostly out of reach. Due to logistical constraints, in most cases only 3–5 duplicates were collected for each vouchered species. Voucher material was also photographed and detailed notes were made in the field. Most plants were identified at least to genus level in the field, and vouchers requiring additional study for identification were examined further at the National Herbarium (PNG Forest Research Institute).

Botanical specimens were dossed in ethanol (diluted to about 70%) and were shipped to Port Moresby where they were dried at the UPNG Herbarium and later freighted to the PNG National Herbarium in Lae for identification. Duplicates of vouchers will be distributed to other herbaria after final identifications have been made.

Two 50 X 20 m (0.1 ha) plots were established. In each plot the diameters at breast height (DBH) of all trees ≥10 cm DBH were measured to calculate basal area (BA) and estimate tree stocking and timber volume for the area. The log lengths for trees ≥50 cm DBH and tree heights were estimated to the nearest 1 m. Small plants (<10 cm DBH) in the plots were sub-sampled in 5 X 5 m quadrats (Plate 1A). Epiphytes (mainly orchids and ferns) which mostly occur on canopy branches were not assessed.

The area was surveyed for the presence of exotic plants, especially well-known invasive species like *Piper aduncum*, *Spathodea campanulata*, and other aquatic weeds.

Vegetation Mapping

Vegetation mapping of the area follows the PNG Forest Inventory Mapping System (FIMS), which recognises 63 major vegetation types for Papua New Guinea (Hammermaster and Saunders 1995). Most recent biodiversity surveys in PNG followed this system, which was based on Saunders (1993), mainly because it was easily applied in mapping. The system is based on aerial photography and remote sensing, and therefore gave detailed information on forest structure and species composition. Base maps used were the 1:100,000 series topographic maps provided by the PNG National Mapping Bureau. However, plot work and ground truthing often helped to provide a more reliable description of the unique forest types.

The generalised floristic lists for the different forest types and areas in Hammermaster and Saunders (1995) were collated from Paijmans (1976), various CSIRO Land Survey reports for the areas covered, and Department of Forests forestry resource surveys. Unfortunately the scale of the FIMS maps, a system generally available only in 1:250,000 scale maps, does not allow the recognition of small but distinct vegetation communities. Plant communities at the study site were therefore ground-truthed against the FIMS classification and are described below.

Results

The Wau Creek proposed WMA falls within WWF's Southern New Guinea lowland rainforest terrestrial ecoregion, and more narrowly within the Sirebi Lowlands 'bioregion' as defined by Crome et al. (2008). The Sirebi Lowlands are described as:

'*A complex lowland bioregion in the drainage of the Sirebi River, consisting of mixed sedimentary hills, alluviums, polygonal karst and limestone ridges, with 40–400 m elevation. The vegetation is typical lowland rainforest types, few swamp forests, but mangroves are absent. The biota is typically lowland rainforest, but probably with increasing presence of hill species towards the foothills and raised plateaus*.'

Forest types in the Wau Creek proposed WMA

Hammermaster and Saunders (1995) recognized 17 vegetation types within the broad Aramia/Kikori and Kerema forest zones. The Kikori River forms the boundary between the Aramia/Kikori to the west and Kerema to the east, and even though Wau Creek falls within the Kerema forest zone these forest zones are not easily distinguished in this transition zone because the zones merge gradually. Within the general area of Wau Creek, are two broad FIMS types: **Pl**—large crowned alluvial forest; and **Hm**—medium crowned hill forest. Ground truthing of the Wau Creek area indicates the presence of swamp forests in low lying areas along the creeks as well a large area east of the research station (upstream). The areas recognized by Saunders (1993) as **Hm9** are actually **Fsw** and include some newly exposed land created by shifting river courses, which have been colonised by pioneer species.

Pl/Fsw – Large to medium crowned forest in low altitude forests on plains and fans (below 1,000 m)/Mixed swamp forest

Large to medium crowned forest (**Pl**) on alluvial plains is the dominant vegetation type around the proposed Wau Creek WMA, with small pockets of **Fsw** along the rivers, creeks and other low lying areas. The forest occurs on well to imperfectly drained alluvial plains that are frequently flooded. The canopy height is 30–35 m, with emergents to 40 m (mainly of *Octomeles sumatrana* as best observed further by some conspicuous examples further away from Wau Creek).

Species composition of **Pl** is similar to **Hm**, with dominant tree species including *Pometia*, *Canarium*, *Terminalia*, *Syzygium*, *Pouteria*, *Terminalia*, *Pterocarpus*, *Pterocymbium*, and *Dysoxylum*. The lower strata are dominated by taxa such as *Dysoxylum*, *Myristica*, *Ficus*, *Canarium*, *Elaeocarpus*, *Cryptocarya*, *Harpulea*, *Barringtonia*, *Celtis*, *Dysoxylum*, and other species. Common tree species in **Fsw** forests include *Nauclea orientalis*, *Bischofia javanica*, *Barringtonia*, *Myristica*, *Artcarpus altilis*, *Endospermum*, *Cananga odorata*, *Euodia* and *Trichospermum*. Rattans (mainly *Calamus* spp.) are common throughout the area, mainly due to disturbance from logging. Sago palm (*Metroxylon sagu*), usually a common feature of this vegetation type, is visibly absent. Herbaceous plants are common on the forest floor, dominated by gingers (*Alpinia*, *Riedelia*, *Pleuranthodium*, *Phrynium*, and *Hellenia*), aroids (*Alocasia*, *Cyrtosperma*, *Homalomena*, *Schismatoglottis*) and terrestrial ferns. The river banks are colonized by grasses and sedges such as *Phragmites karka*, *Saccharum*, *Cyperus*, *Pennisetum* and other grasses, along with *Polygonum*, *Ludwigia* and other herbs and shrubs.

Hm – Medium crowned forest in low altitude forests on uplands (below 1,000 m)

Hm is the dominant vegetation type throughout the Aramia/Kikori and Kerema forest zones (Hammermaster and Saunders 1995), with pockets of other vegetation types distributed within it. In the Wau Creek area **Hm** forest occurs on raised well drained areas towards the boundaries of the proposed WMA.

The canopy height of **Hm** ranges from 25–35 m, with emergents reaching up to 40 m. Dominant tree species include *Pometia*, *Canarium*, *Buchanania*, *Syzygium*, *Pouteria*, *Palaquium*, *Terminalia*, *Pterocymbium*, and *Dysoxyllum*. Understory tree species include *Harpulea*, *Saurauia*, *Ardisia*, *Barringtonia*, *Ixora*, *Atractocarpus*, *Euodia*, *Ficus*, *Myristica* and other small tree species. Rattans are less common, while herbaceous plants are common on the forest floor, dominated by gingers (*Alpinia*, *Riedelia*, *Pleuranthodium*, *Phrynium*, and *Hellenia*), aroids (*Alocasia*, *Cyrtosperma*, *Homalomena*, *Schismatoglottis*) and terrestrial ferns.

One hundred and sixty nine species of vascular plants were documented during this survey. Common canopy species include *Pometia pinnata, Octomeles sumatrana, Anisoptera thurifera, Alstonia scholaris, Canarium, Syzygium,* and *Terminalia* spp. Common lower canopy taxa include *Pterocarpus indicus, Pouteria, Canarium, Elaeocarpus, Cryptocarya, Celtis, Dysoxylum*, and other species.

Because only two plant plots were studied, forest structure and tree diversity can only be discussed in general terms. Comparisons are made with other studies in New Guinea, although plot sizes of the other studies vary greatly, ranging from 0.1 ha (present study) to 2.4 ha. Tree density and diversity from available studies, including a single plot at Uro Creek established during the 2017 survey, are summarised in Table 1.

Table 1. Tree density, species diversity and basal area from various study sites in New Guinea

Study Site	Sample Size (ha)	Altitude (m)	No. of Species	No. of stems ≥ 10 cm dbh/ha	Basal Area (m^2/ha)	Reference
Wau Creek Plot 1	**0.1**	**24**	**42**	**790**	**48**	**Present study**
Wau Creek Plot 2	**0.1**	**24**	**35**	**640**	**28**	**Present study**
Uro Creek	**0.1**	**12**	**24**	**380**	**30**	**Present study**
Crater Mtns., Simbu Province	1.0	850-1350	228	693	37.1	Wright et al. (1997)
Si River, Lakekamu Basin, Gulf Province	1.0	60	93	392	49.32	Oatham & Beehler (1997)
Nagore N, Lakekamu Basin, Gulf Province	1.0	70	149	426	37.67	Oatham & Beehler (1997)
Nagore S, Lakekamu Basin, Gulf Province	1.0	70	178	482	28.72	Oatham & Beehler (1997)
Alluvial, Lakekamu Basin, Gulf Province	1.0	175	182	575	28.46	Reich (1998)
Hill, Lakekamu Basin, Gulf Province	1.0	260	156	759	32.04	Reich (1998)
Woodlark Is., Milne Bay Province	0.52	10-150	142	608	30.4	Gideon (2010)
Nakanai Mtns, E New Britain Province	1.4	200-1600	382	216	67.5	Balun et al. (2000)
Hill Forest,	2.4	n/a	n/a	526-652	30.8	Paijmans (1970)
Alluvial Forest	0.8	n/a	n/a	430	n/a	Paijmans (1970)
Foja Foothills, Memberamo, W Papua	?vars. sizes	?	127	598	32.4	Van Heist et al. (2010)
Ayawasi, W Papua	2.2	?	415	805	35.8	Polak (2000)

Extrapolating from the raw data, the basal area (BA) for the Wau Creek forests is estimated to be about 38 m^2/ha, and an average merchantable timber volume of about 180 m^3/ha (Plot 1: 306 m^3/ha and Plot 2: 54 m^3/ha). The tree density for stems ≥ 10 cm DBH was about 715 trees/ha, and for trees ≥ 50 cm DBH about 40 trees/ha. The most common trees in the plots, with more than 5% dominance were *Myristica* (11%), *Ficus* (8%), *Dysoxyllum* (6%) and *Macaranga* (6%). Other genera with more than 2% representation are shown in Table 2.

The dominance of pioneer tree species in the plots indicates disturbance. Even though the plots were established in unlogged forest, they were less than 50 m from abandoned snig-tracks and logging roads, which are clearly visible in Bing and Google Earth maps.

Table 2. The dominant tree genera at Wau Creek (≥ 2% of the tree flora)

Family	Genus (number of morpho-species)	Number of Trees	Dominance (%)
Myristicaceae	*Myristica* (5–6 spp.)	16	11.2
Moraceae	*Ficus* (6–8 spp.)	12	8.4
Meliaceae	*Dysoxyllum* (3–4 spp.)	8	5.6
Euphorbiaceae	*Macaranga* (3 spp.)	8	5.6
Lauraceae	*Cryptocarya* (4–5 spp.)	7	4.9
Elaeocarpaceae	*Elaeocarpus* (2 spp.)	7	4.9
Meliaceae	*Aglaia* (4–5 spp.)	6	4.2
Burseraceae	*Canarium* (3 spp.)	6	4.2
Sapotaceae	*Pouteria* (3–4 spp.)	6	4.2
Loganiaceae	*Neuburgia* (1 sp.)	5	3.5
Anacardiaceae	*Buchanania amboinicum*	4	2.8
Rutaceae	*Euodia* (2 spp.)	4	2.8
Lauraceae	*Litsea* (2 spp.)	4	2.8
Sapindaceae	*Pometia pinnata*	4	2.8
Meliaceae	*Chisocheton* (2 spp.)	3	2.1
Malvaceae	*Pterocymbium (*1 sp.)	3	2.1
Icacinaceae	*Rhyticaryum* (1 sp.)	3	2.1
Lamiaceae	*Teijmanniodendron bogoriense*	3	2.1

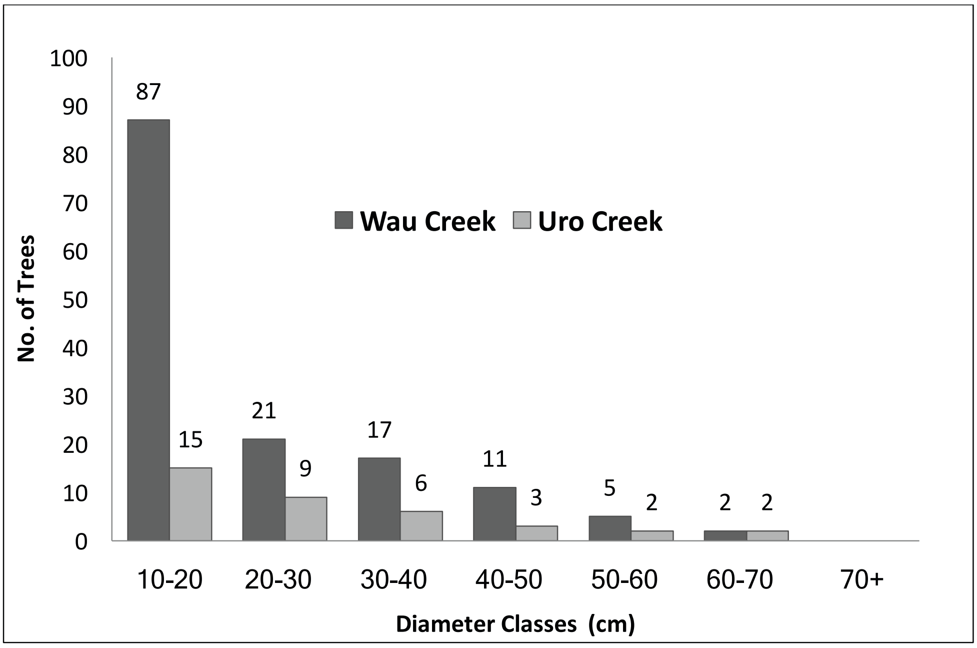

Figure 2. Tree size class distribution (trees ≥ 10 cm DBH) for Wau Creek. Uro Creek is also shown for comparison.

The size class distribution curve for the area shows the typical L-shape for mixed tropical rain forests (Figure 2). The two Wau Creek plots are combined to show size class distribution, and are compared with the Uro Creek plot. A large proportion of the trees (72%) are in the lower diameter classes (10–30 cm DBH), with only 6% of trees reaching merchantable size classes (50+ cm DBH). Although the sample size is small compared to other studies, the raw data and extrapolations from these fall within the general ranges for New Guinea (Table 1), and also from other tropical regions of the world (Paijmans 1970, 1976; Wright et al. 1997; Oatham and Beehler 1997; Reich 1998).

Table 3. Number of taxa recorded from the Wau Creek plots

Group	Families	Genera	Species
Dicotyledons	28	49	81
Monocotyledons	5	7	7
Gymnosperms	1	1	1
Pteridophytes	4	4	5
	38	61	94

During the biodiversity survey at Wau Creek 59 specimens, representing approximately the same number of morpho-species, were collected. Unfortunately, most large trees in flower or fruit were not sampled because fertile material was out of reach; sadly such species are not well represented in existing collections. Most trees in plots were only identified to genus level. The number of families, genera and species censused in the plots are presented in Table 3.

The total sample size of 0.2 ha for the Wau Creek plots yielded 94 morpho-species in 61 genera and 38 families. Most genera are represented by a single species, with only a few genera represented by more than three morpho-species (Table 2), a pattern characteristic of tropical forests. The most abundant tree genera were *Myristica, Ficus, Dysoxyllum*, *Macaranga, Cryptocarya* and *Elaeocarpus,* together representing about 25 morpho-species and about 46% of the trees censused. The plant species list generated for Wau Creek and nearby areas (along the Sirebi and Sire Rivers) based on collections, sightings and photographs, and censused in the plots, totalled 169 taxa (Appendix 1).

In a previous study at the Dark End Lumber eco-forestry project area (adjacent to the Wau Creek proposed WMA), Gebia and Balun (2000) assessed two 0.04 ha plots and recorded 32 and 34 trees in the two plots. Extrapolating from their figures, the tree density for the area is around 400 stems/ha, which falls at the higher end of the range reported for New Guinea (Table 1). They recorded the presence of over 160 plant species, in 112 genera and 61 families. The floristic diversity figures are much higher than most similar studies, which is attributed to the sampling protocols applied. They sampled all plants greater than 5 cm DBH and all epiphytes up to 10 m high, whereas most studies censused only trees greater than 10 cm DBH and epiphytes were usually not censused. In another sample (0.2 ha plot) near Gobe at 50 m elevation, Gebia and Balun (2004) recorded 145 species.

Even though a considerable effort has been made over the last 20 years to improve the level of understanding of the biological diversity of the Kikori lowlands, there is no doubt that more work is still required, especially studies on the flora and invertebrates. The kind of intensive plant collecting carried out by Takeuchi (2008) in the upstream region of the PNG LNG project should be replicated in the Kikori lowlands. There has been much speculation about the characteristics of the flora of the Southern New Guinea Lowlands, and this can only be confirmed by detailed floristic studies using both plots and general collecting, and such a program should be undertaken by botanists with extensive New Guinea experience.

A number of noteworthy plant species were encountered in the Wau Creek proposed WMA and these are discussed below.

Noteworthy plants

Noteworthy plant species encountered in the Wau Creek proposed WMA include potential new species, local endemics, range extensions, and several other taxa of conservation value.

Arecaceae (Palms)

***Brassiophoenix drymophloeoides* Burret (Range extension)**

The genus *Brassiophoenix* contains two species, both of which are endemic to PNG. *Brassiophoenix drymophloeoides* is a slender, solitary palm reaching 5–10 m, with large, fishtail-shaped leaflets and a narrow, bluish-green crown shaft. A single plant was seen from the boat about 6 km downstream from where the Sire River joins the Sirebi River. W. Baker (Baker 1111) collected it previously from the Morere logging concession. It is probably widespread but not common in the Kikori area. This species was previously only known from Central, Milne Bay and Oro Provinces. It has not been assessed by the IUCN.

***Calyptrocalyx albertisianus* Becc. (Uncommon)**

Calyptrocalyx albertisianus is one of the larger species of the genus, which is distinguished by its solitary habit, moderate to tall height (up to 15 m), and its regularly pinnate leaves, numerous stamens and ruminate endosperm. A single specimen was observed in the gorge upstream from the logging camp along the Sirebi River. W. Baker collected it recently in the Gulf lowland swamp forests (Baker 1101, Baker 1109). It is known from several locations in PNG: West and East Sepik, Western, Gulf, Eastern Highlands, Morobe, Central, Milne Bay, New Britain, and New Ireland Provinces. Although *C. albertisianus* is widespread, it is not common (Dowe and Ferrero 2001). The species is highly ornamental and well known to palm enthusiasts, and it is common in private collections and in many tropical botanical gardens. Its conservation status has not been assessed by the IUCN.

***Heterospathe macgregorii* (Becc.) H.E. Moore (Limited distribution; Plate 1B–C)**

A beautiful rheophytic palm that is abundant in parts of the Kikori lowlands. It forms dense clumps along the river banks, especially on limestone. Stems are 5–7 m tall, often crooked, and lean over the water. It is very conspicuous with its red ripe fruits bunches. This species has a limited known distribution, but is common along the Kikori River and its tributaries, including the Sirebi River (pers, observ.). Baker et al. (2000) reported that the species is conspicuous on the Kikori and Sirebi rivers, but less frequent on the Mubi River. The species was also observed at A'oo Creek, a branch of Uro Creek, during the 2017 surveys. It is now known to occur in Gulf (Kikori lowlands), Western, and Southern Highlands (Mubi River) Provinces. Other collections from the Kikori lowlands are W. Baker 651, W. Baker 1090 and K.J. White NGF10714. Heterospathe macgregorii is only known from southern New Guinea, from the Fly River in the west to the Kikori Lowlands including Mubi River in the east. Its conservation status has not been assessed by IUCN.

***Hydriastele apetiolata* Petoe & W.J. Baker (Poorly known species)**

A moderately slender, clustering palm to 6 m tall, leaves to 125 cm long; sheath 60 cm long, crownshaft 120–150 cm long. A specimen was collected at Uro Creek, but the species is likely to be present at Wau Creek so it is included here. The species was recently described by Petoe et al. (2018), and is only known from two localities in southern New Guinea: Timika in Indonesian Papua Province and Kikori in Gulf Province. Apart from my collection, the only other collection from Kikori was along the Kopi-Kikori road (Baker et al. 1103). *Hydriastele apetiolata* is only known from two locations in southern New Guinea. Its conservation status has not been assessed by IUCN.

***Hydriastele flabellata* (Becc.) W.J. Baker & Loo (syn. *Nengella flabellata* Becc.) (New province record; Plate 1D–E)**

A small, very slender, clustering palm reaching 2–4 m tall, with leaves 30–80 cm long (including petiole). It was seen and collected near the Wau Creek research station. This species was previously known from Western and Southern Highlands Provinces, and a few other areas in New Guinea, but had not previously been documented from Gulf Province. SHP: Kutubu patrol area, Waro (Takeuchi 7284 and Takeuchi 7312); Kantobo (Baker et al. 643); Mt Bosavi, Wasaso (Baker et al.

611); Mt. Bosavi, northern side (Jacobs 9470). Although *H. flabellata* is widespread, it is not common. Its conservation status has not been assessed by the IUCN.

Begoniaceae

***Begonia sharpeana* F. Muell. (Limited known distribution; Plate 1F)**

This beautiful begonia was first collected from the Aird Hills by Theodore Bevan (trader and natural history collector) in 1887 and was sent to Dr Ferdinand Mueller, Government Botanist in Melbourne (Australia), who described it in 1889. Even though the species has been known for over 100 years, less than 10 collections exist. This was a species I have wanted to see in the field for a long time. It was previously only known to grow in limestone crevices around Kikori/Aird Hills, and the 2017 collection from the gorge along the Sirebi River extends the species' known range upstream. It was not seen within the Wau Creek Proposed WMA and may not occur there due to lack of suitable steep, limestone habitats. For me, seeing and collecting this interesting species in the field was the highlight of the trip.

Begonia sharpeana is an interesting species, not only because it is beautiful with usually reddish blotches on the upper surface of the leaves, but it is the only New Guinea species to belong to the *Begonia* section *Baryandra*. Until recently it was placed in the section *Diploclinium* (with 7 other New Guinea species) but molecular evidence suggests it belongs to section *Baryandra* which otherwise contains only species from the Philippines and Borneo (Rubite et al. 2013). *Begonia sharpeana* is only known from limestone habitats in the Kikori lowlands, and with this restricted distribution its conservation status needs to be assessed as a matter of urgency.

Gesneriaceae

***Cyrtandra* sp. nov. (New to science; Plate 2A)**

This probable new species was only seen and collected at Wau Creek. The soft-stemmed treelets of this new species occur on the forest floor with few spreading branches. Leaves are obovate, thick and fleshy, and break easily. The flowers are borne in thick clusters amongst the leaves near the top of the stem. Flowers are cream, with brown longitudinal strips. Bracts and sepals are also cream. The species was not sighted at Uro Creek, but is possibly present throughout the Kikori lowlands.

Cyrtandra is a large genus of about 800 species, ranging from Southeast Asia to the Pacific, with centres of diversity in Borneo, Philippines and New Guinea. The New Guinea species have not been critically studied taxonomically and most species are poorly represented in herbarium collections. However, there is growing interest in the phylogeny of the genus and some regional studies have been undertaken elsewhere; and hopefully the New Guinea taxa will eventually receive some attention. This species is most probably new to science. Most collections of this genus at the National Herbarium have not been identified to species level, but I am confident that this species is new and possibly has a narrow range.

Rubiaceae

***Ixora valetoniana* Mouly & B. Bremer (syn. *Versteegia grandifolia* Valeton) (First record for PNG; Plate 2B)**

This is a rare pachycaul treelet to 3 m high. Leaves are large, sessile, broadly obovate to oblanceolate, 30–110 cm long and 10–30 cm wide. Flowers/fruit cauliflorous, corolla red to pink, tube c. 2 mm long, glabrous. Fruits are globose, 3–3.5 X 3–3.5 cm, ripening bright red, pulp fleshy. This species was previously known from just three collections (Branderhorst 320, Kanehira & Hatusima 12396 and Versteeg 1039) from Papua Province, Indonesian New Guinea (Ridsdale et al. 1972). The species was collected at both Wau Creek and Uro Creek, and is apparently quite common. The Wau and Uro Creek collections are the first records from PNG and also the first after more than 70 years. Its conservation status has not been assessed.

***Ixora* sp. nov. (New to science; Plate 2C)**
This is a small dioecious pachycaul treelet to 1 m high, common on the forest floor at Wau Creek and a single plant was sighted at Lake Kutubu. It was not sighted at Uro Creek but may occur there. Leaves are sessile, elliptic to obovate. Flowers/fruit axillary, male inflorescence many flowered, female few flowered. Fruits are green, ovoid, ridged. This species is probably endemic to the Kikori River basin and it may have a very narrow range.

Zingiberaceae

***Pleuranthodium racemigerum* (F.Muell.) R.M.Sm. (syn. *Psychanthus racemigera* (F.Muell.) R.M. Smith). (Range extension; Plate 2D)**
Fruiting material collected at Wau Creek probably belongs to this species, though unfortunately no flowering specimens were observed there. Identification of fruiting material of this genus (also true for *Alpinia* and *Riedelia*) is more difficult than flowering material. A flowering specimen collected at Veimei Camp, Uro Creek probably belongs to this species which was originally described from Queensland, Australia and the Wau Creek fruiting material is also tentatively referred to this species. The pseudostem is 1–1.5 m tall, leaf blades are sessile and glabrous, and inflorescences are pendulous, breaking out just below the top of the pseudostem. Flowers are cream.

Until now, *Pleuranthodium racemigerum* was considered an Australian endemic, one of the few species of the genus that occur outside of New Guinea. However, should this tentative identification of the Kikori basin material be confirmed, the species' range will be shown to extend into New Guinea. Smith (1987) suspected that this species might also be present in New Guinea, but this has never been confirmed. The species probably occurs elsewhere in the Kikori lowlands. The distribution of the species is poorly known, but it probably occurs throughout the southern lowlands. Its conservation status has not been assessed.

***Riedelia* sp. nov. 1 (New species; Plate 2E)**
This species was seen and collected only once, along the banks of Wau Creek. It is a large terrestrial species, with pseudostems up to 2 m. Leaves are dark green above, paler below. Inflorescence up to 40 cm long, with 1–2 branches at the base, axes bright red, corolla cream to pale white. In flower the plants are very conspicuous, because of their large, bright red inflorescence axes and white flowers. Fruit is not known. Only one clump was seen and collected along Wau Creek.

This plant probably represents a new species, because it could not be matched with any species in the collections of the PNG National Herbarium at Lae, or descriptions of any known species in the literature. The genus *Riedelia* is not common in swampy lowland areas and the only significant studies on the genus were carried out over 100 years ago when the southern New Guinea lowlands were botanically unknown. The distribution of the species is unknown, but it may occur widely in suitable habitats in the Kikori lowlands.

***Riedelia* sp. nov. 2 (New species; Plate 2F)**
This species was seen and collected only once, along the banks of Wau Creek. It is an epiphytic species, occurring about 6 m from the ground. Pseudostems up to 1 m. Leaves dark glossy green above and paler below. Inflorescence up to 30 cm long, unbranched, the axes bright red. Flowers curved, pink to pale reddish, corolla pinkish. The plants are easily seen when in flower because of the bright red inflorescence axes and pinkish flowers. Only a single plant was seen and collected.

Like the above species, this probably represents a new species. The genus is so poorly known that a large part of the collections at the PNG National Herbarium in Lae remain undetermined beyond the genus, which badly needs a modern revision. While epiphytic *Riedelia* species are common at higher elevations, they are rare in the lowlands. I have only seen them twice, at Woodlark Island and here. At this stage this plant is tentatively considered to be a new species. The distribution of the species is unknown; it might be locally rare in the Kikori lowlands.

IUCN listed species

The International Union for Conservation of Nature (IUCN) Red List of Threatened Species is widely recognised as the most authoritative global assessment of the conservation status of species (Lamoreux et al. 2003; Rodrigues et al. 2006). It provides up to date taxonomic, conservation and distribution information on taxa that have been assessed using the IUCN Red List Categories and Criteria.

As a country so disproportionately blessed with rich biodiversity, PNG needs to take a strong and committed approach to ensuring that species under threat are properly assessed and rated to help with conservation planning and priority setting. To date only the vertebrates have been comprehensively assessed, while assessment and listing of PNG's rich plant life has barely begun. As of 2017, 573 PNG species had been assessed by the IUCN (Table 4), and 73% of these are in the lower risk categories (NT, LC, DD) (IUCN 2017). Several recent revisions of plant taxa have made recommendations regarding the IUCN conservation status of the species under consideration, but formal assessments of these species have not been completed (e.g. many palm taxa: Heatubun et al. 2018; Petoe et al. 2018).

Table 4. Number of IUCN assessed plant species from PNG (IUCN 2017)

IUCN Categories	Number of Species assessed
EX (Species is Extinct)	0
EW (Species is Extinct in the Wild)	0
CR (Species is Critically Endangered and at high risk of becoming extinct in the wild)	17
EN (Species is Endangered, the stage before CR)	20
VU (Species is Vulnerable, but not yet EN or CR)	119
LR (NT/LC) (Species is Lower Risk, either Near Threatened or Least Concern, but not yet VU)	370
DD (Species is Data Deficient where information is inadequate to make an assessment of its risk of extinction)	47
TOTAL	573

Table 5. Plants with an IUCN status greater than LC that were confirmed as present at Wau Creek or likely to be present in the area

Family	Species	IUCN category	Threat	Notes
Cycadaceae	*Cycas scratchleyana*	NT	Regarded as Near Threatened due to the threat of habitat loss.	Widespread in eastern PNG (Central, Gulf, Milne Bay, and Western Provinces), also in Papua (Indonesia) and Australia. Not sighted at Wau Creek, but was previously collected 70 km east of Wau Creek (Womersley NGF 46475, Mena River, Kikori Dist).
Fabaceae	*Intsia bijuga*	VU	Extensively exploited for its high value timber	Africa to Pacific. Widespread in New Guinea, not sighted at Wau Creek but present at Uro Creek. It is certainly present in the Wau Creek area.
Fabaceae	*Pterocarpus indicus*	VU	Extensively exploited for its high value timber	India to Vanuatu. Sighted at Wau Creek.
Flindersiaceae	*Flindersia amboinensis*	NT	Threatened due to logging	Maluku and New Guinea (sporadic). Not sighted at Wau Creek, but fruit collected at Uro Creek. Certainly present in the area.

Two species listed by the IUCN as Vulnerable, and two as Near Threatened, were identified at Wau Creek or are likely to occur there (Table 5). These are all widespread species that occur throughout the PNG lowlands and most also extend outside of New Guinea.

Weedy and invasive species

Invasive species are considered one of the greatest threats to biodiversity, second only to habitat destruction. By definition, invasive plants are "those species that are not native to the ecosystem under consideration and whose introduction causes or is likely to cause economic or environmental harm." Increasing international trade and travel have greatly increased the chances of introducing invasive species.

Wau Creek is remote from population centres along the lower Sirebi River so anthropogenic impacts on the environment are minimal. However, conventional logging activities in the area remain a potential threat for introducing weedy and invasive plants through movement of logging equipment and personnel.

Assessment of the Wau Creek area and along the Sire River showed that the area was relatively free of invasive plants. None of the well-known PNG invasive plants, such as *Piper aduncum, Chromolaena odorata* (Siam weed), *Spathodea campanulata* (African tulip), *Lantana amara*, and the water weeds *Eichhornia crassipes* (water hyacinth) and *Salvinia molesta* were sighted in the area. Locals were interviewed for the presence of any of these invasive species, but none reported sighting any of them. *Merremia peltata* was sighted at Wau Creek as well as along the Sire and Sirebi Rivers, and although often considered as an invasive species it is indigenous and part of the ecosystem. *Mimosa pudica* was sighted at Wau Creek, but it did not appear to be as common or spreading. Two aquatic weedy plants were sighted along the Sire River, *Ludwigia octovalis* and *Polygonum* cf. *attenuatum*, however, these are not considered invasive.

Biodiversity and conservation values

Although much of the lowland rainforest vegetation within the Wau Creek proposed WMA was logged several years ago, the area retains significant biodiversity values. These include a number of new, poorly-known, and conservation significant species, and the habitats for these species need to be protected. As this report indicates, there is also a strong possibility of discovering more new species, and documenting new records and range extensions for plant species. The most significant botanical discoveries during the survey of Wau Creek and nearby areas were the discovery of the rare *Ixora valetoniana*, (first record for PNG), the local endemic *Begonia sharpeana*, and four potential new or undescribed species (*Riedelia* sp. nov. 1, *Riedelia* sp. nov. 2, *Cyrtandra* sp. nov. and *Ixora* sp. nov.). Amongst the plants collected, further studies may reveal more new species or new records; strong candidates include *Alpinia* sp. 1 and sp. 2, *Riedelia* sp. 1, *Saurauia* sp. 1, and *Psychotria?* sp. 3. Further studies will be undertaken to confirm the identities of the new species so that they can be formally described and published.

Although *Begonia sharpean*a was not sighted at Wau Creek, as a local endemic with a distribution limited to the Kikori River limestone it is a species of high conservation value for the Sirebi River. As currently known, the species is restricted to limestone areas, growing on cliff faces and limestone crevices, usually above high river flood levels. Its IUCN conservation status needs to be assessed as a matter of urgency.

Apart from logging, other human impacts are absent or insignificant in and around the proposed WMA. There are no gardens or mobile mills logging in the area. Given that the area is being proposed as a WMA, a management plan needs to be developed as soon as possible to protect the area from any further damage. The efforts to declare Wau Creek as a WMA are a crucial step towards protecting some of the regions biodiversity, particularly because much of the nearby areas are under logging concessions.

Is there a need for another WMA in the lowlands? The answer to that question is a resounding 'yes.' The Neiru/Aird Hills

WMA is an island surrounded by mangroves, whereas Wau Creek protects a representative sample of the vegetation type that dominates the Kikori lowlands - hill forest with medium sized crowns on low altitude forest on uplands (**Hm**) (Hammermaster and Saunders 1995). Furthermore, most of the large logging concessions in the Kikori lowlands are within this vegetation type. Therefore, a WMA or other type of protected area within this vegetation type is essential in order to save valuable species.

Recommendations

The brief botanical survey reported here is clearly inadequate to fully understand and appreciate the plant life of the area. However, the survey provides some guidance for future botanical studies.

The following recommendations are offered to guide future surveys:

- Future studies should explore the upstream areas of both Wau Creek and Sire River, and also pay attention to the swamp communities along the rivers as well the area east of the research station.

- Give adequate time to opportunistic collecting of the flora, and if possible make multiple visits at different times to ensure plants missed during previous visits are collected.

- Identify any unique habitats or ecologically sensitive areas and survey these habitats adequately for potentially unique species, which should add to the protected area's floristic coverage.

- Local landowners should be encouraged to protect all forest in the proposed WMA from future logging, particularly those areas that currently remain unlogged.

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Plate 1

A. Plant plot study at Wau Creek

B. *Heterospathe macgregorii* (photo I. Woxvold)

C. *Heterospathe macgregorii* (photo I. Woxvold)

D. *Hydriastele flabellata*

E. *Hydriastele flabellata*

F. *Begonia sharpeana*, Sirebi River (Photo I. Woxvold)

Plate 2

A. *Cyrtandra* sp. nov.

B. *Ixora valetoniana*

C. *Ixora* sp. nov.

D. *Pleuranthodium racemigerum*

E. *Riedelia* sp. nov. 1

F. *Riedelia* sp. nov. 2

Appendix 1. List of plants documented at Wau Creek and the nearby Sire and Sirebi Rivers.

Note: ? = the plant could not be identified any further

Family	Species	Location	OGG Field Number	Plot, Photo or Sighting	Comments
Actinidiaceae	*Saurauia* sp. 1	Wau Creek	OGG 009		
Actinidiaceae	*Saurauia* sp. 2	Wau Creek	OGG 011		
Anacardiaceae	*Buchanania arborescens*	Wau Creek		Plot	
Anacardiaceae	*Campnosperma* sp.	Wau Creek		Plot	
Annonaceae	*Pseudovaria* sp. 1 (fruits green)	Wau Creek	OGG 007		
Annonaceae	*Pseudovaria* sp. 2 (white flowers)	Wau Creek	OGG 033		
Anonnaceae	*Polyalthia* sp.	Wau Creek		Plot	
Araceae	*Alocasia hollrungii*	Wau Creek		Plot	
Araceae	*Cyrtosperma* sp.	Wau Creek		sighting	
Araceae	*Homalomena* sp.	Wau Creek	OGG 043		
Araceae	*Pothos* sp.	Wau Creek		Plot	
Araceae	*Schismatoglottis calyptrata*	Wau Creek	OGG 042		
Araceae	*Spathiphyllum* sp.	Wau Creek	OGG 044		
Araliaceae	*Osmoxylon boerlagei*	Wau Creek	OGG 054		
Arecaceae	*Calamus* sp. (thin leaflets)	Wau Creek		Photo	
Arecaceae	*Calyptrocalyx* sp.	Wau Creek		Plot	
Arecaceae	*Calyptrocalyx albertisianus*	Sirebi River		sighting	
Arecaceae	*Caryota rumphiana*	Wau Creek		Plot	
Arecaceae	*Heterospathe macgregorii*	Sirebi River		sighting	
Arecaceae	*Hydriastele flabellata*	Wau Creek	OGG 035		
Aristolochiaceae	*Pararistolochia* sp.	Wau Creek	OGG 047		
Aspleniaceae	*Asplenium* sp. 1	Wau Creek	OGG 039		
Aspleniaceae	*Asplenium* sp. 2	Wau Creek		Plot	
Begoniaceae	*Begonia sharpeana*	Sirebi River	OGG 055		Local endemic
Burseraceae	*Canarium acutifolium*	Sirebi River		sighting	
Burseraceae	*Canarium* sp. 1	Wau Creek		photo	
Burseraceae	*Canarium* sp. 2	Wau Creek		Plot	
Burseraceae	*Protium macgregorii*	Wau Creek		Plot	
Clusiaceae	*Calophyllum* sp.	Wau Creek		Plot	
Commelinaceae	*Commelina* sp.	Wau Creek		Plot	
Costaceae	*Hellenia speciosa*	Wau Creek	OGG 048		syn. *Costus speciosus*
Costaceae	*Tapeinochilos ananassae*	Wau Creek		sighting	Not collected as no fertile material found.
Cyperaceae	*Cyperus* sp.	Sire River		sighting	
Elaeocarpaceae	*Aceratium oppositifolium*	Wau Creek	OGG 006		
Elaeocarpaceae	*Elaeocarpus* sp. 1	Wau Creek		Plot	

Family	Species	Location	OGG Field Number	Plot, Photo or Sighting	Comments
Elaeocarpaceae	*Elaeocarpus* sp. 2	Wau Creek		Plot	
Elaeocarpaceae	*Sloanea* sp.	Wau Creek		Plot	
Euphorbiaceae	*Aporusa* sp.	Wau Creek		Plot	
Euphorbiaceae	*Cordeum* sp.	Wau Creek		Plot	
Euphorbiaceae	*Endospermum* sp.	Wau Creek		Plot	
Euphorbiaceae	*Glochidion* sp.	Wau Creek		sighting	
Euphorbiaceae	*Macaranga* sp.	Wau Creek		Plot	
Euphorbiaceae	*Macaranga* sp. 1	Wau Creek	OGG 022		
Euphorbiaceae	*Macaranga* sp. 2	Wau Creek		Plot	
Euphorbiaceae	*Macaranga* sp. 3	Wau Creek		Plot	
Euphorbiaceae	Unknown	Wau Creek		Plot	
Fabaceae	*Entada phaseoloides*	Wau Creek		Plot	
Fabaceae	*Maniltoa* sp.	Wau Creek		Plot	
Fabaceae	*Mucuna* sp.	Wau Creek	OGG 051		
Fabaceae	Unknown	Wau Creek		Plot	
Flacourtiaceae	*Homalium foetidum*	Wau Creek		Plot	
Flagellariaceae	*Flagellaria indica*	Wau Creek		Plot	
Gesneriaceae	*Cyrtandra* sp.	Wau Creek	OGG 005		
Gesneriaceae	*Cyrtandra* sp. nov.	Wau Creek	OGG 004, OGG 034		
Gnetaceae	*Gnetum gnemon*	Wau Creek		Plot	
Icacinaceae	*Gomphandra* sp.	Wau Creek		Plot	
Icacinaceae	*Rhyticaryum* sp.	Wau Creek		Plot	
Icacinaceae	Unknown	Wau Creek		Plot	
Lamiaceae	*Callicarpa* sp.	Wau Creek		Photo	
Lamiaceae	*Oxera splendida*	Wau Creek		Photo	syn. *Faradaya spendida*
Lamiaceae	*Teijmanniodendron bogoriense*	Wau Creek		Plot	
Lamiaceae	Unknown	Wau Creek		Plot	
Lauraceae	*Cryptocarya* sp. 1	Wau Creek		Plot	
Lauraceae	*Cryptocarya* sp. 2	Wau Creek		Plot	
Lauraceae	*Cryptocarya* sp. 3	Wau Creek		Plot	
Lauraceae	*Cryptocarya* sp. 4	Wau Creek		Plot	
Lauraceae	*Litsea* sp. 1	Wau Creek		Plot	
Lauraceae	*Litsea* sp. 2	Wau Creek		Plot	
Lecythidaceae	*Barringtonia* sp.	Wau Creek		Plot	
Loganiaceae	*Neuburgia* sp.	Wau Creek		Plot	
Malvaceae	*Pterocymbium* sp.	Wau Creek		Plot	
Malvaceae	*Sterculia* sp.	Wau Creek		Plot	
Malvaceae	*Trichospermum* sp.	Wau Creek		Plot	
Marantaceae	*Comminsia guppyanum*	Wau Creek		Photo	
Marantaceae	*Phrynium* sp.	Wau Creek	OGG 021		

Family	Species	Location	OGG Field Number	Plot, Photo or Sighting	Comments
Meliaceae	*Aglaia* sp. 1	Wau Creek		Plot	
Meliaceae	*Aglaia* sp. 2	Wau Creek		Plot	
Meliaceae	*Aglaia* sp. 3	Wau Creek		Plot	
Meliaceae	*Aglaia* sp. 4	Wau Creek		Plot	
Meliaceae	*Chisocheton* sp. 1	Wau Creek		Plot	
Meliaceae	*Chisocheton* sp. 2	Wau Creek		Plot	
Meliaceae	*Dysoxyllum* sp. 1	Wau Creek		Plot	
Meliaceae	*Dysoxyllum* sp. 2	Wau Creek		Plot	
Meliaceae	*Dysoxyllum* sp. 3	Wau Creek		Plot	
Monimiaceae	*Stagenthera* sp.	Wau Creek	OGG 003		
Moraceae	*Ficus damaropsis*	Sirebi River		Sighting	
Moraceae	*Ficus* sp. 1	Wau Creek		Plot	
Moraceae	*Ficus* sp. 2	Wau Creek		Plot	
Moraceae	*Ficus* sp. 3	Wau Creek		Plot	
Moraceae	*Ficus* sp. 4	Wau Creek		Plot	
Moraceae	*Ficus* sp. 5	Wau Creek		Plot	
Moraceae	*Ficus* sp. 6	Wau Creek		Plot	
Myristicaceae	*Horsfieldia*	Wau Creek		Sighting	
Myristicaceae	*Myristica* sp. 1	Wau Creek	OGG 028		
Myristicaceae	*Myristica* sp. 2	Wau Creek		Plot	
Myristicaceae	*Myristica* sp. 3	Wau Creek		Plot	
Myristicaceae	*Myristica* sp. 4	Wau Creek		Plot	
Myristicaceae	*Myristica* sp. 5	Wau Creek		Plot	
Myrsinaceae	*Ardisia* sp. 1	Wau Creek	OGG 020		
Myrsinaceae	*Ardisia* sp. 2	Wau Creek	OGG 020		
Myrsinaceae	*Ardisia* sp. 3	Wau Creek	OGG 041		
Myrsinaceae	*Conandrium* sp.	Wau Creek		Plot	
Myrsinaceae	*Tapeinosperma* sp.	Wau Creek		Photo	
Myrtaceae	*Acmena* sp.	Wau Creek		Plot	
Myrtaceae	*Syzygium* sp. 1	Wau Creek		Plot	
Myrtaceae	*Syzygium* sp. 2	Wau Creek	OGG 008		
Myrtaceae	Unknown	Wau Creek		Plot	
Onagraceae	*Ludwigia* cf. *octovalis*	Sire River		sighting	
Orchidaceae	*Neuwiedia* sp.	Wau Creek	OGG 040		
Pandanaceae	*Freycinetia* sp.	Wau Creek	OGG 002		
Phyllanthaceae	*Bischofia javanica*	Wau Creek		sighting	
Piperaceae	*Piper* sp.	Wau Creek		Plot	
Pittosporaceae	*Pittosporun sinuatum*	Wau Creek		Photo	
Poaceae	*Grass* sp.	Wau Creek		Plot	
Poaceae	*Ichnanthus vicinus*	Wau Creek		sighting	
Poaceae	*Pennisetum* sp.	Sire River		sighting	

Family	**Species**	**Location**	**OGG Field Number**	**Plot, Photo or Sighting**	**Comments**
Poaceae	*Phragmites karka*	Wau Creek		sighting	
Poaceae	*Saccharum* sp.	Sire River		sighting	
Polygonaceae	*Polygonum* sp.	Sire River	OGG 053		
Polypodiaceae	*Microsorium* sp.	Wau Creek		Plot	
Pteridaceae	*Pteris* sp.	Wau Creek		Plot	
Rosaceae	*Prunus* sp.	Wau Creek		Plot	
Rubiaceae	*Atractocarpus decorus*	Wau Creek	OGG 012		
Rubiaceae	*Hydnophytum* sp.	Wau Creek		Plot	
Rubiaceae	*Ixora* sp. (long peduncle)	Wau Creek	OGG 036		
Rubiaceae	*Ixora* sp. nov. aff *cauliflora*	Wau Creek	OGG 023, OGG 045		
Rubiaceae	*Ixora valetoniana*	Wau Creek	OGG 025		Syn. *Versteegia magnifolia*
Rubiaceae	*Mussaenda bevani*	Wau Creek		sighting	
Rubiaceae	*Mussaenda scratchleyi*	Wau Creek	OGG 030		
Rubiaceae	*Nauclea orientalis*	Wau Creek		sighting	
Rubiaceae	*Pachystylus gulcherianus*	Wau Creek	OGG 013		
Rubiaceae	*Psychotria* sp. 1	Wau Creek	OGG 001		
Rubiaceae	*Psychotria* sp. 2	Wau Creek	OGG 010		
Rubiaceae	*Psychotria* sp. 3 (*Airosperma*?)	Wau Creek	OGG 037		
Rubiaceae	*Psychotria* sp. 4 (vine white fruit)	Wau Creek	OGG 029		
Rubiaceae	*Uncaria* cf. *appendiculata*	Wau Creek	OGG 046		
Rubiaceae	*Urophyllum* sp.	Wau Creek	OGG 018		
Rutaceae	*Euodia* sp. 1	Wau Creek		Plot	
Rutaceae	*Euodia* sp. 2	Wau Creek		Plot	
Sapindaceae	*Harpullia* sp.	Wau Creek	OGG 052		
Sapindaceae	*Pometia pinnata*	Wau Creek		Plot	
Sapotaceae	*Palaquium* sp.	Wau Creek		sighting	
Sapotaceae	*Pouteria* sp. 1	Wau Creek		Plot	
Sapotaceae	*Pouteria* sp. 2	Wau Creek		Plot	
Sapotaceae	*Pouteria* sp. 3	Wau Creek		Plot	
Selaginellaceae	*Selaginella* sp. 1	Wau Creek	OGG 032		
Sellaginellaceae	*Selaginella* sp. 2	Wau Creek		Plot	
Theaceae	*Adinandra* sp.	Wau Creek		Plot	
Ulmaceae	*Trema orentalis*	Wau Creek		Plot	
Urticaceae	?	Wau Creek	OGG 016		
Urticaceae	*Poikilinosperma* sp.	Wau Creek	OGG 031		
Urticaceae	Unknown	Wau Creek		Plot	
Urticaeae	*Pilea*sp.	Wau Creek		Plot	
Vitaceae	*Leea ?indica*	Wau Creek	OGG 017		
Vitaceae	*Leea* cf. *papuana*	Wau Creek	OGG 015		rare species

Family	Species	Location	OGG Field Number	Plot, Photo or Sighting	Comments
Vitaceae	*Tetrastigma* sp.	Wau Creek		Photo	
Zingiberaceae	*Alpinia* sp. 1	Wau Creek	OGG 108		
Zingiberaceae	*Alpinia* sp. 2 (red fruits)	Wau Creek	OGG 038		
Zingiberaceae	*Curcuma longa*	Wau Creek		Photo	
Zingiberaceae	*Pleuranthodium racemigerum*	Wau Creek	OGG 024		
Zingiberaceae	*Pleuranthodium* sp. 1	Wau Creek	OGG 026		
Zingiberaceae	*Riedelia corallina*	Wau Creek		Photo	
Zingiberaceae	*Riedelia* sp. 1 (orange fruits)	Wau Creek	OGG 019		
Zingiberaceae	*Riedelia* sp. 2 (yellow fruits)	Wau Creek	OGG 027		
Zingiberaceae	*Riedelia* sp. nov. 1 (red corolla)	Wau Creek	OGG 050		
Zingiberaceae	*Riedelia* sp. nov. 2 (white corolla)	Wau Creek	OGG 049		
?	(white/purple flowers)	Wau Creek	OGG ?		
?	?	Wau Creek	OGG 014		

Chapter 1.2. Butterflies of the Wau Creek proposed Wildlife Management Area, Gulf Province, Papua New Guinea

Chris Müller and Pagi Toko

A pair of Tailed Green-Banded Blues (*Nacaduba cyanea*; *Lycaenidae*) in copulation, female at top

Knowledge about the biodiversity of the Kikori Delta in Gulf Province, Papua New Guinea, is incomplete. As part of a broader program to document the biodiversity and conservation values of the Kikori basin we conducted a survey of butterfly species at Wau Creek, a proposed Wildlife Management Area in the upper Kikori Delta.

One hundred and nine butterfly species were recorded over a five-day period. Two species, *Kobrona* sp. and *Cephrenes* sp. (both Hesperiidae), appear to be new to science and one species of *Perpheres* (Lycaenidae) was previously known only from two specimens taken in Central Province and remains undescribed. Fifteen species were recorded from Gulf Province for the first time. The previously unknown life histories of five butterfly species were documented for the first time.

A male of the hesperiid *Sabera madrella* that was photographed in the field but not collected is otherwise only known by the holotype male, collected at Kiunga in Western Province. Another hesperiid encountered during this survey, *Cephrenes augiana*, was previously known only from the holotype from Aru Island and a male labelled "German New Guinea" (i.e., what is now the northern part of mainland Papua New Guinea). Another poorly known species, *Elodina definita* (Pieridae), was recorded from one individual at Wau Creek, and was previously only known from very few specimens from mainland New Guinea.

The Protected Goliath Birdwing Butterfly (*Ornithoptera goliath*) was observed once, flying high above the canopy and the IUCN Endangered *O. meridionalis* was also recorded in small numbers, especially along the main channel of Wau Creek. Together with the Common Birdwing (*O. priamus*) these butterflies are reared for sale as specimens by some local communities elsewhere in PNG and a sustainable farming program may be an option in the Wau Creek area.

Wau Creek retains considerable conservation values, supporting a diverse butterfly fauna that includes new, poorly known and conservation significant species. Successional vegetation in water-logged strands beside the Wau Creek waterway was recognised as a significant habitat that harboured a number of species not encountered elsewhere. Such conservation values, and potential threats to them, are discussed and recommendations for approaches to retaining and utilising the butterfly diversity are presented.

Introduction

Butterflies are the most well studied of all invertebrates (Kerr 2001; Dincă et al. 2011) and the majority of species are probably already described (Kitching et al. 2001). New Guinea boasts nearly 1000 described butterfly species, of which approximately 840 are recorded from Papua New Guinea (PNG) (Tennent 2006). High endemism (approximately 40%) characterises the New Guinea butterfly fauna, which also includes some spectacular radiations of closely related species including the genera *Delias* and *Philiris* which, combined, comprise nearly 25% of the total fauna. New Guinea is home to the world's largest butterflies, the Birdwings (*Ornithoptera*).

There have been few comprehensive entomological surveys within the Kikori basin. In response to this lack of knowledge, Hartshorn et al. (1993) recommended that biodiversity inventories be assembled for the region and in July 1994 the World Wildlife Fund (WWF) carried out multi-taxon surveys at 33 sites across the middle and lower Kikori basin (Hartshorn et al. 1994; Hartshorn 1995). Thirty-two butterfly species were recorded during the survey, which included sites in primary forest at Lake Kutubu-Moro and the Kopi-Kaiam lowlands. Butterflies were recorded in unpublished assessments but were not included in published checklists, although these included moths (Orsak and Easton 1996). Unfortunately, the two historically most prolific butterfly collectors in PNG, Alfred Meek and William Brandt, who operated in PNG in the late 1800's and early 1900's and during the 1950–60's, respectively, and who made substantial contributions to our knowledge of the PNG butterfly fauna, did not make any collections in Gulf Province.

Butterflies are increasingly being recognised as valuable environmental indicators, both for their rapid and sensitive responses to subtle habitat or climatic changes and as representatives for the diversity and responses of other wildlife (Brereton et al. 2011). For example, Kerr et al. (2000) found that butterflies, including Skippers (Hesperiidae), could be used to predict species richness among Hymenoptera at a range of study sites in the USA. Despite their importance as indicators of environmental health, the conservation status of butterflies on mainland PNG remains poorly known and only a small proportion of the fauna have been assessed using IUCN criteria.

Here we report the results of a survey of butterflies in the Wau Creek proposed Wildlife Management Area. The major objectives of the survey were to document and characterise butterfly diversity, distribution, abundance and life histories with particular attention to new, rare and/or threatened species, migratory species and exotic pest species. In addition the survey aimed to identify significant butterfly communities and habitats, species of community/cultural significance and potential threats to butterfly biodiversity.

Methods

Surveying

Butterflies were sampled by 3–4 searchers (CM, PT and 1–2 assistants) along pre-existing walking tracks, and along new trails established in the forest to maximise coverage of as many microhabitats as possible. Survey coverage is illustrated in Figure 1.

Butterflies were identified visually in the field using binoculars or, when field identification was not possible (e.g., for cryptic, less easily discernible species), voucher specimens were collected using long handled nets and stored in glassine envelopes with the preservatives paradichlorobenzene and chloro-m-chresol for subsequent identification. Two legs from each voucher were stored separately as dried tissue samples in vials for potential DNA sequence analysis.

Surveys were conducted between approximately 0800 to 1630 hrs each day between 20–24 April, 2017, except on one day when surveying continued until dark (1900 hrs) to assess crepuscular species. Temperature and humidity was measured 24 hours a day during the survey (min/max stored in the memory), using a Platinum S Hygrometer that was positioned in shade at the Wau Creek research station. Daily temperatures ranged from 23.1–29.6°C (average daily minimum of 23.4°C; average daily max of 28.8°C) and daily humidity ranged from 76–100% (average daily minimum of 81.3 and average daily max of 100%).

Fruit baits

Because some nymphaline butterflies, particularly in the subfamilies Amathusiinae and Satyrinae are attracted to fruit we sampled these groups using fruit traps. Three fruit traps (for placement see Figure 1) containing fermented pineapple, banana and pawpaw that had been stored for three days in air-tight plastic bags were placed at various heights from 0.5 to 10 m above the forest floor (Plate 1D) and remained in place for the duration of the survey, without being moved. Bait was replaced twice during the survey at Wau Creek. Butterflies enter the trap, which is open at the bottom, and become trapped in the enclosed upper portion.

Paper lures

Many adult hesperiid (skipper) butterflies, and some butterflies of the families Lycaenidae and Nymphalidae, imbibe moisture and presumably nutrients from bird droppings. These species are attracted to small pieces of white paper, cut roughly circular to imitate excrement and placed on the upper sides of leaves in various micro-habitats. Paper lure baits consisted of approximately 10 pieces of paper placed within a ~0.5 m radius on the upper surfaces of leaves in the forest understorey. The lures normally cover a single bush or several adjacent bushes and once attracted the butterflies generally 'feed' for long periods, such that twice daily checks of the baits are adequate. Figure 1 shows the location of paper lure baits set up at Wau Creek.

Identification

Where identification was uncertain, and in two cases to validate a species as new to science, type specimens of certain butterfly taxa were examined in the Australian National Insect Collection, Canberra, Australian Museum, Sydney and the Natural History Museum, London.

Conservation status

Species of conservation significance are those classified as Threatened, Near Threatened or Data Deficient by the IUCN (IUCN 2017), those Protected under PNG law and species that are new to science (discovered for the first time during this survey) or undescribed (previously known from one or more sites but remaining without a name).

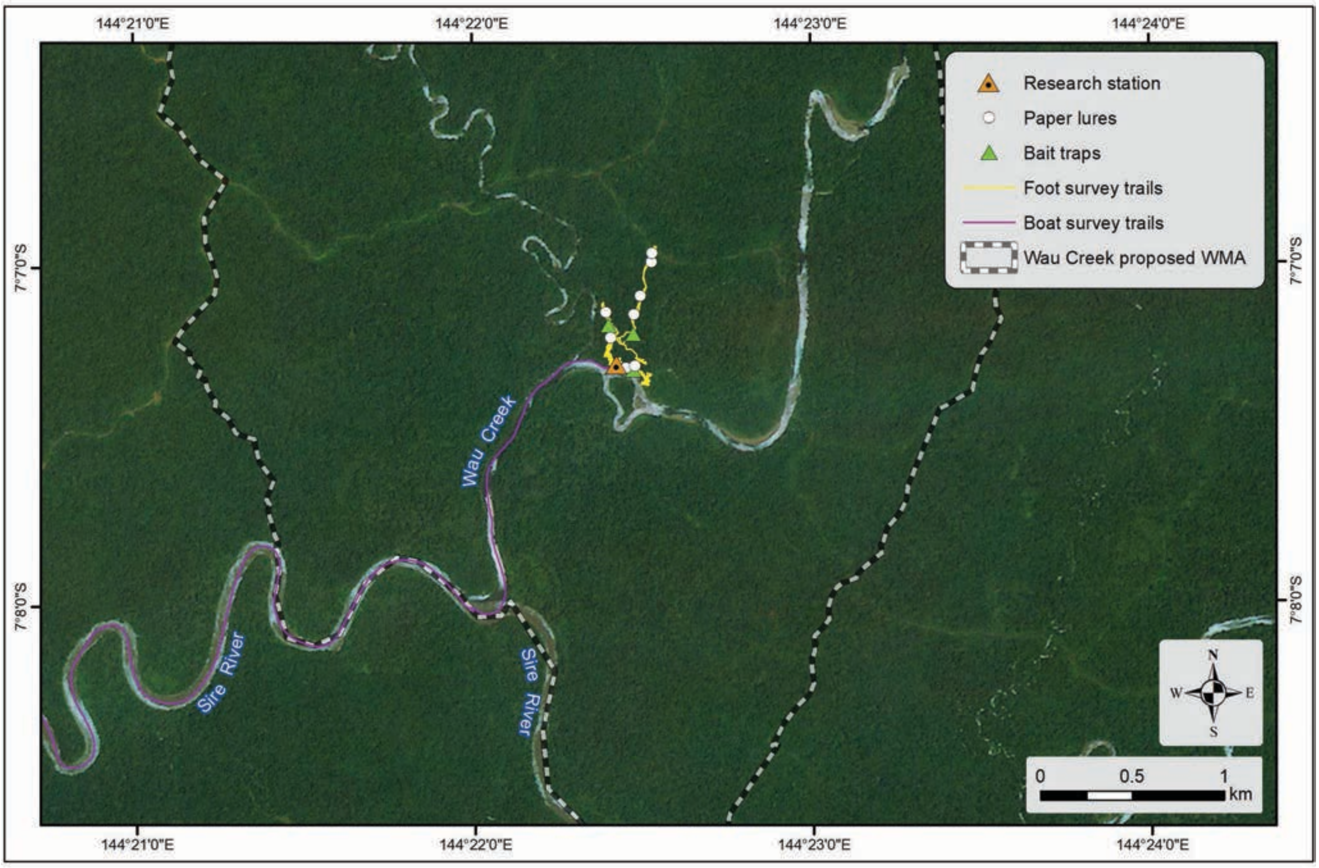

Figure 1. Map of Wau Creek, showing survey trails and the location of bait traps and paper lures.

Taxonomy and nomenclature

Nomenclature in this report follows that of Parsons (1998). Only a few butterflies in New Guinea have common names, so this report generally uses standard scientific names and draws only occasionally on Australian references to common names (Braby 2000).

Results

A total of 109 butterfly species was recorded during the survey over a period of five days (Appendix 1). Conservation significant species are listed in Table 1, and a selection of species are illustrated in Plates 1–3.

Two butterfly species are new to science and one species is undescribed. Two conservation listed birdwing species were recorded from Wau Creek (Table 1). Fifteen species were recorded from Gulf Province for the first time, some of which were also encountered at Uro Creek during this survey program; and the life histories of five butterfly species that were previously unrecorded were documented for the first time (Table 2). Short accounts of these species are presented below.

Species apparently new to science

Cephrenes sp. (Hesperiidae)

A distinctive new species of the hesperiid genus *Cephrenes* was encountered at Wau Creek in sunny clearings created by tree falls. It is a small, dark butterfly with pointed forewings (Plate 3B). Only a few males were observed, all defending territories about five metres above the ground. The species most similar in appearance is the widespread *Cephrenes moseleyi*, which is a much larger and paler insect.

Kobrona sp. (Hesperiidae)

A distinctive species that is distinguished from others in the genus by the presence of black streaks on the underside of both wings (Plate 3C). Most of the ~15 known *Kobrona* also have males with forewing sex brands but the new taxon lacks such a brand. Type specimens of potentially related *Kobrona* taxa were examined in the Australian National Insect Collection, Canberra, and the Natural History Museum, London (the latter from photographs), to confirm the status of this new species. Only three specimens were seen, all attracted around midday to paper lures positioned on foliage in the understorey in dappled sunlight, in mixed succession swamp forest.

Table 1. Significant butterfly species recorded at Wau Creek.

Common Name	Scientific Name	New Species	Undescribed Species	IUCN ststus	PNG Fauna Act	Cultural importance
-	*Kobrona* sp.	x				
-	*Cephrenes* sp.	x				
-	*Perpheres* sp.		x			
Goliath Birdwing	*Ornithoptera goliath*				P[2]	x
Southern Tailed Birdwing	*Ornithoptera meridionalis*			EN[1]	P	x
-	*Taenaris myops*					x

[1]IUCN status EN = Endangered.

[2]Status under the PNG Fauna (Protection and Control) Act. P = Protected

Undescribed species

Perpheres sp. (Lycaenidae)

This undescribed species of *Perpheres* has a unique wing shape, pattern and colour. It clearly differs from *P. perpheres*, the only other member of the genus, in having extensive blue and white colouration on the underside of the wings. The female is largely blue on the upperside (vs black and white in *P. perpheres*). *Perpheres perpheres* is widespread in the lowlands of mainland Indonesian New Guinea and the western half of Papua New Guinea, and there is only fairly minor morphological variation in a large series of that taxon examined suggesting that these differences do not reflect clinal variation. This undescribed species is also known from mid montane altitudes in Central Province (Parsons 1998). It was also found at Uro Creek during the 2017 surveys there.

Conservation significant species

Ornithoptera goliath (Papilionidae)

The Goliath Birdwing is the second largest butterfly in the world and has arguably the greatest wing area of any species. Males attain wingspans up to 160 mm and females to 210 mm. The male is green, black and gold and the female is black with the rear halves of the hindwings yellow. The larvae feed exclusively on the vines *Aristolochia goliathiana* and *A. crassinervia* and each plant is generally occupied by a single larva, which slices through the base of the plant, rendering it unusable by other larvae (Parsons 1998). The reason for this behaviour is not fully understood.

Ornithoptera goliath occurs from the island of Seram in eastern Indonesia, to Papua New Guinea where it is widely distributed and locally common throughout much of the mainland and on several nearby satellite islands. Although they occur from near sea level to about 2,200 m asl, Goliath Birdwings are most common in mountainous areas between 1,200 m and 1,800 m, where they are often encountered flying several metres above the ground along creeks or in deep ravines. They also inhabit primary, and sometimes secondary, lowland forest. At Wau Creek a single female was observed flying high above the canopy. In flight, the enormous female is distinctive with its almost entirely brown forewing and yellow hindwing. Observations throughout mainland PNG by the author (Müller pers. obs.) suggest that, while conspicuous, the species is generally uncommon. However given that extensive suitable habitat remains across a range of altitudes, the species' survival is currently not threatened.

This butterfly is Protected by the PNG Fauna (Protection and Control) Act 1966 and is included on CITES Appendix II.

***Ornithoptera meridionalis* (Papilionidae)**

Although the smallest species in the genus *Ornithoptera*, this is a large birdwing butterfly, the male's wingspan reaching up to 99 mm and the female's up to 124 mm. Males are green and black with a thin spatulate tail to the narrow hindwing, while females are predominantly brown and cream. According to Parsons (1998), the larvae feed exclusively on the vine *Pararistolochia meridionaliana*. Males are rarely observed, probably because they fly only short distances while females are more wide-ranging. This is typical of other Birdwings.

This butterfly is endemic to mainland New Guinea, with all but one dubious record from south of the central cordillera. It is primarily a lowland species, although there are records as high as 700 m asl in the Lake Kutubu area. *Ornithoptera meridionalis* is an inhabitant of the margins of advanced secondary and primary forest and suitable habitat is widespread in the Wau Creek area. During the 2017 survey several females were observed flying close to riparian vegetation along the main Wau Creek channel. It was also observed at Uro Creek during the survey there.

This species is classified as Endangered by the IUCN (Gimenez Dixon 1996) and is protected by the PNG Fauna (Protection And Control) Act 1966. It is also listed on CITES Appendix II.

Culturally important species

***Taenaris myops* (Nymphalidae)**

Considered culturally important since several batches of larvae were found devouring cultivated banana (*Musa* sp., Musaceae) plants in the gardens of the research station (Plate 1E). While the larvae only feed on the foliage and not the fruit, it is not known if a degree of defoliation would impact on the fruit yield. It is considered unlikely, unless the plants were quite small. It is possible that other species of *Taenaris* (Plate 2) may also feed on cultivated banana at Wau Creek. As well as *T. myops*, (Plate 2I) Parsons (1998) records *T. catops* (Plate 2C) and *T. dimona* (Plate 2E) feeding on *Musa* species (*Musaceae*). *Taenaris catops* was common at Wau Creek and *T. dimona* is likely present, since it was observed at Uro Creek.

Other significant records

***Cephrenes augiana* (Hesperiidae)**

Cephrenes augiana (Plate 3A) was previously known only from the holotype from Aru Island and a male labelled "German New Guinea" (ie the northern half of what is now PNG). Two male specimens from Wau Creek are thus the third record of the species. Both males were guarding elevated territories among foliage located in full sunshine within clearings.

***Chaetocneme tenuis* (Hesperiidae)**

Two individuals of this crepuscular species were attracted to paper lures at the same precise swampy locality, at dusk on different days. In PNG, Parsons (1998) records this species only from Central, Northern, Morobe, Western and East Sepik Provinces. The new record from Wau Creek fills a major gap in the known distribution of this species. It was also found at Uro Creek during the 2017 survey there.

Sabera aruana (Hesperiidae)

Sabera aruana was fairly common along several trails at Wau Creek. Although a shy species that is seldom observed, males were attracted to paper lures on low vegetation in shady areas. This is the first record from Gulf Province; Parsons (1998) provides records from various localities in mainland Indonesian Papua and East Sepik, Madang, Morobe, Northern, Milne Bay and Western Provinces in PNG.

Sabera madrella (Hesperiidae)

A male specimen resembling this species was photographed by S. J. Richards at a paper lure along a trail close to a tributary of Wau Creek (Plate 1B). *Sabera madrella* closely resembles *S. aruana*, which flew in the same area, but is larger, has longer, more pointed forewings, a more extensive postmedian band on the hindwing underside and a deeper shade of red-brown than *S. aruana*. Unfortunately, without examination of the sex brand on the forewing upperside, which is diagnostic within *Sabera*, the identity is tentative. *Sabera madrella* is otherwise only known from the holotype collected at Kiunga in Western Province by W. W. Brandt in 1957 (Parsons 1998).

Telicota ixion (Hesperiidae)

Several males (Plate 3E) of this species were encountered at paper lures. *Telicota ixion* belongs to a species complex in which morphological differences between taxa are slight. However examination of comparative material in the Australian National Insect Collection indicates that the Wau Creek population represents this taxon. *Telicota ixion* was previously recorded in PNG from Central, Morobe, Madang and Northern Provinces, and from the d'Entrecasteaux and Bismarck islands. It was also found at Uro Creek during the 2017 surveys. The Wau Creek and Uro Creek records represent a major westerly range extension for this species and the first record for Gulf Province

Telicota vinta (Hesperiidae)

Telicota vinta (Plate 3F) is another species that is difficult to distinguish morphologically from related species, e.g., *Telicota colon* (Plate 3D), but examination of comparative material in the Australian National Insect Collection has verified its identity. Parsons (1998) records *T. vinta* in PNG only from Central, Morobe, Western and East Sepik Provinces so the Wau Creek record fills a major gap in the species' known distribution. Parsons (1998) also records the taxon from Indonesian New Guinea.

Elodina definita (Pieridae)

A single specimen of *Elodina definita* was encountered at Wau Creek. Although known from a few specimens in Indonesian New Guinea (Parsons 1998), in PNG the taxon was previously only known from five specimens from Western, Central and Milne Bay Provinces so the Wau Creek record fills a major gap in the species' known distribution.

Danis phroso (Lycaenidae)

Recorded in PNG by Parsons (1998) from Western, Western Highlands, Morobe, Central and Northern Provinces, *D. phroso* was common at Wau Creek. The species is otherwise known from Indonesian New Guinea. Adults of this species form part of a known mimicry ring, in which the adults of unrelated species have black and green bands on the underside.

Hypochrysops dinawa (Lycaenidae)

A single male of *H. dinawa* was recorded at Wau Creek, flying slowly in a clearing surrounded by dense vegetation. This species was previously known only from Western, Central and Northern Provinces (Sands 1986; Parsons 1998) so the Wau Creek record fills a major gap in the species' known distribution.

***Philiris harterti* (Lycaenidae)**

Early stages of this butterfly were recorded in deep shaded forest near the forest floor, feeding on *Litsea guppyi* (Lauraceae). Larvae and pupae are extremely well camouflaged (Plate 1F), concealed in troughs made by the former on stems of the foodplant. Sands (1981) and Parsons (1998) recorded this species in PNG only from Milne Bay, Northern, Central, Morobe and Western Provinces. It was also found at Uro Creek during the 2017 surveys. The Wau Creek and Uro Creek records fill a major gap in the species' known distribution. The species is also known from Indonesian New Guinea.

***Dolleschallia bisaltide* (Nymphalidae)**

Dolleschallia bisaltide is a widespread species that occurs throughout much of the Indo-Pacific, from Sri Lanka and India through South-East Asia to New Guinea and eastern Australia. However, there are few records from PNG, where it is recorded only from West Sepik, East Sepik and Central Provinces. Three individuals, representing both sexes, were observed at Wau Creek, all within a few metres of the research station. This species was also encountered at Uro Creek during the 2017 survey there.

***Euploea netscheri* (Nymphalidae)**

Parsons (1998) considered *E. netscheri* to be very localised in the western half of mainland PNG (Western, East Sepik, Western Highlands, Madang Provinces). Several specimens were observed at Wau Creek, mostly close to the research station, where they flew with several other *Euploea* species. This species was also encountered at Uro Creek during the 2017 survey there.

***Mycalesis asophis* (Nymphalidae)**

A single male of *Mycalesis asophis* was recorded along an old logging road, in a similar situation to that of *Taenaris honrathi* (Nymphalidae). In PNG *M. asophis* was previously known only from Western, Central, Morobe and Madang Provinces (Parsons 1998).

***Taenaris dioptrica* (Nymphalidae)**

Taenaris dioptrica (Plate 2F) was previously known only from a few specimens from West Sepik, East Sepik, Madang and Western Provinces (Parsons 1998). The species was fairly common along most transects at Wau Creek. This species was also encountered at Uro Creek during the 2017 survey there.

***Taenaris honrathi* (Nymphalidae)**

This species was recorded by Parsons (1998) from Morobe, Madang, East Sepik, West Sepik and Western Provinces. A single individual was observed at Wau Creek, where it had established a territory along a ridge (previously a logging road), approximately 5 m above the ground. The Wau Creek record fills a major gap in the species' known distribution and is the first record for Gulf Province.

Life history records

The life histories of 24 species were recorded in the field and their food plants noted (Table 2). Six of these had not previously been recorded and are hence noteworthy (*Danis phroso*, *Jamides coritus*, both Lycaenidae; *Euploea alcathoe*, *Mycalesis mucia*, *Mycalesis cacodaemon* and *Harsiesis hygea*, all Nymphalidae).

Table 2. Food plants recorded for butterfly fauna at Wau Creek.

Butterfly species	Food plant species	Food plant family
Tagiades japetus	*Dioscorea* sp.	Dioscoraceae
Tagiades nestus	*Dioscorea* sp.	Dioscoraceae
Notocrypta waiguensis	*Alpinia* sp.	Zingiberaceae
Arrhenes marnas	Grass sp.	Poaceae
Papilio ulysses	*Melicope* sp.	Rutaceae
Papilio euchenor	*Melicope* sp.	Rutaceae
Philiris harterti	*Litsea* sp.	Lauraceae
Philiris helena	*Macaranga* cf. *aleurotoides*	Euphorbiaceae
Hypolycaena danis	*Dendrobium* sp.	Orchidaceae
Nacaduba cyanea	*Entada* cf. *phaseoloides*	Fabaceae
Danis phroso	*Rourea* sp.	Connaraceae
Psychonotis caelius	*Alphitonia* cf. *petriei*	Rhamnaceae
Catopyrops ancyra	*Pipturus argentea*	Urticaceae
Jamides coritus	Unidentified legume	Leguminaceae
Euploea leucostictos	*Ficus* sp.	Moraceae
Euploea alcathoe	*Marsdenia* sp.	Apocynaceae
Taenaris myops	*Musa* sp.	Musaceae
Mycalesis mucia	*Centotheca latifolia*	Poaceae
Mycalesis cacodaemon	*Selaginella* sp.	Selaginellaceae
Harsiesis hygea	*Bambusa* sp.	Poaceae
Cyrestis acilia	*Ficus* sp.	Moraceae
Mynes geoffroyi	*Dendrocnide peltata*	Urticaceae
Cethosia cydippe	*Adenia* cf. *heterophylla*	Passifloraceae
Vindula arsinoe	*Adenia* cf. *heterophylla*	Passifloraceae

Discussion

The expedition to Wau Creek and Uro Creek (see Chapter 2.2) represents the most significant survey of butterflies conducted to date in the poorly known Kikori basin lowlands. Note that the WWF species list of Kikori basin butterflies compiled by Hartshorn et al. (1994) contains names for 32 species but gives no indication as to which of the three main sites visited (Agogo Forest, Moro/Kutubu, Kopi/Kikori) the taxa were recorded from. Only one species on the list, *Mycalesis valeria* (misspelled *valeriana*), was not recorded during the survey of Wau Creek (or other Kikori sites visited during 2017). Although *M. valeria* is known from various localities in Central Province (Parsons 1998) it is similar to, and may have been confused with *M. pernotata*, a related species that was recorded at Wau Creek during this survey. Considering the ambiguity of the WWF species list (also including a species endemic to Maluku, Indonesia), the record of *M. valeria* is not incorporated.

The 109 species of butterflies documented at Wau Creek is similar to that reported from similar altitudes elsewhere in PNG including Uro Creek (117 species) the Lake Hargy Caldera and Hargy Oil Palm sites in West New Britain, with a total of 74 species (D. Miller, pers. comm., 2010), and the lower Waria Valley, Morobe Province with 102 species (Dawson et al. 2009). However neither of these latter two surveys recorded new, undescribed or conservation-listed species, unlike the survey at Wau Creek. Furthermore at Wau Creek several species were recorded from only a few individuals and it is likely that the butterfly inventory there will continue to grow as additional rarely encountered species are detected with increased survey effort.

At Wau Creek one particular microhabitat, successional vegetation in water-logged strands beside the Wau Creek waterway, was recognised as a significant habitat that harboured a number of species not encountered elsewhere, including a rich hesperiid diversity; it was also the only habitat where the new species of *Kobrona* was observed.

Biodiversity and conservation values

The forest at Wau Creek comprises a patchwork of primary rainforest, especially close to the research station, and advanced secondary forest where forest degradation has taken place as a result of logging activities. Despite this degradation in some areas, the Wau Creek proposed WMA is considered to have substantial conservation value, with a moderately diverse butterfly fauna that includes a number of new species and species of conservation significance. The large number of species reported from Gulf Province for the first time during this survey suggests that additional important new distribution records remain to be documented. The secondary forest at Wau Creek also provides an important habitat for some butterflies such as *Catochrysops amasea* and *Mycalesis asophis* that prefer disturbed habitats. No exotic butterfly species (of which there are only very few in PNG) were recorded.

Riverine Mixed Successions are susceptible to flooding and changes in the water course and are therefore always in a state of regrowth to varying degrees. It is therefore difficult to gauge their condition. These environments (e.g. Plate 1A) are important for numerous butterfly species (especially Hesperiidae) at Wau Creek where this group was particularly conspicuous along the banks of the Wau Creek.

Recommendations

- A number of butterfly species were recorded from single individuals suggesting that additional surveys focused on detecting low-density species may reveal a somewhat higher total diversity than we documented during 2017. In addition, surveys to better document the distribution and habitat requirements of the IUCN Endangered butterfly *Ornithoptera meridionalis* at Wau Creek would be useful.

- Because habitat loss and degradation are the most significant threats to the butterfly fauna at Wau Creek, it is important that clearing of forest be kept to a minimum and revegetation of affected areas should be a priority. Minimising habitat loss will also reduce the opportunity for invasive plant and animal species to take a hold. We encountered invasive weeds along the water ways and overgrown logging roads at Wau Creek. As well as invasive plants, aggressive invasive ant species (whose establishment is commonly associated with human settlement) can have a dramatic negative impact on native ants and other native species (Berman et al. 2013). Impacts on native ants can in turn have significant impacts on butterfly species that rely on symbiotic ant - early butterfly stage relationships for successful reproduction.

- With the closure in 2009 of the Insect Farming and Trading Agency (IFTA), and the Wau Ecology Institute which supplied Birdwing butterflies that were 'ranched' (reared under controlled conditions), there is potentially an opportunity for local communities to obtain export permits to trade in insects. Three *Ornithoptera* birdwing species, which have been successfully reared elsewhere in PNG for commercial purposes (i.e., the sale of specimens), were recorded during this survey: *Ornithoptera priamus*, *O. goliath* and *O. meridionalis*.

- There is potential to further develop the Wau Creek research station as a base for research projects (the prospect of discovering new species would be alluring for specialist entomologists), and possibly even for eco-tourism although the costs of access and improvements to accommodation facilities would need to be considered for the latter to be viable. Training community members in techniques for monitoring the entomological diversity present at Wau Creek would give them an appreciation of the resident butterfly fauna and also give them the knowledge to act as experienced tour guides for researchers and adventurous tourists. If successful, income from research and tourism would encourage the community to care for their environment for generations to come.

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Plate 1

A. Swampy riverine habitat at Wau Creek

B. *Sabera madrella* male at paper lure.

C. *Mycalesis pernotata* male in territory.

D. Bait trap alongside Wau Creek tributary.

E. Larvae of *Taenaris myops* on banana (*Musa* sp.)

F. Partly concealed pupa of *Philiris harterti*.

Plate 2. *Taenaris* butterflies known or expected to occur at Wau Creek

A.*Taenaris artemis*

B. *Taenaris bioculatus*

C. *Taenaris catops*

D. *Taenaris cyclops* (from Lake Kutubu)

E. *Taenaris dimona* (from Uro Creek)

F. *Taenaris dioptrica*

G. *Taenaris gorgo* (from Uro Creek)

H.*Taenaris honrathi*

I. *Taenaris myops*

J. *Taenaris onolaus*

Scale bar = 10mm

Plate 3. Wau Creek Skippers (Hesperiidae)

A. *Cephrenes augiana*

B. *Cephrenes* sp.

C. *Kobrona* sp.

D. *Telicota colon*

E. *Telicota ixion*

F. *Telicota vinta*

Scale bar = 10mm

Appendix 1. Butterfly species recorded at Wau Creek.

Family	Subfamily	Species	English Name
Hesperiiidae	Pyrginae	*Chaetocneme tenuis*	
Hesperiiidae	Pyrginae	*Tagiades japetus*	Black and White Flat
Hesperiiidae	Pyrginae	*Tagiades nestus*	
Hesperiiidae	Hesperiinae	*Borbo impar*	Yellow Swift
Hesperiiidae	Hesperiinae	*Cephrenes augiana*	
Hesperiiidae	Hesperiinae	*Cephrenes* sp.	
Hesperiiidae	Hesperiinae	*Kobrona* sp.	
Hesperiiidae	Hesperiinae	*Notocrypta renardi*	
Hesperiiidae	Hesperiinae	*Notocrypta waiguensis*	Banded Demon
Hesperiiidae	Hesperiinae	*Pelopidas agna*	Dingy Swift
Hesperiiidae	Hesperiinae	*Pelopidas lyelli*	
Hesperiiidae	Hesperiinae	*Pelopidas mathias*	
Hesperiiidae	Hesperiinae	*Sabera aruana*	
Hesperiiidae	Hesperiinae	*Sabera madrella*	
Hesperiiidae	Hesperiinae	*Telicota colon*	
Hesperiiidae	Hesperiinae	*Telicota ixion*	
Hesperiiidae	Hesperiinae	*Telicota melanion*	
Hesperiiidae	Hesperiinae	*Telicota vinta*	
Papilionidae	Papilioninae	*Graphium agamemnon*	Green-Spotted Triangle
Papilionidae	Papilioninae	*Graphium aristeus*	Five-Bar Swordtail
Papilionidae	Papilioninae	*Graphium euryplus*	Pale-Green Triangle
Papilionidae	Papilioninae	*Graphium sarpedon*	Blue Triangle
Papilionidae	Papilioninae	*Graphium wallacei*	
Papilionidae	Papilioninae	*Ornithoptera goliath*	Goliath Birdwing
Papilionidae	Papilioninae	*Ornithoptera meridionalis*	Ornithoptère Méridional
Papilionidae	Papilioninae	*Ornithoptera priamus*	Common Birdwing
Papilionidae	Papilioninae	*Papilio aegeus*	Orchard Swallowtail
Papilionidae	Papilioninae	*Papilio ambrax*	Ambrax Swallowtail
Papilionidae	Papilioninae	*Papilio euchenor*	
Papilionidae	Papilioninae	*Papilio ulysses*	Ulysses
Pieridae	Coliadinae	*Eurema blanda*	
Pieridae	Coliadinae	*Eurema puella*	Broad-Margined Yellow
Pieridae	Coliadinae	*Gandaca butyrosa*	
Pieridae	Pierinae	*Appias celestina*	Blue Albatross
Pieridae	Pierinae	*Delias ornytion*	
Pieridae	Pierinae	*Elodina definita*	
Pieridae	Pierinae	*Elodina hypatia*	
Pieridae	Pierinae	*Saletara cycinna*	
Lycaenidae	Riodininae	*Dicallaneura decorata*	
Lycaenidae	Lycaeninae	*Anthene seltuttus*	Dark Ciliated-blue
Lycaenidae	Lycaeninae	*Candalides helenita*	Helenita Blue

Family	Subfamily	Species	English Name
Lycaenidae	Lycaeninae	*Catochrysops amasea*	Cobalt Pea Blue
Lycaenidae	Lycaeninae	*Catopyrops ancyra*	
Lycaenidae	Lycaeninae	*Danis danis*	Large Green-Banded Blue
Lycaenidae	Lycaeninae	*Danis phroso*	
Lycaenidae	Lycaeninae	*Hypochrysops dinawa*	
Lycaenidae	Lycaeninae	*Hypochrysops polycletus*	
Lycaenidae	Lycaeninae	*Hypolycaena danis*	Black and White Tit
Lycaenidae	Lycaeninae	*Hypolycaena phorbas*	Common Tit
Lycaenidae	Lycaeninae	*Ionolyce helicon*	
Lycaenidae	Lycaeninae	*Jamides aetherialis*	
Lycaenidae	Lycaeninae	*Jamides coritus*	
Lycaenidae	Lycaeninae	*Jamides cytus*	Pale Cerulean
Lycaenidae	Lycaeninae	*Jamides nemophilus*	
Lycaenidae	Lycaeninae	*Nacaduba cyanea*	Tailed Green-Banded Blue
Lycaenidae	Lycaeninae	*Nacaduba tristis*	
Lycaenidae	Lycaeninae	*Perpheres* sp.	
Lycaenidae	Lycaeninae	*Petrelaea tombugiensis*	Mauve Line Blue
Lycaenidae	Lycaeninae	*Philiris harterti*	
Lycaenidae	Lycaeninae	*Philiris helena*	
Lycaenidae	Lycaeninae	*Prosotas dubiosa*	Dubiosa Line Blue
Lycaenidae	Lycaeninae	*Psychonotis caelius*	Small Green-Banded Blue
Nymphalidae	Ithomiinae	*Tellervo nedusia*	
Nymphalidae	Ithomiinae	*Tellervo zoilus*	Hamadryad
Nymphalidae	Danainae	*Euploea alcathoe*	No-brand Crow
Nymphalidae	Danainae	*Euploea leucostictos*	
Nymphalidae	Danainae	*Euploea netscheri*	
Nymphalidae	Danainae	*Euploea wallacei*	Wallace's Crow
Nymphalidae	Danainae	*Parantica schenkii*	
Nymphalidae	Morphinae	*Hyantis hodeva*	
Nymphalidae	Morphinae	*Taenaris artemis*	
Nymphalidae	Morphinae	*Taenaris bioculatus*	
Nymphalidae	Morphinae	*Taenaris catops*	Catops Owl
Nymphalidae	Morphinae	*Taenaris dioptrica*	
Nymphalidae	Morphinae	*Taenaris honrathi*	
Nymphalidae	Morphinae	*Taenaris myops*	
Nymphalidae	Morphinae	*Taenaris onolaus*	
Nymphalidae	Satyrinae	*Elymnias agondas*	Palmfly
Nymphalidae	Satyrinae	*Harsiesis hygea*	
Nymphalidae	Satyrinae	*Mycalesis asophis*	
Nymphalidae	Satyrinae	*Mycalesis cacodaemon*	
Nymphalidae	Satyrinae	*Mycalesis mucia*	
Nymphalidae	Satyrinae	*Mycalesis pernotata*	
Nymphalidae	Satyrinae	*Mycalesis phidon*	

Family	Subfamily	Species	English Name
Nymphalidae	Charaxinae	*Charaxes latona*	Orange Rajah
Nymphalidae	Charaxinae	*Prothoe australis*	
Nymphalidae	Apaturinae	*Cyrestis acilia*	
Nymphalidae	Nymphalinae	*Cethosia cydippe*	Red Lacewing
Nymphalidae	Nymphalinae	*Cirrochroa regina*	Red Yeomen
Nymphalidae	Nymphalinae	*Cupha prosope*	Rustic
Nymphalidae	Nymphalinae	*Dolleschallia bisaltide*	
Nymphalidae	Nymphalinae	*Dolleschallia hexopthalmus*	
Nymphalidae	Nymphalinae	*Euthaliopsis aetion*	
Nymphalidae	Nymphalinae	*Hypolimnas alimena*	Blue-Banded Eggfly
Nymphalidae	Nymphalinae	*Hypolimnas bolina*	Common Eggfly
Nymphalidae	Nymphalinae	*Hypolimnas deois*	
Nymphalidae	Nymphalinae	*Junonia erigone*	Northern Argus
Nymphalidae	Nymphalinae	*Junonia hedonia*	Chocolate Soldier
Nymphalidae	Nymphalinae	*Mynes geoffroyi*	White Nymph
Nymphalidae	Nymphalinae	*Neptis brebissonii*	
Nymphalidae	Nymphalinae	*Pantoporia consimilis*	Orange Aeroplane
Nymphalidae	Nymphalinae	*Pantoporia venilia*	Cape York Aeroplane
Nymphalidae	Nymphalinae	*Parthenos tigrina*	
Nymphalidae	Nymphalinae	*Vindula arsinoe*	Cruiser
Nymphalidae	Nymphalinae	*Yoma algina*	Lurcher

Chapter 1.3. Dragonflies and damselflies (Odonata) of the Wau Creek proposed Wildlife Management Area, Gulf Province, Papua New Guinea

Stephen Richards, Pagi Toko and Günther Theischinger

Nannophlebia ballerina

Summary

We report the results of a survey of dragonflies and damselflies in the Wau Creek proposed Wildlife Management Area (WMA) in Gulf Province, Papua New Guinea (PNG). Forty-six species of odonates were encountered in five days, including 23 species of damselflies (Zygoptera) and 23 species of dragonflies (Anisoptera). Another six species are known from the adjacent Dark End Lumber site, bringing the total number of species from this small area to 52. Two species from Wau Creek (one in the libellulid genus *Nannophlebia* and one in the platycnemidid genus *Nososticta*) are new to science. They were discovered for the first time during this survey, are currently known only from Wau Creek, and were formally described during preparation of this report. At least two additional species (in the genera *Bironides* and *Idiocnemis*) are undescribed, but they were each previously known from other sites in south-central PNG. The *Bironides* species was also formally described during preparation of this report. All four of these species are associated with clear-flowing streams in forest. Two species in the taxonomically difficult coenagrionid genus *Teinobasis* may also be new to science but additional studies are required before this can be confirmed. Two species, the damselfly *Nososticta nigrifrons* and the dragonfly *Nannophya paulsoni* are listed as Data Deficient by the IUCN.

The diversity of odonates documented around Wau Creek is among the highest reported for any site of similar size in New Guinea, and reflects the wide range of high-quality aquatic habitat types available for dragonflies and damselflies there.

Introduction

More than 600 species of dragonflies and damselflies are currently known from the New Guinea region (Michalski 2012; Kalkman and Orr 2013; Orr and Kalkman 2015) and about half of the species are endemic to the region. However this impressive diversity is certainly an underestimate because recent fieldwork in remote areas has revealed numerous new species, particularly in the forested interior of mainland New Guinea. (e.g. Englund and Polhemus 2007; Kalkman et al. 2013; Orr et al. 2012, 2014; Theischinger and Richards 2012a,b, 2013, 2015, 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) who examined and described (among other collections) the odonate collections of the 1933–1964 Archbold Expeditions to New Guinea. The papers by Lieftinck continue to provide the foundation for current taxonomic and biogeographical work on New Guinean odonates.

The odonates of the Kikori River basin were most recently documented by Polhemus (1995) and Richards (2000). The surveys by Polhemus, which were part of WWF's 1995 Kikori basin multi-taxon biodiversity survey, sampled damselflies at 33 sites scattered across the basin and recorded a rich damselfly fauna of 37 species. One new species, *Idiocnemis polhemi*, which was collected during that survey and described by Gassmann (2000) is currently known only from a small area to the southeast of Lake Kutubu (Polhemus 1995; Gassmann 2000). The surveys reported by Richards (2000) incorporated both damselflies and dragonflies and included a site at Dark End Lumber, a patch of forest located adjacent to the proposed Wau Creek Wildlife Management Area. The survey at Dark End Lumber led to the discovery and description of *Nososticta acudens* and *Papuagrion nigripedum* (Theischinger and Richards 2006a), *Nososticta smilodon* (Theischinger and Richards 2006b), *Idiocnemis patriciae* (Gassmann and Richards 2008) and *Metagrion trigonale* (Theischinger and Richards 2008).

Here we report the results of a short (5-day) but intensive survey of odonates in lowland rainforest at Wau Creek in the Kikori basin of Gulf Province, Papua New Guinea.

Methods

The survey at Wau Creek was conducted by four people (SR, PT and two local assistants) between 22 and 26 April 2017. Some additional observations from two brief visits to the site by SR on November 28 and December 5, 2016 are also incorporated. During 2017 searches were conducted along forest trails within an approximately 1 km radius of the Wau Creek research station, which is located on the bank of Wau Creek. Adult odonates were observed with close-focus binoculars or collected with a long-handled net during daylight (normally 10 am to ~4.30 pm) from around freshwater habitats including the main channel of Wau Creek, smaller streams in closed forest, forest pools and seepages, and streams in more open habitats. Figure 1 illustrates the trails accessed during the 2017 survey and Plate 1A–B illustrates typical aquatic habitats sampled. Voucher specimens of species requiring further examination were treated with acetone for about 12 hours, sun-dried, and subsequently stored in labelled envelopes. Larvae were not sampled because larval stages of most New Guinea odonates cannot be assigned confidently to species.

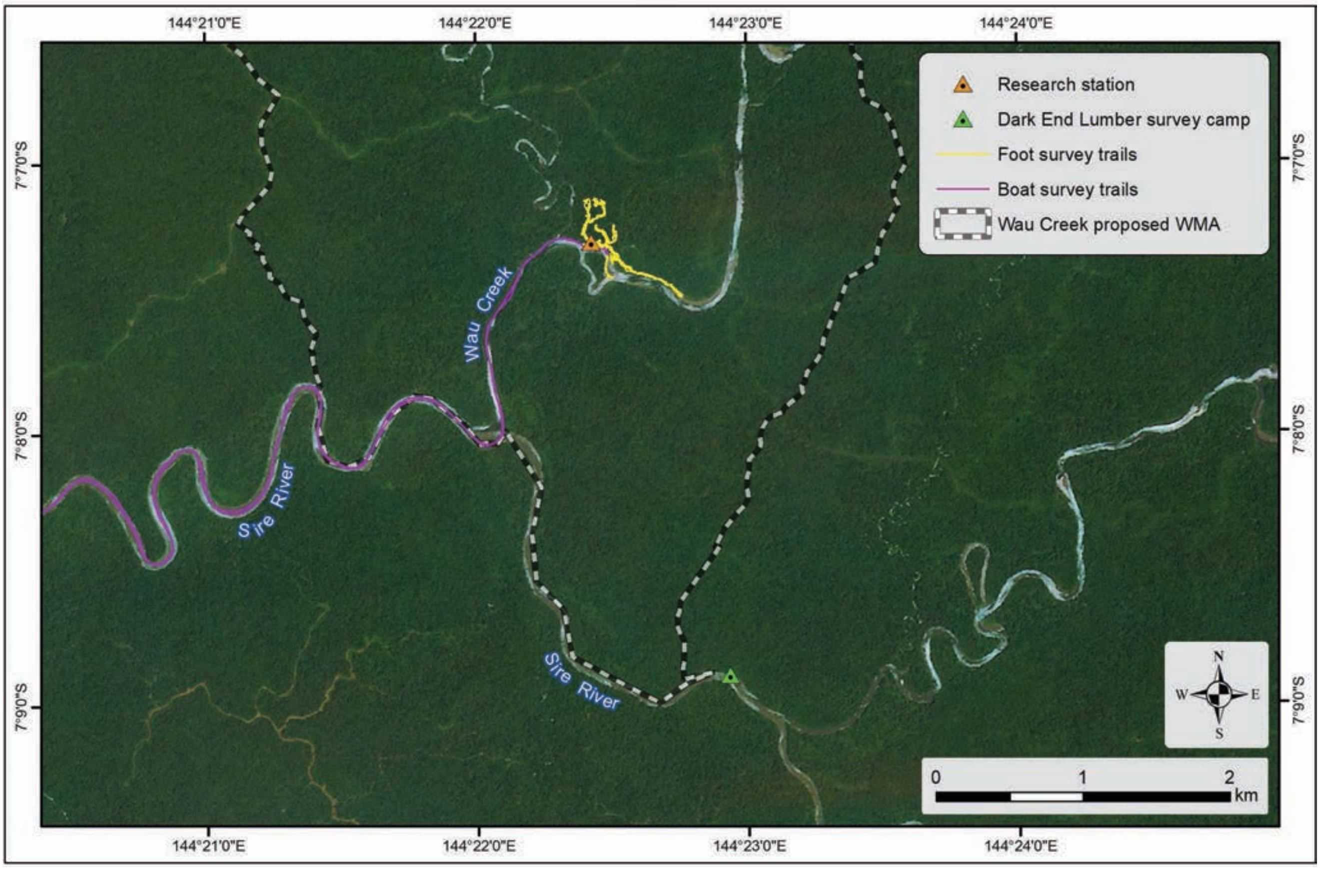

Figure 1. Odonate survey coverage at Wau Creek

Identifications are based largely on Michalski (2012), which summarises the papers on New Guinean odonates published by M. A. Lieftinck between 1933 and 1978, with reference also to Theischinger and Richards (2006a,b), Gassmann and Richards (2008), Theischinger and Richards (2008), Kalkman and Orr (2013) and Orr and Kalkman (2015). Comparative odonate material in existing public collections was also examined where necessary.

The conservation status of each species was taken from the IUCN Red List (IUCN 2017): LC = Least Concern; DD = Data Deficient; NE = Not Evaluated. Species are referred to as 'new to science' if they were discovered for the first time during this survey, and as 'undescribed' if they are unnamed but were previously know from other sites.

The general vegetation structure of the area is described in Chapter 1.1, and only those habitat features relevant to odonates are mentioned further here.

Results and discussion

Forty-six species of odonates were encountered at Wau Creek, including 23 species of damselflies (Zygoptera) and 23 species of dragonflies (Anisoptera). Six additional species, the damselflies *Idiocnemis patriciae*, *Nososticta acudens*, *Palaiargia* sp., *Papuagrion nigripedum* and *Tanymecosticta* sp. and the dragonflies *Orthetrum glaucum* and *Tetrathemis irregularis*, were recorded from Dark End Lumber immediately adjacent to Wau Creek by Richards (2000) bringing the total number of species from this small area to at least 52 (Appendix 1).

One species of damselfly in the platycnemidid genus *Nososticta* and one dragonfly in the libellulid genus *Nannophlebia* are new to science. They were discovered for the first time during this survey and are currently known only from Wau Creek. At least two additional species (in the genera *Bironides* and *Idiocnemis*) are undescribed, but they were each previously known from other sites in south-central PNG. All four of these species are associated with clear-flowing streams in forest. The *Nososticta*, *Bironides* and *Nannophlebia* were formally described during preparation of this report (Theischinger et al. 2017, 2018) and the description of the *Idiocnemis* is currently in press (Gassmann and Richards in press). Two species in the taxonomically difficult coenagrionid genus *Teinobasis* may also be new to science but additional studies are required before this can be confirmed.

Two species, the damselfly *Nososticta nigrifrons* and the dragonfly *Nannophya paulsoni* are listed as Data Deficient by the IUCN. All other species are listed as Least Concern or have not been evaluated (IUCN 2017).

A list of all species encountered during the 2017 survey, and additional species encountered at Dark End Lumber in 1999 (Richards 2000) is presented in Appendix 1, and species accounts are presented below for new species and other species of conservation significance. Representative species are illustrated in Plates 1 and 2.

Significant species

IUCN listed species

Two of the species encountered at Wau Creek have been evaluated by the IUCN as Data Deficient.

Family Platycnemididae: *Nososticta nigrifrons*

This is a small, blue and black damselfly (Plate 1C) that was common along small, moderately exposed side channels emptying into the main channel of Wau Creek. It is listed as Data Deficient by the IUCN due to the fact that it was 'Only known from the male holotype. No further information on distribution and habitat known' (Kalkman 2009). The holotype was collected in the Lorentz Drainage of southern Papua Province in 1910. However *N. nigrifrons* is now also known from the Lakekamu Basin (Richards et al. 1998) and from the foothills of the Star Mountains near Tabubil (Richards and Theischinger 2015). Its presence at Wau Creek confirms that this species has a wide distribution in the lowlands south of New Guinea's central cordillera.

Family Libellulidae: *Nannophya paulsoni*

Nannophya paulsoni is a tiny, slender dragonfly with a bright red abdomen (Plate 1D) that was previously known only from northern Australia. It is similar to *Nannophya pygmaea*, a species widespread from India to the Solomon Islands, and previous records of *N. pygmaea* from southern New Guinea may refer to *N. paulsoni*. At Wau Creek several males and one female were observed in full sun in a shallow, grassy seepage along the edge of an old logging trail. This species is listed as Data Deficient by the IUCN in part because: '*Nannophya paulsoni* is only known from two widely separated locations, with insufficient information on habitat requirements.' (Dow 2017). Based on current taxonomy the Wau Creek locality represents a significant range extension for this poorly known dragonfly and the first confirmed record of this species from Papua New Guinea. However, it is also possible that typical *Nannophya pygmaea* and *N. paulsoni* may represent extremes of clinal variation in a single, widespread species (Orr and Kalkman 2015).

Undescribed species and species new to science

Two species collected at Wau Creek were undescribed (previously known but not yet named), and two were new to science (discovered for the first time during this survey) at the time of the survey. Brief accounts for each of these species are provided below.

Family Platycnemididae: *Idiocnemis* sp.

A small species of the damselfly genus *Idiocnemis* with a banded abdomen and a distinct pattern on the thorax, is undescribed. This species was previously known from the Lakekamu Basin to the east of Wau Creek, and from Dark End Lumber immediately adjacent to Wau Creek, and is currently being described (Gassmann and Richards in press). At Wau Creek it was found only along small, clear-flowing streams where adults perched in dappled sunlight in low riparian vegetation. It was also found at Uro Creek during this survey.

Family Libellulidae: *Bironides ypsilon*

A medium-sized, rather nondescript green and black dragonfly (Plate 1E) that was found in forest adjacent to small, shaded, clear-flowing streams in lowland forest where adults perched in small sunny patches on low foliage. This species was previously known from several sites to the east of the Kikori Basin in Gulf Province and was recently described by Theischinger et al. (2017).

Family Platycnemididae: *Nososticta moginae*

A small, slender *Nososticta* species with a black face and purple markings on the thorax (Plate 1F) was discovered for the first time at Wau Creek during this survey. It is similar to the recently described *N. paraconifera*, but that species has larger blue (vs purple) patches on the thorax in life (Theischinger and Richards 2016). This new species of damselfly is known only from Wau Creek where it was found in dappled sunlight along narrow (< 5 m wide) and shallow (< 10 cm deep), slow-flowing streams under extensive canopy cover. It was recently described by Theischinger et al. (2018).

Family Libellulidae: *Nannophlebia ballerina*

A medium-sized, yellow and black dragonfly (cover photo, this chapter) that was found along the main channel of Wau Creek is new to science. Adults occupied open, sunny but inaccessible positions on steep banks where they perched on vegetation hanging over, or nearly so, the water below. This new species is currently known only from Wau Creek and it was recently described by Theischinger et al. (2017).

Family Coenagrionidae: *Teinobasis* ?spp nov.

Two species of the coenagrionid genus *Teinobasis* that were found along forest trails at Wau Creek may also be new to science, but additional studies are required to confirm their taxonomic status.

General comments

The documentation of 46 species within just five days of sampling demonstrates that the odonate fauna at Wau Creek is exceptionally diverse. For example Richards et al. (1998) documented 34 species of odonates during 23 days of sampling at a lowland site of comparable size in the Lakekamu Basin ~240 km to the southeast of Wau Creek. Although the number of species documented is also substantially higher than that recorded at the adjacent Dark End Lumber site during 1999 (Richards 2000), this reflects at least in part the fact that odonates were not the major target of that survey.

Comparison of damselfly diversity at Wau Creek (23 species) with that presented by Polhemus (1995) for the broader Kikori Basin is complicated by the fact that Polhemus visited most 'sites' – normally a single stream - only once, and very briefly (less than one day). As a result species totals per site in that study were an average of just 3.3 (Polhemus 1995). However Polhemus spent three days sampling streams around Omo, approximately 17 km NW of Wau Creek and reported a total of just 13 damselfly species from five sites. Most if not all of these are a subset of the Wau Creek fauna, although uncertainty about identifications of some species documented during the 1994 survey needs to be resolved before this can be confirmed.

Irrespective of these uncertainties it is clear that the Wau Creek odonate fauna is exceptionally diverse, that it contains a number of species that are new to science or undescribed, and that several of these are currently known only from the forests around Wau Creek.

Biodiversity and conservation values

The forest at Wau Creek supports an exceptionally high diversity of odonate species, among the highest recorded at any site in PNG. Despite previous logging activity within and around the Wau Creek proposed WMA the area also continues to support a suite of forest interior specialists, including undescribed and new to science species that are dependent on cool, shaded riparian habitats along clear-flowing streams for their survival. In contrast degraded forest habitats with more open canopies are hotter and drier and tend to support more common, widespread species that rapidly replace forest dependent species (Dolny et al. 2011, 2012). Although data on the pre-logging odonate fauna at Wau Creek are not available it is likely that some shifts in the structure of the local assemblage have occurred. This is indicated by the extremely high abundance of widespread libellulid dragonflies such as *Neurothemis* spp. that were observed along recent logging trails in the forest.

While much of the forest at Wau Creek has been affected by logging, patches of primary forest remain, particularly around the research station. These areas of unlogged forest provide habitat for forest interior specialists that were rare or absent in heavily disturbed areas. In particular the small, shaded clear-flowing watercourses and their adjacent riparian vegetation provide important habitat for a number of forest stream specialists. Dragonflies are considered to be excellent indicators of the health of freshwater environments and of the impacts of climate change (Clark and Samways 1996; Ott 2010) so the high species diversity documented, and the persistence of stream-dwelling forest interior species requiring clear, cool, unpolluted waterways for their survival suggest that the freshwater ecosystems at Wau Creek remain in excellent health.

Recommendations

Maintaining the high diversity of odonates at Wau Creek, and ensuring the long-term survival of stream-dwelling forest interior species in particular, will require that forest within the WMA be protected from future logging. In addition the following activities are recommended:

- Activities that damage or degrade riparian vegetation along small forest interior streams (such as collection of firewood, felling of trees on stream banks), particularly in the remnant patches of primary forest, should be minimised.

- Further research into the local odonate fauna, with a focus on understanding the impacts of logging and variation in forest structure on odonate diversity and community structure at Wau Creek should be encouraged.

- Local landowners intend to conserve the Wau Creek environment, and their support for research activities in the area should be encouraged more broadly, as a mechanism to generate income from their commitment to conservation.

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Plate 1

A. The main channel of Wau Creek

B. Forest stream in closed forest

C. *Nososticta nigrifrons* (IUCN Data Deficient)

D. *Nannophya paulsoni* (IUCN Data Defcient)

E. *Bironides ypsilon*

F. *Nososticta moginae*

Plate 2

A. *Metagrion trigonale*

B. *Rhinocypha tincta*

C. *Selysioneura cervicornu*

D. *Lyriothemis hirundo*

E. *Protorthemis coronata*

F. *Macromia celaeno*

Appendix 1. List of odonate species documented at Wau Creek in 2017 and at Dark End Lumber in 1999.

Species	Wau Creek	Dark End Lumber	IUCN Status
Damselflies			
Argiolestidae			
Metagrion trigonale	X	X	NE
Calopterygidae			
Neurobasis australis	X	X	LC
Chlorocyphidae			
Rhinocypha tincta	X	X	LC
Coenagrionidae			
Archibasis crucigera	X		LC
Papuagrion magnanimum	X		NE
Papuagrion nigripedum		X	NE
Papuagrion occipitale	X	X	NE
Pseudagrion fumipennis	X		NE
Pseudagrion microcephalum	X		LC
Teinobasis buwaldai	X		NE
Teinobasis debeauxi	X		NE
Teinobasis sp. 1 (black & white tail)	X		NE
Teinobasis sp. 3 (Wau Creek yellow)	X		NE
Teinobasis sp. 4 (Wau Creek)	X		NE
Isostictidae			
Selysioneura cervicornu	X		NE
Tanymecosticta sp.		X	NE
Platycnemididae			
Idiocnemis australis	X		NE
Idiocnemis patriciae		X	NE
Idiocnemis sp. 1	X	X	NE
Nososticta acudens		X	NE
Nososticta chrismulleri	X		NE
Nososticta moginae	X		NE
Nososticta nigrifrons	X	X	DD
Nososticta rosea	X	X	NE
Nososticta smilodon	X	X	NE
Nososticta truncata	X		NE
Platystictidae			
Drepanosticta dendrolagina	X		NE
Dragonflies			
Aeshnidae			
Agyrtacantha microstigma	X		NE
Anax maclachlani	?*		NE
Gynacantha kirbyi	X		LC

Species	Wau Creek	Dark End Lumber	IUCN Status
Corduliidae			
Hemicordulia continentalis	X		LC
Metaphya tillyardi	X		LC
Libellulidae			
Agrionoptera insignis	X		LC
Agrionoptera longitudinalis	X	X	LC
Bironides ypsilon	X		NE
Brachydiplax duivenbodei	X		LC
Diplacina erigone	X	X	NE
Huonia epinephele	X		NE
Lyriothemis hirundo	X		NE
Lyriothemis meyeri	X		LC
Nannophlebia ballerina	X		NE
Nannophya paulsoni	X		DD
Nesoxenia mysis	X		NE
Neurothemis decora	X		NE
Neurothemis stigmatizans	X		LC
Orthetrum glaucum		X	LC
Orthetrum serapia	X		LC
Orthetrum villosovittatum	X	X	LC
Pantala flavescens	X		LC
Protorthemis coronata	X		NE
Tetrathemis irregularis		X	LC
Macromiidae			
Macromia celaeno	? *		NE
Total number of species	**46**	**17****	

*Seen but not captured, most likely this species.

**The total number of species documented at Dark End Lumber was 20 (Richards 2000) but the taxonomic status of several species collected there is uncertain so their association with species at Wau Creek cannot be confirmed and they are excluded from this list.

Chapter 1.4. Herpetofauna of the Wau Creek proposed Wildlife Management Area, Gulf Province, Papua New Guinea

Stephen Richards, Simon Clulow, Deborah Bower and Arthur Georges

A juvenile Pig-nosed Turtle (*Carettochelys insculpta*)

Summary

We report the results of a survey of frogs and reptiles in the Wau Creek proposed Wildlife Management Area in Gulf Province, Papua New Guinea (PNG). Fifty-one species were encountered including 23 frogs and 28 reptiles. Five species of frogs are undescribed; and four of these are known only from a small area in south-central PNG. One species of treefrog, *Litoria richardsi*, is classified as Data Deficient by the IUCN owing to its poorly-known distribution and habitat requirements, and two species of large freshwater turtles are classified by the IUCN as Endangered (Pig-nosed Turtle, *Carettochelys insculpta*), and Vulnerable (New Guinea Giant Softshell Turtle, *Pelochelys bibroni*) owing to unsustainable harvesting over at least some of their range.

The forests at Wau Creek support a high diversity of frog and reptile species, and the freshwater streams there provide significant habitat for nesting Pig-nosed Turtles. Ongoing protection of these important nesting sites will help to ensure the long-term future of this iconic species in the Kikori basin.

Introduction

The herpetofauna of New Guinea is exceptionally diverse, with the total number of frog and reptile species known from the region currently exceeding 600 (Papuan Herpetofauna 2013). This number is expected to increase substantially as recent taxonomic revisions of the fauna and exploration of remote regions have revealed numerous new species, particularly in the frog families Hylidae (now Pelodryadidae) and Microhylidae (e.g. Kraus and Allison 2009; Richards et al. 2009; Günther et al. 2012; Günther and Richards 2011, 2016), the gecko genus *Cyrtodactylus* (e.g. Rösler et al. 2007; Oliver et al. 2008; Oliver et al. 2012, 2016) and the snake genus *Stegonotus* (Ruane et al. 2017).

Existing knowledge about the frogs and reptiles of the Kikori basin is derived largely from a series of surveys sponsored by the World Wildlife Fund (WWF) between 1995 and 2003. These covered habitats including mangroves, lowland, hill, and montane forest, and resulted in a number of unpublished flora and fauna inventories (e.g. Hartshorn 1995; Richards 2000, 2002b,c; Richards and Allison 2003) and a guide to the frogs of the Kikori basin (Richards 2002a). One of the surveyed sites, Dark End Lumber (DEL), is located immediately adjacent to the Wau Creek survey area (Richards 2000). Descriptions of numerous newly-discovered frog and several reptile species also resulted from these surveys (e.g. Richards 2007; Richards et al. 2007; Rösler et al. 2007; Richards and Oliver 2006, 2010). In addition, an assessment of the diversity and conservation status of freshwater turtles in the Kikori River basin was produced by Georges et al. (2008a).

Despite these efforts, survey coverage within the basin remains patchy and herpetofaunal communities are incompletely documented. Here we report the results of a series of herpetofauna surveys conducted at Wau Creek in Gulf Province, Papua New Guinea between 2015 and 2017.

Methods

Field methods

Sampling was undertaken during three survey periods; by SC, DB and AG from 15–26 November 2015 and 13–25 November 2016, and by SR from 22–26 April 2017, always with support and guidance from 2–3 local assistants. Field methodology closely followed the protocols proposed by Catenazzi et al. (2016) for rapid herpetofauna assessments in tropical environments. We conducted intensive searches for frogs and reptiles along a network of existing trails. During the day we searched for heliothermic (basking) reptiles along trails through forest, in clearings, and on stream banks. Small lizards were collected by hand or were stunned with a large rubber band. Large lizards and snakes were collected by hand. Non-basking reptiles were sampled by searching in deeply shaded forest, during rain, or at dusk. We searched for nocturnal reptiles, including geckos, by walking along forest trails at night with a headlamp. We searched for frogs at night by conducting visual-encounter and aural surveys along streams, and in and around small ponds. Because a large proportion of New Guinea's frogs have life cycles that are independent of freestanding water, we also conducted extensive visual and aural searches along trails in forest away from water. Frog calls are an important diagnostic character that assists greatly with species identification so whenever possible we recorded the advertisement calls of frogs with a Marantz PMD-661 Solid-state Recorder with a Sennheiser ME66 microphone [SR] or Marantz PMD660 Professional Solid State Recorder with a RØDE NTG-2 directional condenser microphone at a distance of approximately 30 cm [SC].

Representatives of most species were photographed alive and a small number of voucher specimens were retained for more detailed examination and identification. Voucher specimens were euthanized by submersion in chlorotone (for amphibians and small reptiles), or with lethal injection of chlorotone for larger reptiles. Specimens were fixed in 10% formalin solution, and then stored in 70% ethanol. Samples of liver tissue for DNA analyses were extracted from representative specimens and stored in 95% ethanol. Voucher specimens will be deposited in the Papua New Guinea National Museum and Art Gallery, Port Moresby, South Australian Museum, Australia and Australian Museum, Australia; tissue samples will be lodged with the Wildlife Tissue Collection at the University of Canberra and at the University of Newcastle.

The conservation status of each species was taken from the IUCN Red List (IUCN 2017): LC = Least Concern; DD = Data Deficient; NE = Not Evaluated. Species are referred to as 'undescribed' if they are unnamed but were previously known from other sites.

The general vegetation structure of the area is described in Chapter 1.1, and only those habitat features relevant to herpetofauna are mentioned further here. A map illustrating the trails used during this survey is presented in Figure 1.

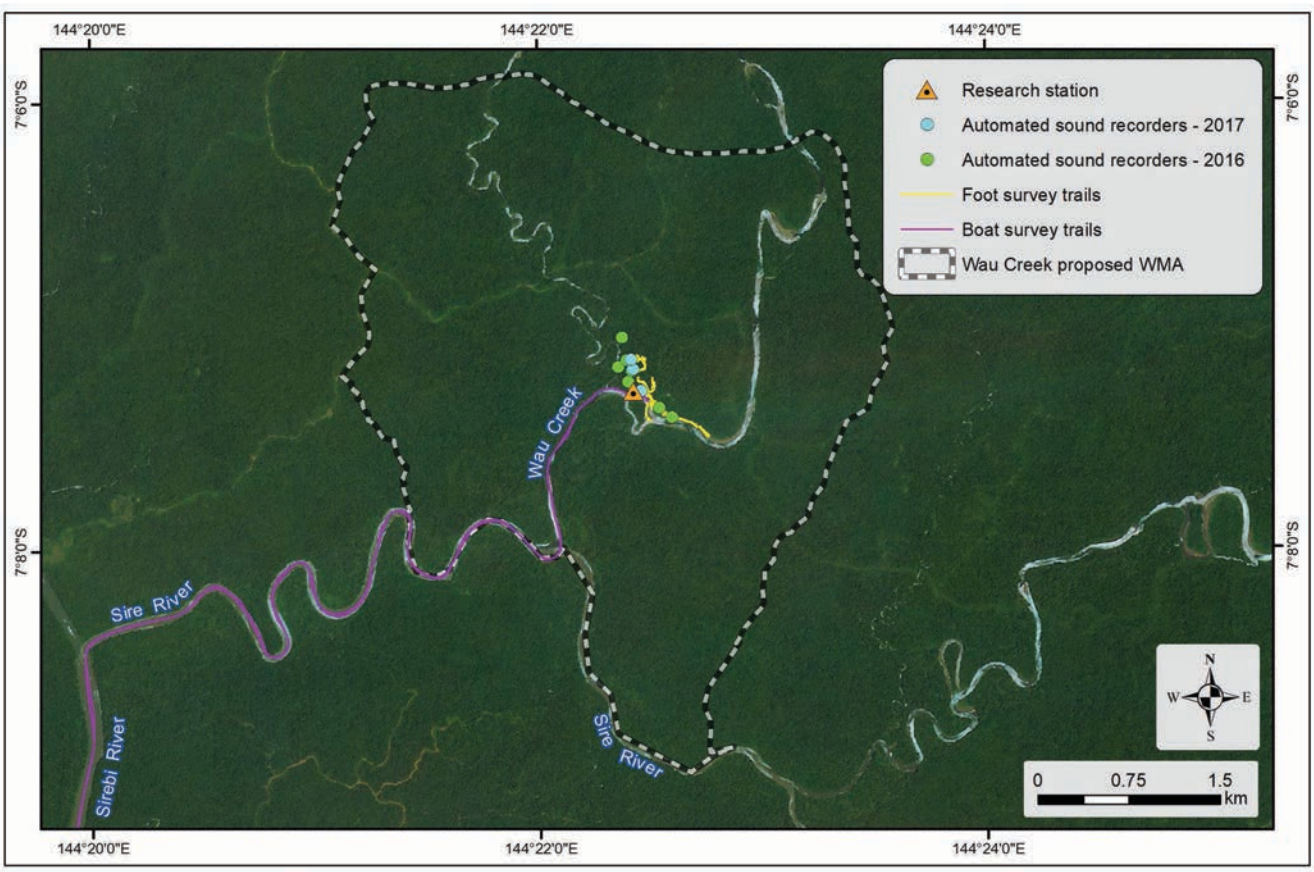

Figure 1. Herpetofauna survey coverage at Wau Creek

Automated sound recorders

In November 2016, SC, DB and AG deployed seven SongMeter SM2 audio recorders in forest and along watercourses within 500 m of the Wau Creek research station (Figure 1). Each unit recorded all audible sounds, including frog calls continuously for 6–7 days. In April 2017 SR deployed three automated sound recorders (SongMeter SM3) in forest environments within 300 m of the research station (Figure 1). These recorded continuously for four days of the 5-day survey period. All SongMeter recordings were screened for the calls of notable species, including frogs not detected during active survey periods, using Adobe Audition software. Images of all reptiles captured by the camera trap arrays established during both the 2016 reconnaissance and the 2017 survey (see Chapter 1.5) were also examined and species identified from these images are incorporated into the lists presented here.

Results and discussion

Fifty-one species were encountered during the three surveys including 23 frogs and 28 reptiles (Appendices 1 & 2). Five species of frogs appear to be undescribed and four of these are known only from a small area in south-central PNG. One species of treefrog, *Litoria richardsi*, is classified as Data Deficient by the IUCN owing to its poorly-known distribution and habitat requirements, and two species of large freshwater turtles are classified by the IUCN as Endangered (Pig-nosed Turtle, *Carettochelys insculpta*), and Vulnerable (New Guinea Giant Softshell Turtle, *Pelochelys bibroni*) owing to unsustainable harvesting over at least some of their range. Examples of frog and reptile species encountered and their habitats are illustrated in Plates 1 and 2.

The forests at Wau Creek support a high diversity of frog and reptile species, and the freshwater streams there provide significant habitat for nesting Pig-nosed Turtles. Ongoing protection of these important nesting sites will help to ensure the long-term future of this iconic species in the Kikori basin.

Undescribed and other significant species

Undescribed species

Five species collected during this survey are undescribed. These include three microhylid frogs in the genera *Copiula, Oreophryne* and *Xenorhina*, and two treefrogs in the genus *Litoria*. Brief accounts for each of these species are presented here. The status of one other species, the ranid frog here referred to *Papurana arfaki*, is uncertain. Some populations of this species in southern PNG are genetically distinct but we conservatively retain *arfaki* for the Wau Creek population pending further studies.

***Copiula* sp. 1. (Plate 1C)**

A moderately small (males 26–31 mm), short-legged microhylid frog with a plump body and an angular snout. At Wau Creek this species called from within litter on the forest floor. The call is a series of 2–4 harsh, rapidly produced 'yapping' notes lasting about 0.2–0.3 s. This species was previously known from several other sites in Gulf Province, including Kopi, and is listed as *Copiula* sp. nov. 2 in Richards (2002a).

***Oreophryne* sp. 1.**

A small (males <25 mm) microhylid frog with large finger discs that calls with a series of brief chirping notes from high in the canopy, and sometimes from lower foliage, in lowland forests. It is known from several localities in the south-central lowlands of Papua New Guinea but has yet to be formally described.

***Xenorhina* sp. 1. (see Plate 1C in Chapter 2.4)**

A moderately large (~45 mm), semi-fossorial (burrowing) frog with extremely short legs, a narrow snout and small eyes. This species lives under moist leaf litter on the forest floor where males call from small depressions in the soil under dense litter, or from within burrows in the humus layer itself. Occasionally a male will call from a semi-exposed position in the upper surfaces of the litter layer. The call consists of a long series of soft, hooting notes that increases in both pitch and intensity during the call sequence. *Xenorhina* sp. 1 is undescribed but it is known from several localities in the southern lowlands and foothills of Papua New Guinea spanning both the Kikori and Purari River catchments in Gulf Province. It is listed as *Xenorhina* sp. by Richards (2002a).

***Litoria* sp. 1. cf. *genimaculata* (Plate 1D)**

A medium sized (males to ~ 40 mm) slender treefrog with large eyes, limited webbing between the fingers and a small spine on each heel. This species is closely associated with slow-flowing but clear streams where males call from low riparian vegetation with a series of quiet ticking notes occasionally followed by a short trill. It belongs to a taxonomically difficult group of frogs related to *Litoria genimaculata* and is listed as *Litoria* sp. nov. 5 in Richards (2002a).

***Litoria* sp. 2. cf. *graminea* (Plate 1E)**

A large (to ~80 mm) green treefrog with extensive finger webbing that lives high in the forest canopy where males call with a guttural grunting sound. This species was previously confused with *Litoria graminea*, a species now known to occur only in the north-east of Papua New Guinea, and *Litoria sauroni*, which is known to occur nearby at Dark End Lumber (Richards and Oliver 2006). It is currently being described by Kraus (in press).

Species listed by IUCN or protected under PNG legislation

The conservation status of most frog and reptile species known from PNG has been evaluated by the IUCN for inclusion in the IUCN Red List. No species listed by the IUCN as Critically Endangered were encountered during this project but one species listed as Endangered, one species listed as Vulnerable and one that is listed as Data Deficient, were documented.

***Litoria richardsi* (Data Deficient; Plate 1F)**

A moderately small (30 mm), strikingly coloured treefrog with extensive thick, black webbing between the fingers and bold black and yellow markings ventrally. This species was previously known from a small number of sites between Tabubil in Western Province and the Gulf Province lowlands, with a single specimen also known from the Mamberamo basin of Papua Province, Indonesian New Guinea. In the original description of the species Dennis and Cunningham (2006) noted that they expected it to occur more widely in suitable habitat in intervening areas between the Star Mountains and the Mamberamo basin. The discovery of this species at Wau Creek confirms that *L. richardsi* has a broad distribution in central New Guinea. It is possible that this species breeds in tree-holes (Dennis and Cunningham 2006) and remains high in the canopy for most of its life.

One other frog species that was assessed as Data Deficient by the IUCN almost certainly occurs at Wau Creek. *Litoria sauroni* is a large, green treefrog related to *L. graminea* that has a striking colour pattern on the eye and extensive pigmentation on the nictitating membrane (third eyelid). This species was recorded adjacent to Wau Creek at the WWF Dark End Lumber survey site in 1999 (Richards and Oliver 2006) and was assessed as Data Deficient 'since it has only recently been described, and there is still very little known about its extent of occurrence, area of occupancy, status and ecological requirements' (Richards 2008).

***Carettochelys insculpta* (Pig-nosed Turtle; Endangered, see chapter cover)**

A large (to > 55 cm carapace length and 22 kg) freshwater turtle known only from the southern lowlands of New Guinea and several drainages in the Northern Territory of Australia (Georges and Rose 1993). In New Guinea it occupies most of the major drainages south of the central cordillera (Georges and Rose 1993; Rhodin and Genorupta 2000; Georges et al. 2008a,b). The Pig-nosed Turtle inhabits a wide variety of water bodies including rivers, swamps and lagoons. Adults are omnivorous, and in the Gulf Province lowlands feed primarily on unripe fruits, leaves, and stems of mangroves and Sonneratia spp. (Georges et al. 2008b), on other fruits and on various molluscs and crustaceans.

The Pig-nosed Turtle nests in sandy banks along major river channels, and it is also known to nest adjacent to water in the mouths of major rivers, on islands in river deltas, and even on coastal beaches (summary in Georges et al. 1980b). In New Guinea nesting occurs at night between September and February.

Adults and eggs of this species are widely consumed in the Kikori basin (Pernetta and Burgin 1980; Eisemberg et al. 2011, 2015). Other sources of mortality include predation by varanid lizards and inundation of nests during river flooding. The harvesting of *Carettochelys* for local consumption in at least some of its range in PNG is unsustainable, and a significant threat to the survival of these populations (Eisemburg et al. 2011, 2015).

***Pelochelys bibroni* (New Guinea Giant Softshell Turtle; Vulnerable, Plate 2A)**
A very large (carapace to > 100 cm) freshwater turtle endemic to the southern river drainages of New Guinea (Rhodin et al. 1993; Rhodin and Genorupa 2000). It occurs primarily in rivers and streams, although some coastal records do exist. Information about this species' distribution and natural history were presented by Rhodin et al. (1993). Few data have become available since, and Georges et al. (2008b) reported that this species is rarely encountered in the Kikori basin. Unlike the Pig-nosed Turtle *P. bibroni* feeds primarily on crustaceans, molluscs and fish and some aquatic plants may also be eaten. Nesting occurs between June and August or September along 'mudflats of the major rivers' when between 20 and 45 eggs are normally laid per clutch (Rhodin et al. 1993). Owing to its large size humans and crocodiles are the only predators of adults.

Rhodin et al. (1993) concluded that this species appears to be naturally rare and is heavily exploited when encountered, and Georges et al. (2008b) reported that in the Kikori basin the species is rare and probably critically endangered locally. It is listed as Vulnerable by the IUCN because of 'expected continuing decline in the future' (Asian turtle trade working group 2000, updated 2016). None of the species documented during this survey are protected by PNG law.

General comments

The total of 23 species of frogs documented at Wau Creek between 2015 and 2017 is similar to the diversity reported from the adjacent Dark End Lumber (DEL) site in 1999 (20 species; adjusted from 21 species in the original report based on new taxonomic knowledge) and there is a near-complete overlap of component species (Richards 2000). However the number of reptile species encountered at Wau Creek (28) is substantially higher than the 16 species found at DEL, and this probably reflects the generally slower rate of detection of reptiles (because frog calls are more easily detected) and the brief survey period at DEL (9 days vs a total of 30 days at Wau Creek).

The only other site with a comparable search effort for herpetofauna in the lowland forests of PNG is the Lakekamu basin (Allison et al. 1998). A six-week survey at Lakekamu in 1996 recorded 74 species including 30 frogs and 44 reptiles. The major differences between that site and Wau Creek are a much higher number of treefrog species (10 vs 5) and skinks (21 vs 9) at Lakekamu. Of particular note was a much higher diversity of skinks in the genera *Emoia* (7 vs 3 species) and *Sphenomorphus* (8 vs 3 species) at Lakekamu.

There are two possible explanations for this discrepancy. Firstly, the Lakekamu site was topographically more varied so more habitat types were encountered there than at Wau Creek. Habitats at Lakekamu that were not found at Wau Creek included large, permanent natural forest pools isolated from flowing streams containing fish; and torrential streams in the upper basin that supported a suite of specialist torrent-dwelling frogs. It is likely that, given the greater range of habitats available at Lakekamu, the herpetofauna diversity there really is somewhat greater than at Wau Creek.

However secondly, the survey effort at Wau Creek was focused heavily towards detecting frogs. Many skinks in the genus *Sphenomorphus* in particular are crepuscular, occur at low density, and can be difficult to detect. These reptiles require intensive search effort focused on cryptic litter-dwelling lizards. The survey effort at Lakekamu was substantially more focused on this component of the fauna than the survey at Wau Creek and it is likely that the number of lizard species occurring at Wau Creek is substantially higher than we documented.

Biodiversity and conservation values

The forests at Wau Creek support a high diversity of frog and reptile species, and the freshwater streams there provide significant habitat for nesting Pig-nosed Turtles. The invasive Cane Toad (*Rhinella marina*), which is abundant at Kopi, was not detected at Wau Creek. Despite previous logging activity within and around the Wau Creek proposed WMA the area continues to support both a rich herpetofauna and a number of iconic species, including the Pig-nosed Turtle and Giant New Guinea Softshell Turtle, listed by the IUCN as Endangered and Vulnerable respectively owing to unsustainable harvesting. Also detected on camera traps at Wau Creek was a Crocodile Monitor (*Varanus savadorii*; Plate 2B), a poorly known species that is one of the longest lizards in the world.

One species of canopy-dwelling frog found at Wau Creek, *Litoria richardsi*, is listed as Data Deficient and another, *L. sauroni*, almost certainly occurs there. Both have small known distributions focused on south-central PNG so the forest at Wau Creek, and particularly the patches of primary forest around the research station, represents significant habitat for these species. The small, shaded clear-flowing watercourses and their adjacent riparian vegetation at Wau Creek also provide important habitat for an undescribed treefrog related to *Litoria genimaculata*, and the moist litter on the forest floor shelters two species of undescribed microhylid frogs (*Copiula* sp. 1 and *Xenorhina* sp. 1) that have small known distributions in the lowlands of southern PNG. Like other terrestrial Australopapuan microhylid frogs (Anstis et al. 2011) these species are predicted to lay direct-developing eggs in or under moist litter on the forest floor. Because reduction of the forest canopy through damage to or removal of trees in the primary forest increases insolation to, and reduces humidity and moisture content of, the litter layer potentially increasing embryonic mortality of these species the patches of primary forest at Wau Creek are important for their long-term survival.

Recommendations

Maintaining the diversity of herpetofauna at Wau Creek, and ensuring the long-term survival of freshwater turtles and of canopy and litter-dwelling frogs in particular, will require that forest within the proposed WMA be protected from future logging. In addition the following activities are recommended:

- Ongoing protection of Pig-nosed Turtle nesting sites, and further research into the species' ecology and conservation status, will help to ensure the long-term future of this iconic turtle in the Kikori basin.

- Formal recognition of the Wau Creek area as a WMA should be finalised, working with the local landowners, local and regional government authorities and the CEPA.

- Landowners at Wau Creek should be encouraged to broaden their focus from the Pig-nosed Turtle to the accompanying benefits of the proposed WMA for the ecological community more generally, and the other vulnerable or threatened species that reside there.

- Activities that damage or degrade the remaining patches of primary forest in the proposed WMA should be prevented or minimised, including cutting of timber for construction activities or fuel.

- The invasive Cane Toad (*Rhinella marina*), which is abundant at Kopi, was not detected at Wau Creek. This species is commonly transported between sites in human cargo, and in PNG and Solomon Islands is sometimes deliberately moved to new sites in the belief that it control snakes. Care should be taken to avoid accidentally transporting this toad to Wau Creek among cargo in canoes.

- Local landowners intend to conserve the Wau Creek environment, and their support for research activities in the area should be encouraged more broadly, as a mechanism to generate income from their commitment to conservation and attendant loss of opportunity from logging and harvesting.

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Plate 1

A. The main channel of Wau Creek

B. Small stream in forest interior

C. *Copiula* sp. 1

D. *Litoria* sp. 1

E. *Litoria* sp. 2

F. *Litoria richardsi* (IUCN Data Deficient)

Plate 2

A. *Pelochelys bibroni*

B. *Varanus salvadorii*

C. *Litoria auae*

D. *Lechriodus melanopyga*

E. *Sphenophryne cornuta*

F. *Callulops doriae*

Appendix 1. List of frog species encountered at Wau Creek and their IUCN status

Species	IUCN Status
Limnodynastidae	
Lechriodus melanopyga	LC
Microhylidae	
Austrochaperina palmipes	LC
Callulops doriae	LC
Callulops omnistriatus	NE
Choerophryne crucifer	NE
Copiula derongo	LC
Copiula guttata	LC
Copiula sp. 1 (fast call)	NE
Hylophorbus rufescens	LC
Mantophryne lateralis	LC
Metamagnusia slateri	LC
Oreophryne oviprotector	NE
Oreophryne pseudunicolor	NE
Oreophryne sp. 1 (small chirper)	NE
Sphenophryne cornuta	LC
Xenorhina sp. 1	NE
Pelodryadide	
Litoria auae	LC
Litoria infrafrenata	LC
Litoria richardsi	DD
Litoria sp. 1 cf. *genimaculata*	NE
Litoria sp. 2 cf. *graminea*	NE
Ranidae	
Papurana arfaki	LC
Papurana daemeli	LC
Total number of species = 23	

Appendix 2. List of reptiles encountered at Wau Creek and their IUCN status

Species	IUCN Status
Agamidae	
Hypsilurus dilophus	LC
Hypsilurus magnus	LC
Hypsilurus modestus	LC
Gekkonidae	
Cyrtodactylus novaeguineae	LC
Cyrtodactylus serratus	LC
Gehyra sp.	NE
Scincidae	
Carlia aenigma	LC
Emoia caruleocauda	LC
Emoia longicauda	NE
Emoia physicina	LC
Lygisaurus sp.	NE
Sphenomorphus muelleri	NE
Sphenomorphus meyeri	LC
Sphenomorphus simus	LC
Tiliqua gigas	NE
Varanidae	
Varanus indicus-group	LC
Varanus salvadori	LC
Colubridae	
Boiga irregularis	NE
Dendrelaphis calligaster	LC
Stegonotus cucullatus	NE
Stegonotus parvus	NE
Pythonidae	
Morelia amethestina	LC
Morelia viridis	LC
Carettochelyidae	
Carettochelys insculpta	VU
Chelidae	
Elseya rhodini	NE
Trionychidae	
Pelochelys bibroni	VU
Crocodylidae	
Crocodylus novaeguineae	LC
Crocodylus porosus	LC
Total number of species = 28	

Chapter 1.5. Avifauna of the Wau Creek proposed Wildlife Management Area, Gulf Province, Papua New Guinea

Iain A. Woxvold

A juvenile Southern Cassowary at Wau Creek

Summary

Birds were surveyed at the Wau Creek proposed Wildlife Management Area (WMA) in the Sirebi River catchment of the lower Kikori River basin in Gulf Province, Papua New Guinea. Surveys were conducted in two phases during November–December 2016 and April–May 2017. Survey methods included active searches (across seven days), camera trapping (35 cameras, >263 camera trap days), mist netting (18 nets) and automated sound recording (10 recorders, 60 recorder days). The results of bird surveys conducted by Jared Diamond and David Bishop at 'Dark End Lumber' on the Sire River in October 1999 (across four days) are combined with those of the present study. One hundred and thirty-five bird species have been recorded. Twenty birds from 13 species were mist netted or otherwise captured and 12 bird species were photographed by camera trap. Bare-eyed Rail (*Gymnocrex plumbeiventris*) and Black-billed Brushturkey (*Talegalla fuscirostris*) were the most frequently camera trapped species. Fourteen conservation listed species were recorded, including three birds listed by the IUCN as Vulnerable (Papuan Eagle (*Harpyopsis novaeguineae*), Scheepmaker's Crowned Pigeon (*Goura scheepmakeri*), Pesquet's Parrot (*Psittrichas fulgidus*) and 14 species that are Protected under Papua New Guinean law. Camera trap records of Scheepmaker's Crowned Pigeon extend the known geographic range of this restricted-range species west from the Purari basin. Existing avian conservation values are discussed and recommendations for their future enhancement are proposed.

Introduction

New Guinea and its satellite islands support the world's highest concentration of endemic birds (Gregory 2013). The region is exclusively home to seven bird families (Melanocharitidae, Paramythiidae, Cnemophilidae, Melampittidae, Rhagologidae, Eulacestomidae, Ifritidae) and to most species of bird-of-paradise (Paradisaeidae), bowerbirds (Ptilonorhynchidae), Australasian robins (Petroicidae), cassowaries (Casuariidae) and owlet-nightjars (Aegothelidae). Of nearly 800 bird species recorded in the New Guinea region, nearly half are found nowhere else (365/779 species: Pratt and Beehler 2015).

Rates of endemism are highest in New Guinea's montane environments, its lowland biotas having stronger affinities with those of neighbouring regions. The southern lowlands of New Guinea form part of the northern rim of the Australo-Papuan continental shelf, and accordingly support a comparatively high proportion of Australian taxa (Gressitt 1982). In general, these affinities are strongest at higher taxonomic levels (genera and above) and within the seasonally dry and coastal environments that characterize much of northern Australia and parts of southern mainland Papua New Guinea (the Trans-Fly and around Port Moresby). By contrast, the lowland rainforests of southern mainland Papua New Guinea support a comparatively high proportion of regional-endemic forest bird species.

In western mainland Papua New Guinea, the Hegigio-Kikori River system drains some of New Guinea's wettest forest environments, from the Southern Fold Mountains of Hela and Southern Highlands Provinces through Gulf Province and into the Gulf of Papua. In western Gulf Province, the Kikori River flows south through predominantly karstic landforms of the Kikori-Lake Kutubu Karst Area to the estuarine swamps and mangrove plains of the expansive Kikori River delta (Löffler 1977; Bryan and Shearman 2008). Upstream of the delta, the lower Kikori basin extends east beyond the limestone deposits via the Sirebi River catchment across non-calcareous sedimentary hills and the volcanic footslopes of Mount Duau.

In the centre of the Sirebi River catchment, landowners are in the process of establishing a protected area – the Wau Creek proposed Wildlife Management Area (WMA) – initially set up to protect nesting sites of the Pig-nosed Turtle (*Carettochelys insculpta*) (Eisemberg and Georges 2012). As part of a broader multi-disciplinary biodiversity study, this report outlines the results of bird surveys undertaken in 2016–2017 within the Wau Creek proposed WMA.

The Wau Creek environment

The Wau Creek proposed WMA is located approximately 20 km southwest of Mount Duau and 22 km east of the Kikori River at its closest point (see Figure 1 in Report Summary). Centred on Wau Creek and bordered in the south by the Sire River (Figure 1), a tributary of the Sirebi River, the proposed WMA covers 1,605 hectares (ha) of foothill and alluvial terrain, mostly below 100 m above sea level (asl) with some sites in the northwest reaching over 165 m asl.

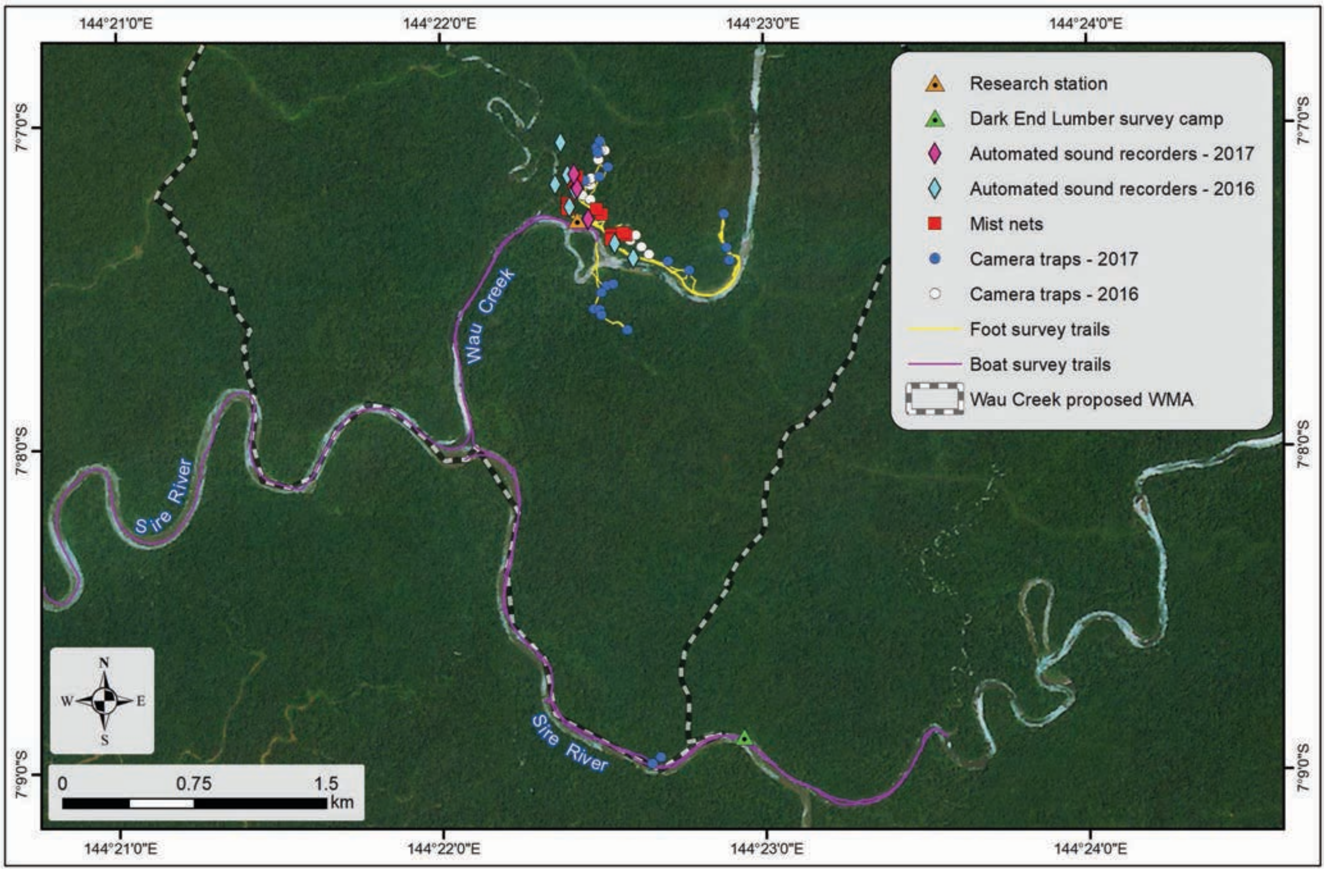

Figure 1. Bird survey coverage at the Wau Creek proposed WMA.

The proposed WMA is located near the eastern end of the South Papuan Lowlands Endemic Bird Area (EBA) as defined by BirdLife International (Stattersfield et al. 1998):

"This EBA includes the south-west lowlands and foothills bordering the Snow and Star mountains from the Mimika River (in the Indonesian province of [Papua]) to the drainages of the Kikori and Purari rivers (in Papua New Guinea)" (Stattersfield et al. 1998, p. 556).

In a local regional context, the proposed WMA lies within the 'Kikori-Purari' biogeographic region identified by Beehler (1993) for warm-blooded vertebrates (mammals and birds). This biogeographic region is contained within the Gulf Province lowlands (not above 500 m asl) and extends from the Turama River east to the Vailala River.

The landforms, geology, climate and vegetation of the Wau Creek area are summarised in detail in the Report Summary.

Existing Data

In the late 1980s commercial reserves of oil and gas were discovered in Southern Highlands Province in the uplands of the Kikori River basin. In partnership with industry leaders (a joint venture led by Esso Highlands Limited, then operator of the PNG LNG Project), in 1994 WWF initiated the Kikori Integrated Conservation and Development Project (KICDP), currently termed the Kikori Basin Conservation Program, aimed at preserving biodiversity within the Kikori drainage (Leary et al. 1996; McCall and Flemming 2000). Since then, the avifauna of the Kikori lowlands has been surveyed in a variety of habitats by a number of experienced ornithologists, including Ian Burrows, Jared Diamond, David Bishop and Roger Jaensch. Most of these surveys were conducted more than 25 km west of the Wau Creek proposed WMA and within a few kilometres of the Kikori River.

Within the Sirebi River catchment, during 2–5 October 1999 Diamond and Bishop surveyed birds at 'Dark End Lumber' on the Sire River (Diamond and Bishop, Undated A). The Dark End Lumber camp was situated within 500 m of the proposed Wau Creek WMA boundary and within the boat survey coverage achieved during the 2017 surveys (Figure 1). Survey methods included active searches and tape recording of bird vocalizations with subsequent analysis of recorded sounds; no trapping was undertaken. The results of the 1999 surveys are combined with those of the present study.

Numerous additional surveys have been conducted in comparable lowland environments elsewhere within the lower Kikori basin—in the Sirebi River catchment near Omo village upstream from the Sire River (Burrows 1995); at various sites along the lower Kikori River and its tributaries upstream from the deltaic zone (Utiti Creek, Pinini Creek, Uro (Veiru) Creek, Iviri, Kopi and Kikori: Burrows 1995; Diamond and Bishop, Undated A, B; Jaensch and Watkins, Undated; Leary, Undated A, B; Leary and Seri, Undated; Woxvold, Chapter 2.5); and in the Kikori delta (Diamond and Bishop, Undated A, B; Jaensch and Watkins, Undated). The results of these surveys provide context for a broader understanding of the Wau Creek bird community.

Methods

Birds were surveyed by IW at Wau Creek in two phases:

- During November–December 2016, as part of a reconnaissance survey of various sites in the lower Kikori basin.
- During April–May 2017.

Accommodation on most nights was based on a boat moored off-site, either at Kopi Shore Base on the Kikori River approximately 27.5 km southwest of the proposed WMA boundary (2016 and part of 2017), or on the Sirebi River approximately 4 km (6.9 river-km) southwest of the proposed WMA (most of 2017). The proposed WMA was accessed daily by tender from these locations. One night was spent at the research station (at S 7.12170° E 144.37390°; Figure 1) on 24 April 2017.

Survey methods included 'active' searches, automated sound recording, mist netting and camera trapping (Table 1). These techniques were combined to maximise completeness of the bird species inventory in the time available.

Table 1. Effort summaries.

Sampling method/effort	2016 reconnaissance	2017 survey
Active searches		
Sampling period	28 November & 5 December	22–26 April
Search hours	10.00	22.25
Camera trapping		
Sampling period	28 November–5 December	22 April–3 May
No. camera traps	15	20
Camera trap hours	2,483.50	3,844.25
Mist netting		
Sampling period	–	22–26 April
No. mist nets	–	18
Diurnal net-hours	–	81
Automated sound recording		
Sampling period	–	22–26 April
No. recorders	–	3
Recording hours	–	273.00

Active searches

Active searches were conducted by boat (motorised tender) along the Sire River and Wau Creek, and by foot through forest, along watercourses and along pre-existing walking trails. Foot surveys were conducted within a 1 km radius of the research station located on Wau Creek in the centre of the proposed WMA (Figure 1). Birds were surveyed at all times of day and identified visually and/or by their calls. Effort was weighted to early morning and late afternoon when access was possible at these times.

Camera trapping

Thirty-five white-flash digital camera traps (Reconyx HC550/PC850) were deployed unbaited along animal trails and at apparent feeding stations in an effort to photograph terrestrial birds and mammals. All camera traps were programmed to maximum detection sensitivity and to take three photographs on each 'trigger event' with the minimum amount of rest time between triggers (<2 seconds). Units were deployed for a total of more than 6,300 camera trap-hours (Table 1). Camera trap locations are shown in Figure 1.

Relative abundance indices (RAIs) were calculated from the rate of independent photographic capture 'events' (per hour x 100) summed across all cameras (Appendix 1). Events were considered independent where consecutive pictures of the same species were taken more than 30 minutes apart. Multiple events were scored within 30-minute periods where more than one individual was seen in a single photograph and/or where plumage differences permitted identification of separate individuals in successive photographs.

Mist netting

Eighteen mist nets (12 m, 31 mm mesh) were deployed by the bird and mammal survey teams in forest on ridges, terraces and alluvial flats. All nets were erected close to the ground (<6 m high) on trimmed saplings and checked regularly during daylight hours. Nets were left in position for 1–3 days before being moved to a new location or closed permanently. Most nets were open overnight in an effort to catch bats. Eight mist nets were open during the day for a total of 81 daylight net-hours.

Captured birds were measured (bill, head, tarsus, wing), photographed and a small sample of blood was collected in 70% ethanol. All birds were released with the terminal end of three outer tail feathers clipped to permit identification on recapture.

Automated sound recorders

In 2017, three automated sound recorders (Wildlife Acoustics: Song Meter SM3) were deployed by herpetologist Stephen Richards in forest environments within 300 m of the research hut (Figure 1). These recorded audible sounds, including bird calls, continuously throughout the four-day sampling period (Table 1).

Previously, in November 2016 herpetologists from the University of Newcastle, James Cook University and University of Canberra (hereafter 'University of Canberra team') deployed seven Song Meter SM2 recorders in forest and along watercourses within 500 m of the research hut (Figure 1). Each unit recorded continuously for 6–7 days for a total of more than 1,070 sampling hours.

All Song Meter recordings were screened for the calls of notable species, including conservation listed species and birds not detected during active survey periods, using iZotope RX 5 Audio Editor software.

Conventions used

Taxonomy and nomenclature (common and scientific names) follow the International Ornithological Congress (IOC) World Bird List (version 8.1) (Gill and Donsker 2018). Where species are mentioned in the text the scientific name appears with the common name on first mention and only the common name is used thereafter.

Species appearing in square brackets (in text, tables and appendices) were only provisionally identified to species level. Though not definitively identified, encounters are considered most likely to have involved the species named.

Conservation listed species include those listed in the IUCN Red List of Threatened Species (IUCN 2017) as Threatened (Vulnerable—VU; no Endangered or Critically Endangered bird species were recorded or are expected to occur at Wau Creek), Near Threatened (NT) or Data Deficient (DD) and those listed as Protected (P) under the *PNG Fauna (Protection & Control) Act 1966*. The list of nationally protected species was obtained from Kula and George (1996). Restricted range (RR) species are those having a total global breeding range of less than 50,000 km^2 (Stattersfield et al. 1998).

A Garmin 60CSx GPS unit was used to record tracks and coordinates in the field.

Results

At least 135 bird species from 42 families have been recorded within and/or immediately adjacent to the Wau Creek proposed WMA (Appendix 1), including 110 species during the 2016–2017 surveys and 117 species in 1999 (Diamond and Bishop, Undated A).

Adjustments were made to the identity of three species reported by Diamond and Bishop in 1999:

- Brushturkeys recorded only to genus level in 1999 (*Talegalla* sp.) are here referred to Black-billed Brushturkey (*Talegalla fuscirostris*) based on 2016–2017 camera trap records (Figure 2), discussion with local landowners and the results of extensive camera trapping effort across the Gulf Province lowlands (Kikori, Era and Purari River catchments; I. Woxvold, unpublished data).

- The 1999 record of Southern Crowned Pigeon (*Goura scheepmakeri*) does not indicate which former subspecies (*G. s. scheepmakeri* or *G. s. sclaterii*) was involved. Many direct encounters with crowned pigeons are fleeting and do not enable identification beyond genus level. Based on 2016–2017 camera trap records (see Species accounts), the 1999 record is here provisionally referred to Scheepmaker's Crowned Pigeon (*G. scheepmakeri*), the eastern taxon recently elevated to species level.

- Diamond and Bishop's listing of Buff-faced Pygmy Parrot (*Micropsitta pusio*) is here provisionally changed to Yellow-capped Pygmy Parrot (*P. keiensis*). The reasoning for this change is outlined below (Species accounts).

During the 2016–2017 surveys, 20 birds from 13 species were mist netted (19 birds, 12 species) or otherwise captured (one cassowary chick) and 12 bird species were photographed by camera trap (Appendix 1). Camera trap rates (RAIs) for photographed species are displayed in Figure 2. The Bare-eyed Rail (*Gymnocrex plumbeiventris*) and Black-billed Brushturkey were the most frequently camera trapped bird species; the number of photographic events for these taxa (33 and 29 respectively) was more than twice that of the next most frequently photographed birds—Papuan Pitta (*Erythropitta macklotii*; 11 events), Blue Jewel-babbler (*Ptilorrhoa caerulescens*; 10 events), Southern Cassowary (*Casuarius casuarius*; eight events) and Cinnamon Ground Dove (*Gallicolumba rufigula*; eight events).

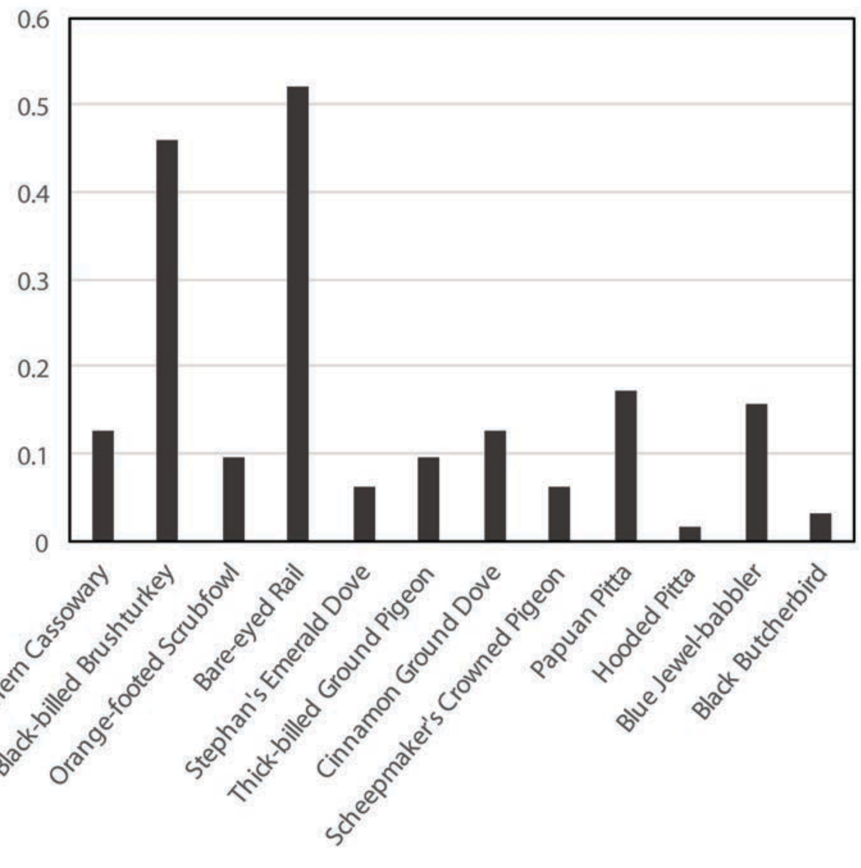

Figure 2. Camera trap rates (RAIs).

The Wau Creek avifauna includes 124 breeding resident species and 11 species that occur in the Kikori basin only or predominantly as non-breeding migrants (Appendix 1). Two breeding resident species – Pacific Koel (*Eudynamys orientalis*) and Oriental Dollarbird (*Eurystomus orientalis*) – have local populations seasonally augmented by non-breeding visitors from Australia. Breeding resident taxa include 122 species of terrestrial environments and two potentially locally breeding wetland species—Little Ringed Plover (*Charadrius dubius*) and Torrent Flyrobin (*Monachella muelleriana*). Recorded migrants include: seven terrestrial species—Pacific Koel, Channel-billed Cuckoo (*Scythrops novaehollandiae*), Oriental Cuckoo (*Cuculus optatus*), White-throated Needletail (*Hirundapus caudacutus*), Oriental Dollarbird, Sacred Kingfisher (*Todirhamphus sanctus*) and Rainbow Bee-eater (*Merops ornatus*); and six wetland species—Great Egret (*Ardea alba*), Intermediate Egret (*A. intermedia*), Little Egret (*Egretta garzetta*), Little Pied Cormorant (*Microcarbo melanoleucos*), Australasian Darter (*Anhinga novaehollandiae*) and Common Sandpiper (*Actitis hypoleucos*). Most migratory birds occurring at Wau Creek breed outside New Guinea in Australia (at least seven species) or in Asia (Oriental Cuckoo, Common Sandpiper). Four of the migratory wetland species – Great Egret, Intermediate Egret, Little Pied Cormorant and Australasian Darter – breed both in Australia and locally in New Guinea outside of the Kikori basin (predominantly Trans-Fly wetlands), so that the provenance of birds sighted at Wau Creek cannot be determined.

Fourteen conservation listed species have been recorded (Table 2). They include three birds listed by the IUCN as Vulnerable (Papuan Eagle (*Harpyopsis novaeguineae*), Scheepmaker's Crowned Pigeon, Pesquet's Parrot (*Psittrichas fulgidus*)) and 14 species that are Protected under Papua New Guinean law. One bird species – Scheepmaker's Crowned Pigeon – is restricted-range. Conservation listed species are discussed individually below (Species accounts).

Table 2. Conservation listed bird species recorded from Wau Creek.
Status indicates species listed as globally threatened (VU—Vulnerable) by the IUCN, those Protected (P) under the *PNG Fauna (Protection & Control) Act 1966*, and restricted-range (RR) species.

Scientific Name	English Name	Status
Ardea alba	Great Egret	P
Ardea intermedia	Intermediate Egret	P
Egretta garzetta	Little Egret	P
Harpyopsis novaeguineae	Papuan Eagle	VU, P
Goura scheepmakeri	Scheepmaker's Crowned Pigeon	VU, P, RR
Rhyticeros plicatus	Blyth's Hornbill	P
Probosciger aterrimus	Palm Cockatoo	P
Psittrichas fulgidus	Pesquet's Parrot	VU, P
Manucodia ater	Glossy-mantled Manucode	P
Phonygammus keraudrenii	Trumpet Manucode	P
Ptiloris magnificus	Magnificent Riflebird	P
Cicinnurus regius	King Bird-of-paradise	P
Seleucidis melanoleucus	Twelve-wired Bird-of-paradise	P
Paradisaea raggiana	Raggiana Bird-of-paradise	P

Species accounts

Species accounts follow for conservation listed taxa, rarely recorded species, species of significance to local communities, and wherever records extend a species' known geographical limits. Accounts for IUCN Threatened species include a summary of threats and susceptibilities.

Southern Cassowary (*Casuarius casuarius*)
The Southern Cassowary (Plate 2C-D) occurs in southern New Guinea and Australia in lowland and foothill forest, normally below 300 m asl but occasionally higher (Coates 1985; Beehler and Pratt 2016). The world's largest avian frugivores, cassowaries play a critical role in forest ecosystem dynamics by dispersing the seeds of many rainforest plant species, including those with large fruits that lack alternative biological dispersal vectors (Mack 1995; Mack and Wright 2005; Westcott et al. 2008).

All cassowary species are hunted in New Guinea for their meat, plumes and other body parts, and captive chicks are reared by hand for food or trade (Coates 1985; Johnson et al. 2004; I. Woxvold, pers. obs.). Cassowaries are currently in high demand as bride price gifts in Papua New Guinean highland communities, providing opportunity for large financial rewards for some local hunters. Consequently, cassowaries are now rare or have been extirpated from the vicinity of many settled areas (e.g. Brodie and Pangau-Adam 2017). Until recently considered Vulnerable by the IUCN, the Southern Cassowary is now classified as Least Concern due largely to the presence in southern New Guinea of extensive areas of remote lowland forest where human population and hunting pressure are low.

The Southern Cassowary was moderately common at Wau Creek—footprints and faeces were observed near the research station in 2016 and 2017, cassowaries were photographed on seven camera traps in 2016 and one camera trap in 2017, cassowary calls were recorded on a Song Meter unit deployed by the University of Canberra team in 2016, and the species was recorded by Diamond and Bishop in 1999. Camera trap records include pictures of adult and subadult birds, indicating local breeding activity. Lower camera trap rates in 2017 may reflect increased human activity in the vicinity of the research station during the main biodiversity study phase; the one bird photographed in 2017 was along the Sire River some 3 km south of the research station.

Great Egret (*Ardea alba*), Intermediate Egret (*A. intermedia*), Little Egret (*Egretta garzetta*) (P)
Three nationally Protected egret species have been recorded at Wau Creek—the Great Egret (*Ardea alba*) in 1999, and singles of Intermediate Egret (*A. intermedia*) and Little Egret (*Egretta garzetta*) seen along the Sire River in April 2017.

Each of these species occurs throughout New Guinea in a variety of wetland habitats, predominantly in the lowlands but occasionally up to montane elevations (Coates 1985). Their breeding status in New Guinea is poorly understood; some birds are present in all months, but each year there is a significant exchange of waterbirds between Australia and New Guinea with most birds occurring locally as non-breeding visitors (Coates 1985; Dingle 2004). Breeding at specific locations has been confirmed for the Great Egret (Aroa River, Trans-Fly) and Intermediate Egret (Trans-Fly) but not for the Little Egret (Bishop 2005; Beehler and Pratt 2016). There are no notable off-river waterbodies in the Wau Creek proposed WMA, and these species are not expected to breed locally or to visit in large numbers.

Papuan Eagle (*Harpyopsis novaeguineae*) (VU, P)
New Guinea's largest raptor, the Papuan Eagle inhabits forested habitats from sea-level to over 3,000 m asl. Visually inconspicuous (it does not soar), this species is most readily detected by its distinctive and far-carrying call.

The Papuan Eagle was recorded locally by Diamond and Bishop in 1999.

This low-density species is uncommon throughout its range and is vulnerable to habitat loss and hunting (Coates 1985; Watson and Asoyama 2001). While most records are from undisturbed forest, it also persists in logged forest (I. Woxvold, unpublished data), presumably where suitable prey remains. In many areas it is actively targeted by hunters for its plumes which are used for ceremonial purposes. As a result, it is now rare or extirpated from areas near human settlement where hunting persists (Coates 1985; Watson and Asoyama 2001).

Bare-eyed Rail (*Gymnocrex plumbeiventris*)
This elusive ground-bird is shy and difficult to detect. Not previously recorded in the lower Kikori basin, in 2016–2017 it was the most frequently camera trapped bird species (Figure 2; Plate 1D). All camera trap events were recorded during the November–December 2016 reconnaissance survey; the event rate for that period is thus more than double that shown in Figure 2 (1.3288 cf. 0.5215). Most of the photographs (29 cf. 4 in nearby foothills) were taken in forest with muddy alluvial substrate.

The behavioural ecology of Bare-eyed Rails is poorly known, with little information available on breeding or movement patterns. Bare-eyed Rails evidently breed at Wau Creek—multiple images were taken of partially-feathered (still partially downy) juveniles, sometimes in the presence of an adult bird (Plate 1D). Breeding in this instance likely commenced towards the end of the relatively wet southeast 'trade winds' season (May–October).

Given the high rate of detection in 2016, and a higher camera trap effort in 2017 (Table 1), the absence of rails in the latter period suggests some seasonal movement patterns. Seasonal occurrence of Bare-eyed Rails was similarly reported for a rainforest study site in the Brown River area near Port Moresby, where breeding rails were present during the wet season but absent during the dry season, presumably because the ground became too dry to probe for invertebrate prey (Bell 1982). The seasonal pattern observed at Wau Creek may have been due to a reduction in local food availability towards the end of the drier season in April 2017.

Scheepmaker's Crowned Pigeon (*Goura scheepmakeri*) (VU, P, RR)
The world's largest pigeon, Scheepmaker's Crowned Pigeon is a terrestrial-foraging species endemic to the lowlands (below c. 500 m asl) of southeast mainland Papua New Guinea. It occurs in groups of up to 30 birds (though usually less than seven) in closed-canopy evergreen forest, preferring areas of gentle alluvial terrain including seasonally flooded habitats (Coates 1985; Gibbs et al. 2001).

The distribution of *Goura* pigeons in southern Papua New Guinea is poorly known. There are prior confirmed records of Scheepmaker's Crowned Pigeon west to at least as far as the Purari River (Beehler and Pratt 2016) and Era River catchments (I. Woxvold, unpublished data). Its western counterpart, Sclater's Crowned Pigeon (*Goura sclaterii*), occurs east at least as far as the Hegigio River catchment north of Mount Bosavi (I. Woxvold, unpublished data). Until the present surveys there was no available information on which species occupies the intervening expanse, including the lower Kikori basin. All prior Kikori basin records refer to Southern Crowned Pigeon – within which both Sclater's Crowned Pigeon and Scheepmaker's Crowned Pigeon were formerly subsumed prior to a recent taxonomic split – with no information on which taxon (subspecies) was involved.

There are four camera trap records of Scheepmaker's Crowned Pigeon from Wau Creek—one in alluvial forest east of the research station on 30 November 2016 (Plate 1E), two in foothill forest south of Wau Creek on 27 April 2017, and one in foothill forest north of the research station on 27 April 2017. Based on these records Diamond and Bishop's 1999 record of Southern Crowned Pigeon from the Dark End Lumber site is provisionally assigned to Scheepmaker's Crowned Pigeon (see above).

Further west, on 29 November 2016 a captive bird said to have been caught on the banks of the Kikori River near Kikori Station was shown to us at Kopi. These are the most westerly confirmed records of Scheepmaker's Crowned Pigeon and the first from the Kikori basin. This may be close to the western limit of the species, given the occurrence of Sclater's Crowned Pigeon at Uro (Veiru) Creek (Woxvold Chapter 2.5) and to the north near the Hegigio River. More work is required to understand the precise geographic limits of these species and to determine whether any hybridisation and/or habitat segregation occurs in the potential zone of overlap.

Scheepmaker's Crowned Pigeon is described by BirdLife International as having a distribution covering just 15,700 km^2, with a western known range limit in the Lakekamu River basin (BirdLife International 2016). With its range now extended to the Kikori River, a conservative maximum extent of suitable habitat amounts to no more than 30,000 km^2, well within the 50,000 km^2 threshold for restricted-range status. Scheepmaker's Crowned Pigeon is the only restricted-range bird species recorded at Wau Creek.

Of all resident forest bird species recorded at Wau Creek, Scheepmaker's Crowned Pigeon is of the highest conservation concern. Compared with other locally occurring IUCN Threatened forest species (Papuan Eagle, Pesquet's Parrot), it occupies a much more limited geographic range and shows a marked preference for forest on alluvial terrain, a vegetation type that is under significant pressure from industrial logging operations across its known range, including within the lower Kikori basin (see Discussion). It has been hunted to extinction across parts of its range in the densely populated southeast peninsula (BirdLife International 2017), and the Kikori-Purari biogeographic region supports the largest remaining expanse of suitable habitat within its known range.

Habitat loss, degradation and hunting present the major threats to crowned pigeons. All *Goura* species are susceptible to hunting, being easily captured and highly prized for their meat and plumes (Coates 1985; King and Nijboer 1994). Further study is required to understand their tolerance of logged forest, though logging is cited as a major threat to crowned pigeons (King and Nijboer 1994; BirdLife International 2017).

Papuan Hawk-Owl (*Uroglax dimorpha*)

The Papuan Hawk-Owl (*Uroglax dimorpha*) is endemic to New Guinea where it has been recorded throughout the mainland from the lowlands to 1,500 m asl, including in Gulf Province (Beehler and Pratt 2016). It occupies a wide range of habitats including rainforest, forest edge and gallery forest in savannah (Coates 1985; Pratt and Beehler 2015). Until recently considered Data Deficient by the IUCN, the Papuan Hawk-Owl is now classified as Least Concern due to a growing number of records from across New Guinea.

A Papuan Hawk-Owl was recorded on a Song Meter unit deployed by the University of Canberra team near the research station in November 2016.

Blyth's Hornbill (*Rhyticeros plicatus*) (P)

This species occurs throughout New Guinea in a variety of forest types up to 1,500+ m asl but is most common in the lowlands and hills (Coates 1985; Kemp 2001). As New Guinea's only hornbill species, and one of the region's largest and most mobile frugivores, Blyth's Hornbill (*Rhyticeros plicatus*) plays a critical role in forest ecosystem dynamics (Mack and Wright 2005; Kinnaird and O'Brien 2007).

It was fairly common at Wau Creek, with singles or groups of up to three birds seen or heard on most days in 2016–2017. It was also recorded by Diamond and Bishop in 1999. More widely, Blyth's Hornbill is fairly common in forest (excluding mangroves) throughout the lower Kikori basin up to at least 1,000 m asl (I. Woxvold, unpublished data). As a mobile and easily detected species, multiple records at the same site may involve repeat encounters with the same individuals; although widespread, at the local scale hornbills may be present in fairly low numbers.

Palm Cockatoo (*Probosciger aterrimus*) (P)

The Palm Cockatoo (*Probosciger aterrimus*) is a large and conspicuous species occurring throughout the New Guinea lowlands and hills (to 1,300 m asl) in rainforest, secondary forest and tropical savannah where birds feed on a variety of seeds and fruit.

It was fairly common at Wau Creek, with singles or groups of up to three birds seen or heard on most days in 2016–2017. It was also recorded by Diamond and Bishop in 1999. More widely, Palm Cockatoos are uncommon but widespread in forest (including mangroves) throughout the lower Kikori basin up to at least 1,400 m asl (I. Woxvold, unpublished data). As a mobile and easily detected species, multiple records at the same site may involve repeat encounters with the same individuals.

Pesquet's Parrot (*Psittrichas fulgidus*) (VU, P)

This unusual, large black-and-red parrot is a nomadic and specialist frugivore that feeds on a select variety of figs (Mack and Wright 1998). It is endemic to New Guinea where it inhabits hill and lower montane forest up to 1,200 m asl (occasionally to 2,000 m) (Coates 1985). Pesquet's Parrot has been listed as one of Papua New Guinea's rarest birds (Beehler 1993), though recent surveys indicate the species remains secure in large areas of suitable habitat in central and western mainland Papua New Guinea, much of which occurs in rugged terrain in areas with a low human population density (I. Woxvold, unpublished data).

It was fairly common at Wau Creek, with singles or duos seen or heard on most days in 2016–2017. It was also recorded by Diamond and Bishop in 1999. It is a mobile and easily detected species and multiple records at the same site may involve repeat encounters with the same individuals. As a nomadic frugivore, numbers present in any one area are likely to change with seasonal patterns in food availability.

Hunting presents the major threat to Pesquet's Parrot. In some areas it is hunted for its plumes which are used for traditional ceremonial and trade purposes. As a result of hunting pressure, it is now rare or extirpated from the vicinity of many settled areas (Coates 1985; Kocher Schmid 1993; Mack and Wright 1998; Igag 2002). Other threats include habitat loss and loss of food trees (*Ficus* spp.) and nesting trees. It has been observed in logged forest (I. Woxvold, unpublished data; this study), though the birds may rely on more mature forest for nest sites.

Yellow-capped Pygmy Parrot (*Micropsitta keiensis*)
Two Yellow-capped Pygmy Parrots were mist netted near the research station on 24 April 2017 (Plate 2F).

The distribution of pygmy parrots (*Micropsitta*) in southern New Guinea is poorly known. Of two similar-looking lowland species, the Yellow-capped Pygmy Parrot occurs in the west and the Buff-faced Pygmy Parrot in the east, with a potential zone of contact/overlap somewhere in the Gulf of Papua hinterland. At the time of Diamond and Bishop's visit it was not known which species occupy the expanse between the Fly River and Lakekamu basin (Coates 1985; Collar 1997; Juniper and Parr 1998), a position still held in Collar and Boesman (2017). Recent field guides and regional checklists report that both species occur locally in the Kikori basin (Pratt and Beehler 2015; Beehler and Pratt 2016; Gregory 2017), though it is unclear on what records these assessments are based (Beehler and Pratt (2016) cite Schodde and Hitchcock (1968) as the source for a Lake Kutubu record of Buff-faced Pygmy Parrot, though no such record appears in that report).

Pygmy parrots are listed in many Kikori basin bird reports. Among these, one record from Lake Kutubu (at c. 800 m asl) is sufficiently well annotated to confidently accept the occurrence there of Buff-faced Pygmy Parrot (Burrows 1995). By contrast, all confirmed records from the lower Kikori basin involve Yellow-capped Pygmy Parrot—at Uro Creek (Woxvold, Chapter 2.5), Iviri and Keboi Kerowa (Leary, Undated A) and within the Wau Creek proposed WMA (this study). Moreover, all confirmed *Micropsitta* records (mist netting and sightings) from the lower Purari basin (all records below 250 m asl) east of the Kikori basin also involve Yellow-capped Pygmy Parrot (I. Woxvold, unpublished data). Diamond and Bishop reported Buff-faced Pygmy Parrot from Dark End Lumber but have since stated that this was a provisional record that, in light of the 2017 mist netting results, is best reported at genus level (J. Diamond *in litt*. 2018); the record is here provisionally reassigned to Yellow-capped Pygmy Parrot.

Glossy-mantled Manucode (*Manucodia ater*) (P)
All birds-of-paradise (Paradisaeidae) are Protected under Papua New Guinean law.

The manucodes are a group of glossy black, rather crow-like birds-of-paradise. Unlike most birds-of-paradise, they form monogamous pairs and are sexually monomorphic. The Glossy-mantled Manucode (*Manucodia ater*) is endemic to New Guinea and satellite islands where it inhabits a variety of forest habitats in the lowlands and foothills, locally up to c. 900 m asl (Coates 1990; Frith and Beehler 1998). It is the most common manucode in open and disturbed habitats.

It was fairly common at Wau Creek, with birds seen or heard daily in 2016–2017. It was also recorded by Diamond and Bishop in 1999.

Trumpet Manucode (*Phonygammus keraudrenii*) (P)
The Trumpet Manucode (*Phonygammus keraudrenii*) occurs in forest from the lowlands to 2,000 m asl where it feeds mainly on figs (Coates 1990; Frith and Beehler 1998).

It was uncommon at Wau Creek—recorded in 1999 and on at least three Song Meter units deployed by the University of Canberra team in November 2016.

Magnificent Riflebird (*Ptiloris magnificus*) (P)
This species is widespread in lowland and hill forests across most of New Guinea and on Cape York Peninsula (Australia) (Coates 1990; Frith and Beehler 1998). In southern New Guinea it occurs as far east as the Purari basin.

It was uncommon (or at least formerly present) at Wau Creek where it was recorded in 1999 but not in 2016–2017. Seasonal reductions in calling behaviour have been noted for some areas (Frith and Beehler 1998); although apparently scarce near the research station, the lack of recent records there may not indicate absence from the proposed WMA.

King Bird-of-paradise (*Cicinnurus regius*) (P)
A common resident of lowland and foothill forests (to c. 300 m asl, less common higher), including swamp forest, of New Guinea and nearby islands.

This species was fairly common at Wau Creek with one or more birds heard daily in 2016–2017. It was also recorded by Diamond and Bishop in 1999.

Twelve-wired Bird-of-paradise (*Seleucidis melanoleucus*) (P)
Twelve-wired Bird-of-paradise (*Seleucidis melanoleucus*) is endemic to New Guinea and Salawati Island where it inhabits lowland forest, especially swamp forest with sago (*Metroxylon sagu*), mostly near sea level but in places up to 180 m asl (Coates 1990; Frith and Beehler 1998).

This species is scarce at Wau Creek, where the preferred sago swamp woodland is apparently lacking (or at least too restricted for mapping under the Papua New Guinea Forest Inventory Mapping System (FIMS)). It was not recorded in 1999 and not directly encountered in 2016–2017. The only record is of a single bird calling in the distance on the evening of 13 November 2016, recorded by an automated sound recorder deployed by the University of Canberra team.

Raggiana Bird-of-paradise (*Paradisaea raggiana*) (P)
Endemic to southern and northeast Papua New Guinea where it inhabits primary and disturbed lowland, hill and lower montane forest to c.1,800 m asl. Males of the genus *Paradisaea* engage in elaborate and conspicuous group displays with up to 10 birds performing at a 'lek', usually in the upper portion or top branches of a canopy tree (Coates 1990; Frith and Beehler 1998).

This species was not common at Wau Creek, with one or two birds heard on half of the active search days in 2016–2017. It was also recorded by Diamond and Bishop in 1999.

Biodiversity and conservation values

Survey completeness and possible additional species

The total of 135 bird species recorded at Wau Creek compares favourably with the results of surveys conducted at comparable elevations elsewhere in southern mainland Papua New Guinea, and available data are sufficient to conclude that the Wau Creek proposed WMA supports a rich community of resident and migratory birds that includes multiple species of conservation significance.

After repeated surveys of lowland bird communities in the Lakekamu basin, Beehler and colleagues (Beehler et al. 1995; Beehler and Mack 1999) concluded that a total survey period of two months spread over multiple seasons is required to comprehensively census a lowland forest bird community in Papua New Guinea. While the total of 11 days (including partial days) spent by all surveyors in the Wau Creek area falls well short of this benchmark, coverage of the broader lower Kikori basin – a much closer analogue to the 1,700 km^2 Lakekamu study area than the Wau Creek site – is well in excess of that proposed by Beehler.

Diamond and Bishop (Undated A) noted a strong similarity between the bird communities at Dark End Lumber and at other sites they surveyed in the lower Kikori basin. This pattern persists with the addition of 18 species to the Wau Creek bird list that were not recorded by Diamond and Bishop in 1999. Of the 135 bird species recorded to date at Wau Creek, all but two are known from other sites surveyed in the lower Kikori basin (by all workers; see Existing data)—the Bare-eyed Rail, a shy terrestrial species easily missed without the aid of camera traps, and the Obscure Honeyeater (*Caligavis obscura*), an uncommon but vocally conspicuous species of hill forest that is seemingly rare in the extreme lowlands but regularly recorded further north in the Kikori basin (for example at Gobe and Lake Kutubu: Schodde and Hitchcock 1998; Diamond and Bishop, Undated B; Woxvold, Chapter 3.5).

Given the occurrence of most species more broadly across the lower Kikori basin, a list of most birds not yet recorded but that may occur at Wau Creek can be gleaned from the results of surveys conducted in comparable habitats at other lower Kikori basin sites. Excluding predominantly coastal species most likely to occur in the deltaic zone, species of swamp vegetation (a habitat not observed Wau Creek), and Sclater's Crowned Pigeon (assumed not to co-occur with Scheepmaker's Crowned Pigeon at Wau Creek), some 45 potential additional species are listed in Appendix 2 along with their conservation status, residency/migratory status and broad habitat preference (terrestrial/freshwater environments). They include:

- Thirty-seven species that occupy terrestrial habitats (forest and/or open environments), including 32 breeding residents and five non-breeding migrants that breed in Australia.

- Eight species that occupy freshwater rivers and streams, including six breeding residents and two non-breeding migrants.

Two IUCN Near Threatened species are included in Appendix 2:

- Forest Bittern (*Zonerodius heliosylus*)—A rare heron endemic to New Guinea in forest swamps, streams and pools from the lowlands to 1,430 m asl. Recorded previously at Kopi (Diamond and Bishop, Undated B).

- Yellow-eyed Starling (*Aplonis mystacea*)—A communally breeding species endemic to the south New Guinea lowlands from the Bird's Neck (Indonesian New Guinea) east to Gulf Province, Papua New Guinea. Its preferred habitat is alluvial forest, including flood disturbed riparian zones. It has been recorded previously in the Kopi-Kikori area and at Pinini Creek (Burrows 1995; Diamond and Bishop, Undated B).

In addition to those species recorded previously nearby, the Wau Creek proposed WMA includes habitat suitable for a number of additional uncommon species that are yet to be recorded in the lower Kikori basin. They include the following IUCN listed species:

- Gurney's Eagle (*Aquila gurneyi*) (IUCN Near Threatened)—A very large bird of prey (wingspan to 1.85 m) present throughout New Guinea where it is widespread though sparsely distributed in all forest habitats, mostly in the lowlands and hills. It is known from further upstream in the Kikori basin in the Lake Kutubu area (see Chapter 3.5).

- Doria's Goshawk (*Megatriorchis doriae*) (IUCN Near Threatened)—A rarely encountered bird of prey endemic to lowland and hill forest throughout New Guinea, from sea level to at least 1,650 m asl. It is not yet reported from the Kikori basin.

- Starry Owlet-Nightjar (*Aegotheles tatei*) (IUCN Data Deficient)—A poorly known night-bird endemic to the southern New Guinea lowlands from the Indonesia-Papua New Guinea border area east to near Port Moresby. It was recently recorded for the first time in Gulf Province in the lower Purari River catchment (I. Woxvold, unpublished data).

- Three-toed Swiftlet (*Aerodramus papuensis*)—Very difficult to distinguish in the field from three other all-dark New Guinea swiftlets. It is endemic to New Guinea where it has been recorded with certainty from only four localities between sea level and 2,400 m asl. Suitable roosting and breeding caves potentially occur locally in limestone areas, from which birds may forage more widely.

Conservation value of forest environments

Forest habitats support the vast majority of bird species residing or regularly occurring at Wau Creek—of the 135 bird species recorded, 120 (88.9%) occur in forest environments and most of these are forest-dependent (cannot persist in converted habitats alone). All resident IUCN listed and restricted-range species and all nationally Protected species except egrets are dependent on forest habitats.

The conservation value of forest environments within and around the Wau Creek proposed WMA has been impacted by recent and extensive logging activity.

Much of the forest surveyed in 2016–2017 had been affected by logging. The Wau Creek proposed WMA is located centrally within the Kikori Block 2 logging concession (Figure 3). Covering approximately 4,433 km^2, the southern third (1,465 km^2; 33.0%) of Kikori Block 2 had been logged by 2015 (Figure 3), and logging was continuing at the time of the 2016–2017 survey (pers. obs.). The proposed WMA is located within the northern rim of the logged area.

All areas surveyed near the research station are mapped under FIMS as large crowned alluvial forest (FIMS type Pl), a favoured source of commercial timber with restricted local availability (pre-logging <2% of Gulf Province land surface). Post-logging regenerating forest was observed along a former logging road 800 m east of the research station, and logging damage was evident along skid trails a short distance north of the research station. The damage is widespread across the proposed WMA, judging from the distribution of logging tracks visible in recent satellite imagery (Figure 1) and an earlier road network displayed on the 1970s topographic mapsheet. Based on PNG Forest Observatory mapping (http://forest.pngsdf.com/) the proposed WMA includes areas of unlogged forest buffers along the Sire River and Wau Creek. This regional mapping exercise is often inaccurate at the local scale, and the largely unregulated logging industry often does not adhere to riparian buffer requirements outlined in the Papua New Guinea Logging Code of Practice. Accordingly, while some of the forest observed by boat along the Sire River did appear largely undisturbed, there were also extensive sections of riverine forest that were severely damaged. While flood damage may have been the cause in some areas, logging was certainly implicated in others.

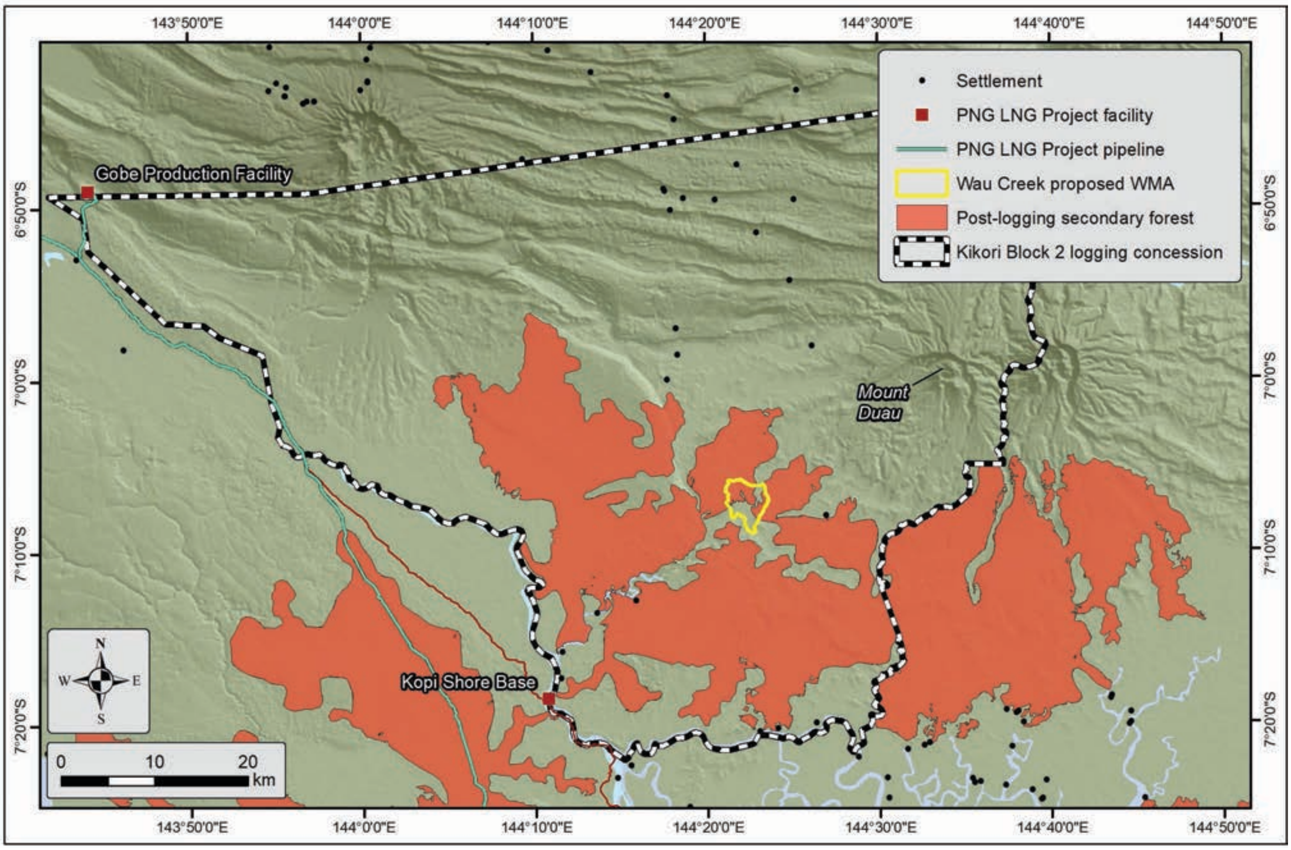

Figure 3. Post-logging secondary forest in the lower Kikori River basin. (Reproduced from the PNG Forest Observatory, http://forest.pngsdf.com/).

The influence of logging on forest bird communities in New Guinea has been little studied (reviewed in Munks and Watling 2013). In general, results indicate that bird species richness and abundance is lower in logged secondary forest than in unlogged forest (Driscoll 1984, summarised in Lamb 1990; Marsden and Symes 2008; Tvardikova 2010; Dawson et al. 2011). However, studies have also variously found that: (1) species assemblages change with time as the forest regenerates; (2) species richness is highest in sites with intermediate disturbance, and; (3) species richness is higher in disturbed sites that are near primary forest habitats (Marsden and Symes 2008; Munks and Watling 2013).

Forest bird community structure within the proposed WMA has no doubt been altered by logging. Available data are too few to describe these changes in detail. However, the following broad-scale patterns were observed.

- At the patch-scale, interior forest specialists were rare or absent in heavily disturbed sites but persisted in remnant areas of primary (or little disturbed) forest. Understorey insectivores are particularly sensitive to changes in their interior forest environment. Relevant taxa present at Wau Creek include Sooty Thicket Fantail (*Rhipidura threnothorax*), Rufous-backed Fantail (*R, rufidorsa*), Spot-winged Monarch (*Symposiachrus guttula*), Hooded Monarch (*S. manadensis*) and Black-sided Robin (*Poecilodryas hypoleuca*). These species were uncommon and restricted locally to areas with more mature and multi-layered forest structure.

- Fruiting trees were common. Most of the hardwood tree species targeted by loggers produce seeds with capsules, so that many of the commercially undesirable trees that are retained are fleshy-fruited species attractive to frugivorous birds. Even compared to other tropical regions, New Guinea's avifauna includes a high proportion of frugivorous species (Pearson 1977; Mack and Dumbacher 2007). Accordingly, relatively high species richness and abundance was recorded among major frugivore groups including pigeons and doves (Columbidae—19 species), parrots (Psittaculidae—11 species), cuckooshrikes (Campephagidae—6 species), birds-of-paradise (Paradisaeidae—6 species) and Blyth's Hornbill (Bucerotidae).

- All IUCN Threatened forest bird species potentially present in the lower Kikori River basin are confirmed present at Wau Creek—Papuan Eagle, Scheepmaker's Crowned Pigeon and Pesquet's Parrot. For most or all of these species their local population density may be lower than that in unlogged forest. Their status throughout the proposed WMA and the impacts of logging on these species are still not well known.

- Birds preferring open and disturbed habitats were present along open watercourses and in adjacent regrowth. Relevant species include Brahminy Kite (*Haliastur indus*), Black-billed Coucal (*Centropus bernsteini*), Sacred Kingfisher (*Todirhamphus sanctus*), Willie Wagtail (*Rhipidura lucophrys*), Pacific Swallow (*Hirundo tahitica*) and Olive-backed Sunbird (*Cinnyris jugularis*).

Elsewhere locally, extensive areas of ecologically similar (landform, substrate and elevation) unlogged forest are present 5–10 km to the north and east of the proposed WMA. Although these may currently have a higher conservation value than the disturbed forest environments observed at Wau Creek, they are not protected from future logging. Should the Wau Creek forests be protected from further logging through establishment of a WMA they will present a number of conservation opportunities in relation to avifauna. For example:

- In their current condition the Wau Creek forests support a rich bird community that includes a variety of conservation listed taxa. Notably, they support, or form part of an area that supports, viable populations of three IUCN Vulnerable forest bird species.

- As part of a broader ecosystem-complex, the proposed WMA lies within 25 km of multiple additional forest ecosystems, including limestone, montane (above 1,000 m asl), freshwater swamp and mangrove forest environments. It therefore provides habitat (for foraging and/or breeding) for a variety of wide-ranging landscape-level nomadic bird species, including various large frugivores and birds of prey.

- Regenerating forest will provide future opportunity for population growth of, or recolonization by, a variety of primary forest specialist bird species. Potential sources for recolonization include localised patches of remnant mature forest within the proposed WMA and ecologically similar unlogged forest to the north and east of the proposed WMA.

- Future logging is expected to impact at least some areas of primary forest remaining in Gulf Province. Since 2002, Gulf Province has endured the highest rate of logging-related forest loss of any mainland Papua New Guinean province (10.9% of commercially accessible forest: Bryan and Shearman 2015). The logging is ongoing and continues apace in multiple concessions within the Kikori-Purari biogeographic district, including Kikori Block 2. As the Wau Creek forest regenerates, the expansion of logging activities elsewhere in Gulf Province will enhance the future conservation value of the Wau Creek environment.

- The proposed WMA provides an excellent opportunity for research into the effects of logging and forest regeneration on individual bird species and avian community structure (as well as research into other flora and fauna). To properly assess the influence of forest condition it will be important to ensure that no hunting takes place within the WMA.

Conservation value of watercourses and riparian habitats
Watercourses and adjacent riparian vegetation provide habitat for a small number of resident wetland/riparian specialists, including Little Ringed Plover, Shining Flycatcher (*Myiagra Alecto*) and Torrent Flyrobin. Six migratory waterbird species have also been recorded—Great Egret, Intermediate Egret, Little Egret, Little Pied Cormorant, Australasian Darter and Common Sandpiper. Additional migratory waterbirds no doubt visit the area, though in the absence of significant off-river waterbodies within or near the proposed WMA all are expected to occur in small numbers as non-breeding visitors. Given the extensive network of watercourses and estuaries nearby, watercourses within the proposed WMA are considered to be of local importance to resident and migratory waterbirds.

Conclusions and recommendations

In terms of avifauna, the Wau Creek proposed WMA is set in one of the world's most biologically diverse and endemically rich terrestrial regions (Olson and Dinerstein 1998; Brooks et al. 2006) and more than one quarter of all bird species residing or regularly occurring in the New Guinea region (including satellite islands: 180/677; 26.6%) have to date been recorded there or may occur based on data from surveys conducted in comparable habitats elsewhere in the lower Kikori basin. It supports viable resident populations of a suite of conservation listed species, including three globally threatened bird species confirmed present (Papuan Eagle, Scheepmaker's Crowned Pigeon, Pesquet's Parrot) and multiple additional nationally Protected and New Guinean endemic species.

Importantly, the demonstrated intent of local landowners to conserve the Wau Creek environment and to support current research activities underpins all of the above-listed conservation opportunities (see Conservation value of forest environments). The following actions are recommended to enhance the scientific and conservation value of the Wau Creek bird community:

- Protect all forest within the proposed WMA from future logging.

- Avoid hunting birds within the proposed WMA. This is required to support future research into local bird populations. Hunting in logged areas is common in many tropical forest environments. Where hunting and logging co-occur, it can be very difficult to quantify the impacts associated with any one of these processes (Meijaard et al. 2005).

- As far as possible, keep dogs out of the proposed WMA.

- Support research into bird species and communities within the proposed WMA and surrounding areas.

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Plate 1

A. Southern Cassowary chick (*Casuarius casuarius*)

B. Adult Southern Cassowary (*Casuarius casuarius*)

C. Grey-headed Goshawk (*Accipiter poliocephalus*)

D. Adult and juvenile Bare-eyed Rail (*Gymnocrex plumbeiventris*)

E. Scheepmaker's Crowned Pigeon (*Goura scheepmakeri*)

F. Frank John with a Papuan Dwarf Kingfisher (*Ceyx solitarius*)

Plate 2

A. Yellow-capped Pygmy Parrot (*Micropsitta keiensis*)

B. Papuan Pitta (*Erythropitta macklotii*)

C. Long-billed Honeyeater (*Melilestes megarhynchus*)

D. Yellow-bellied Gerygone (*Gerygone chrysogaster*)

E. Papuan Babbler (*Garritornis isidorei*)

F. Hooded Monarch (*Symposiachrus manadensis*)

Appendix 1. Birds recorded in the Wau Creek area by Diamond and Bishop in 1999 and by IW in 2016–2017.

Conservation status is shown for those species listed by the IUCN as Vulnerable (VU) (no other non-Least Concern categories were represented), species Protected (P) by law under the PNG Fauna (*Protection & Control*) Act 1966, and restricted-range (RR) species. Camera trap results are shown as Relative Abundance Index for all photographed species (ctRAI). Residency/migratory (Res/Mig) status indicates: BR—breeding resident species; M—species that occur in New Guinea only as non-breeding migrants; BR/M—breeding residents with populations seasonally augmented by non-breeding visitors, and with widespread local breeding range potentially overlapping the study area; M(BR)—breeding residents augmented by non-breeding visitors, but known breeding sites are localised and outside of the Kikori Basin; t—birds of terrestrial environments, including forest, open areas and aerial foraging species; w—birds of wetlands, including lakes, rivers and streams; data from Coates (1985, 1990) and Beehler and Pratt (2016). The number of individuals captured in mist nets (most species) or by hand (Southern Cassowary chick) is shown in brackets after the English Name.

Scientific Name	English Name	Status	1999	2016–2017	ctRAI	Res/Mig
CASUARIIDAE						
Casuarius casuarius	Southern Cassowary (1)		X	X	0.1264	BRt
MEGAPODIIDAE						
Talegalla fuscirostris	Black-billed Brushturkey		X	X	0.4583	BRt
Megapodius reinwardt	Orange-footed Scrubfowl		X	X	0.0948	BRt
ARDEIDAE						
Ardea alba	Great Egret	P	X			M(BR)w
Ardea intermedia	Intermediate Egret	P		X		M(BR)w
Egretta garzetta	Little Egret	P		X		Mw
PHALACROCORACIDAE						
Microcarbo melanoleucos	Little Pied Cormorant		X			M(BR)w
ANHINGIDAE						
Anhinga novaehollandiae	Australasian Darter		X			M(BR)w
ACCIPTRIDAE						
Aviceda subcristata	Pacific Baza		X	X		BRt
Henicopernis longicauda	Long-tailed Honey Buzzard			X		BRt
Harpyopsis novaeguineae	Papuan Eagle	VU, P	X			BRt
Accipiter hiogaster	Variable Goshawk		X			BRt
Accipiter poliocephalus	Grey-headed Goshawk (1)			X		BRt
Haliastur indus	Brahminy Kite		X			BRt
Haliaeetus leucogaster	White-bellied Sea Eagle			X		BRt
RALLIDAE						
Rallina tricolor	Red-necked Crake			X		BRt
Gymnocrex plumbeiventris	Bare-eyed Rail			X	0.5215	BRt
CHARADRIIDAE						
Charadrius dubius	Little Ringed Plover			X		BRw
SCOLOPACIDAE						
Actitis hypoleucos	Common Sandpiper		X	X		Mw
COLUMBIDAE						
Macropygia amboinensis	Amboyna Cuckoo-Dove		X	X		BRt

Scientific Name	English Name	Status	1999	2016–2017	ctRAI	Res/Mig
Macropygia nigrirostris	Bar-tailed Cuckoo-Dove		X			BRt
Reinwardtoena reinwardti	Great Cuckoo-Dove		X	X		BRt
Chalcophaps stephani	Stephan's Emerald Dove			X	0.0632	BRt
Trugon terrestris	Thick-billed Ground Pigeon		X	X	0.0948	BRt
Gallicolumba rufigula	Cinnamon Ground Dove			X	0.1264	BRt
Otidiphaps nobilis	Pheasant Pigeon		X			BRt
Goura scheepmakeri	Scheepmaker's Crowned Pigeon	VU, P, RR	[X]	X	0.0632	BRt
Ptilinopus magnificus	Wompoo Fruit Dove		X	X		BRt
Ptilinopus perlatus	Pink-spotted Fruit Dove		X	X		BRt
Ptilinopus superbus	Superb Fruit Dove		X	X		BRt
Ptilinopus coronulatus	Coroneted Fruit Dove			X		BRt
Ptilinopus pulchellus	Beautiful Fruit Dove		X	X		BRt
Ptilinopus iozonus	Orange-bellied Fruit Dove		X	X		BRt
Ptilinopus nainus	Dwarf Fruit Dove		X	X		BRt
Ducula rufigaster	Purple-tailed Imperial Pigeon		X	X		BRt
Ducula pinon	Pinon's Imperial Pigeon		X	X		BRt
Ducula zoeae	Zoe's Imperial Pigeon		X	X		BRt
Gymnophaps albertisii	Papuan Mountain Pigeon		X	X		BRt
CUCULIDAE						
Centropus menbeki	Ivory-billed Coucal		X	X		BRt
Centropus bernsteini	Black-billed Coucal		X			BRt
Microdynamis parva	Dwarf Koel		X	X		BRt
Eudynamys orientalis	Pacific Koel		X	X		BR/Mt
Scythrops novaehollandiae	Channel-billed Cuckoo			X		Mt
Chrysococcyx minutillus	Little Bronze Cuckoo		X	X		BRt
Cacomantis leucolophus	White-crowned Cuckoo		X	X		BRt
Cacomantis variolosus	Brush Cuckoo		X	X		BRt
Cuculus optatus	Oriental Cuckoo		X			Mt
STRIGIDAE						
Uroglaux dimorpha	Papuan Hawk-Owl			X		BRt
PODARGIDAE						
Podargus ocellatus	Marbled Frogmouth		X	X		BRt
Podargus papuensis	Papuan Frogmouth		X	X		BRt
HEMIPROCNIDAE						
Hemiprocne mystacea	Moustached Treeswift			X		BRt
APODIDAE						
Collocalia esculenta	Glossy Swiftlet		X	X		BRt
Aerodramus vanikorensis	Uniform Swiftlet		X	X		BRt
Mearnsia novaeguineae	Papuan Spine-tailed Swift			X		BRt
Hirundapus caudacutus	White-throated Needletail		X			Mt
CORACIIDAE						
Eurystomus orientalis	Oriental Dollarbird		X	X		BR/Mt

Scientific Name	English Name	Status	1999	2016–2017	ctRAI	Res/Mig
ALCEDINIDAE						
Melidora macrorrhina	Hook-billed Kingfisher		X	X		BRt
Dacelo gaudichaud	Rufous-bellied Kookaburra		X	X		BRt
Todiramphus sanctus	Sacred Kingfisher		X	X		Mt
Syma torotoro	Yellow-billed Kingfisher		X	X		BRt
Ceyx solitarius	Papuan Dwarf Kingfisher (1)		X	X		BRt
Ceyx pusillus	Little Kingfisher		X			BRt
MEROPIDAE						
Merops ornatus	Rainbow Bee-eater		X			Mt
BUCEROTIDAE						
Rhyticeros plicatus	Blyth's Hornbill	P	X	X		BRt
CACATUIDAE						
Probosciger aterrimus	Palm Cockatoo	P	X	X		BRt
Cacatua galerita	Sulphur-crested Cockatoo		X	X		BRt
PSITTACIDAE						
Psittrichas fulgidus	Pesquet's Parrot	VU, P	X	X		BRt
Micropsitta keiensis	Yellow-capped Pygmy Parrot (2)		[X]	X		BRt
Eclectus roratus	Eclectus Parrot		X	X		BRt
Geoffroyus geoffroyi	Red-cheeked Parrot		X	X		BRt
Charmosyna placentis	Red-flanked Lorikeet		X			BRt
Lorius lory	Black-capped Lory		X	X		BRt
Chalcopsitta scintillata	Yellowish-streaked Lory		X	X		BRt
Pseudeos fuscata	Dusky Lory		X	X		BRt
Trichoglossus haematodus	Coconut Lorikeet		X	X		BRt
Cyclopsitta gulielmitertii	Orange-breasted Fig Parrot		X			BRt
Cyclopsitta gulielmitertii/ diophthalma	Orange-breasted/Double-eyed Fig Parrot			X		BRt
Loriculus aurantiifrons	Orange-fronted Hanging Parrot		X			BRt
PITTIDAE						
Erythropitta macklotii	Papuan Pitta (1)		X	X	0.1738	BRt
Pitta sordida	Hooded Pitta		X	X	0.0158	BRt
PTILONORHYNCHIDAE						
Ailuroedus stonii	Ochre-breasted Catbird		X			BRt
MELIPHAGIDAE						
Pycnopygius stictocephalus	Streak-headed Honeyeater		X	X		BRt
Xanthotis flaviventer	Tawny-breasted Honeyeater		X	X		BRt
Philemon novaeguineae	New Guinea Friarbird		X	X		BRt
Melilestes megarhynchus	Long-billed Honeyeater (3)		X	X		BRt
Caligavis obscura	Obscure Honeyeater		X			BRt
Meliphaga aruensis	Puff-backed Honeyeater		X			BRt
Meliphaga sp.	Honeyeater sp.			X		BRt
ACANTHIZIDAE						
Crateroscelis murina	Rusty Mouse-warbler (1)		X	X		BRt

Scientific Name	English Name	Status	1999	2016–2017	ctRAI	Res/Mig
Gerygone chrysogaster	Yellow-bellied Gerygone (2)		X	X		BRt
Gerygone chloronota	Green-backed Gerygone		X	X		BRt
POMATOSTOMIDAE						
Garritornis isidorei	Papuan Babbler (1)		X	X		BRt
MELANOCHARITIDAE						
Melanocharis nigra	Black Berrypecker		X			BRt
Toxorhamphus novaeguineae	Yellow-bellied Longbill (3)		X	X		BRt
PSOPHODIDAE						
Ptilorrhoa caerulescens	Blue Jewel-babbler		X	X	0.1580	BRt
ARTAMIDAE						
Peltops blainvillii	Lowland Peltops		X	X		BRt
Melloria quoyi	Black Butcherbird		X	X	0.0316	BRt
Cracticus cassicus	Hooded Butcherbird		X	X		BRt
CAMPEPHAGIDAE						
Coracina boyeri	Boyer's Cuckooshrike		X	X		BRt
Coracina incerta	Black-shouldered Cicadabird		X			BRt
Coracina schisticeps	Grey-headed Cuckooshrike		X	X		BRt
Coracina melas	Black Cicadabird		X	X		BRt
Campochaera sloetii	Golden Cuckooshrike		X	X		BRt
Lalage leucomela	Varied Triller		X	X		BRt
PACHYCEPHALIDAE						
Pachycephala simplex	Grey Whistler		X	X		BRt
Pseudorectes ferrugineus	Rusty Pitohui (1)		X	X		BRt
Colluricincla megarhyncha	Little Shrikethrush		X	X		BRt
ORIOLIDAE						
Pitohui uropygialis	Southern Variable Pitohui		X	X		BRt
Oriolus szalayi	Brown Oriole		X	X		BRt
DICRURIDAE						
Dicrurus bracteatus carbonarius	(Papuan) Spangled Drongo (1)		X	X		BRt
RHIPIDURIDAE						
Rhipidura leucophrys	Willie Wagtail		X	X		BRt
Rhipidura rufiventris	Northern Fantail		X			BRt
Rhipidura threnothorax	Sooty Thicket Fantail		X			BRt
Rhipidura maculipectus	Black Thicket Fantail		X			BRt
Rhipidura leucothorax	White-bellied Thicket Fantail		X			BRt
Rhipidura maculipectus/ leucothorax	Black/White-bellied Thicket Fantail			X		BRt
Rhipidura rufidorsa	Rufous-backed Fantail		X	X		BRt
MONARCHIDAE						
Symposiachrus guttula	Spot-winged Monarch		X			BRt
Symposiachrus manadensis	Hooded Monarch (2)		X	X		BRt
Carterornis chrysomela	Golden Monarch		X	X		BRt
Arses telescophthalmus	Frilled Monarch		X	X		BRt

Scientific Name	English Name	Status	1999	2016–2017	ctRAI	Res/Mig
Myiagra alecto	Shining Flycatcher		X	X		BRt
CORVIDAE						
Corvus tristis	Grey Crow		X	X		BRt
PARADISAEIDAE						
Manucodia ater	Glossy-mantled Manucode	P	X	X		BRt
Phonygammus keraudrenii	Trumpet Manucode	P	X	X		BRt
Ptiloris magnificus	Magnificent Riflebird	P	X			BRt
Cicinnurus regius	King Bird-of-paradise	P	X	X		BRt
Seleucidis melanoleucus	Twelve-wired Bird-of-paradise	P		X		BRt
Paradisaea raggiana	Raggiana Bird-of-paradise	P	X	X		BRt
PETROICIDAE						
Poecilodryas hypoleuca	Black-sided Robin		X	X		BRt
Monachella muelleriana	Torrent Flyrobin		X	X		BRw
HIRUNDINIDAE						
Hirundo tahitica	Pacific Swallow		X			BRt
STURNIDAE						
Aplonis metallica	Metallic Starling		X	X		BRt
Mino dumontii	Yellow-faced Myna		X	X		BRt
Mino anais	Golden Myna			X		BRt
DICAEIDAE						
Dicaeum geelvinkianum	Red-capped Flowerpecker		X	X		BRt
NECTARINIIDAE						
Leptocoma aspasia	Black Sunbird		X	X		BRt
Cinnyris jugularis	Olive-backed Sunbird			[X]		BRt
Total			117	110		

Appendix 2. Possible additional species recorded in comparable habitats at nearby sites in the lower Kikori basin.

Conservation status is shown for those species listed by the IUCN as Near Threatened (NT) (no other non-Least Concern categories, nationally Protected or restricted-range were represented). Residency/migratory (Res/Mig) status indicates: BR—breeding resident species; M—species that occur in New Guinea only as non-breeding migrants; BR/M—breeding residents with populations seasonally augmented by non-breeding visitors, and with widespread local breeding range potentially overlapping the study area; M(BR)—breeding residents augmented by non-breeding visitors, but known breeding sites are localised and outside of the Kikori Basin; t—birds of terrestrial environments, including forest, open areas and aerial foraging species; w—birds of wetlands, including lakes, rivers and streams; data from Coates (1985, 1990) and Beehler and Pratt (2016). The list of potential additional species excludes predominantly coastal species most likely to occur in the deltaic zone, species of swamp vegetation (a habitat not observed Wau Creek), and Sclater's Crowned Pigeon (assumed not to co-occur with Scheepmaker's Crowned Pigeon at Wau Creek until evidence to prove otherwise).

Scientific Name	**English Name**	**Status**	**Kopi-Kikori**	**Omo**	**Pinini Ck**	**Utiti Ck**	**Uro Ck**	**Iviri**	**Res/Mig**
Dendrocygna guttata	Spotted Whistling Duck		X			X	X		BRw
Dendrocygna arcuata	Wandering Whistling Duck		X						BR/Mw
Zonerodius heliosylus	Forest Bittern	NT	X						BRw
Dupetor flavicollis	Black Bittern			X					BRw
Nycticorax caledonicus	Nankeen Night Heron		X						M(BR)w
Butorides striata	Striated Heron		X						BRw
Phalacrocorax sulcirostris	Little Black Cormorant		X						M(BR)w
Hieraaetus weiskei	Pygmy Eagle		X						BRt
Accipiter cirrhocephalus	Collared Sparrowhawk		X						BRt
Haliastur sphenurus	Whistling Kite		X				X		BRt
Gallirallus philippensis	Buff-banded Rail		X						BRt
Amaurornis moluccana	Pale-vented Bush-hen		X						BRt
Henicophaps albifrons	New Guinea Bronzewing		X		X		X		BRt
Ducula mullerii	Collared Imperial Pigeon			X					BRt
Chrysococcyx megarhynchus	Long-billed Cuckoo		X				X		BRt
Cacomantis castaneiventris	Chestnut-breasted Cuckoo		X		X				BRt
Ninox theomacha	Papuan Boobook		X						BRt
Todiramphus macleayii	Forest Kingfisher		X	X			X		Mt
Ceyx azureus	Azure Kingfisher		X	X	X	X	X		BRw
Falco cenchroides	Nankeen Kestrel		X						Mt
Falco longipennis	Australian Hobby		X						Mt
Falco peregrinus	Peregrine Falcon		X						BRt
Alisterus chloropterus	Papuan King Parrot			X					BRt
Psittaculirostris desmarestii	Large Fig Parrot		X		X		[X]		BRt
Cyclopsitta diophthalma	Double-eyed Fig Parrot		X		X				BRt
Malurus cyanocephalus	Emperor Fairywren		X		X		X		BRt
Myzomela eques	Ruby-throated Myzomela		X						BRt
Myzomela nigrita	Papuan Black Myzomela		X						BRt

Scientific Name	**English Name**	**Status**	**Kopi-Kikori**	**Omo**	**Pinini Ck**	**Utiti Ck**	**Uro Ck**	**Iviri**	**Res/Mig**
Glycichaera fallax	Green-backed Honeyeater		X						BRt
Pycnopygius ixoides	Plain Honeyeater		X						BRt
Meliphaga albonotata	Scrub Honeyeater		X						BRt
Meliphaga analoga	Mimic Honeyeater		X	X	X	X			BRt
Meliphaga flavirictus	Yellow-gaped Honeyeater							X	BRt
Sericornis spilodera	Pale-billed Scrubwren		X	X		X	X		BRt
Gerygone magnirostris	Large-billed Gerygone		X		X		[X]	X	BRt
Gerygone palpebrosa	Fairy Gerygone		X			X	X		BRt
Oedistoma iliolophus	Dwarf Longbill		X	X			X		BRt
Oedistoma pygmaeum	Pygmy Longbill		X						BRt
Artamus leucorynchus	White-breasted Woodswallow		X						BRt
Coracina novaehollandiae	Black-faced Cuckooshrike		X						M(BR)t
Coracina papuensis	White-bellied Cuckooshrike		X						BRt
Myiagra cyanoleuca	Satin Flycatcher		X				[X]		Mt
Zosterops minor	Black-fronted White-eye			X					BRt
Aplonis mystacea	Yellow-eyed Starling	NT	X		X				BRt
Lonchura tristissima/leucosticta	Streak-headed/White-spotted Mannikin		X			X			BRt

Chapter 1.6. Mammals of the Wau Creek proposed Wildlife Management Area, Gulf Province, Papua New Guinea

Enock Kale, Kyle N. Armstrong, Pita Amick and Iain Woxvold

A Lowland Ringtail (*Pseudochirulus canescens*) observed during night surveys at Wau Creek

Summary
The lowland rainforest of the Wau Creek area in the Kikori basin of southern Papua New Guinea provides habitat for a diverse mammal fauna. The area is known for recent conservation work involving the traditional landowning clan that is investigating the presence and nesting of the Pig-nosed Turtle (*Carettochelys insculpta*; 'Piku' in local language), which has prompted a wider interest in conservation at Wau Creek. The Wau Creek area is now proposed as a Wildlife Management Area (WMA).

The aims of this study were to: 1. assess mammal diversity and determine the presence and status of significant species in the proposed Wau Creek WMA by conducting a rapid inventory survey; 2. encourage local landowners to conserve the forest and riparian habitats of Wau Creek and its biodiversity; and 3. summarise information on mammal diversity to support the establishment of a Wildlife Management Area at Wau Creek.

The survey was conducted between 22 and 26 April 2017. While brief, the survey incorporated numerous techniques to maximise detection of species. Non-volant (non-flying) mammals were surveyed by live trapping with Elliott box traps (361 trap-nights), camera trapping with unattended movement-triggered cameras (15 sites between 28 November and 5 December 2016 as part of a reconnaissance; 20 sites in 2017), and by conducting spotlighting searches at night. Bats were surveyed by trapping with harp traps (four sites) and mist nets (14 nets over five sites), and by recording their echolocation calls with electronic bat detectors (20 recording nights/sites).

The survey resulted in the detection of 11 native non-volant mammal species in 10 genera from four marsupial families (Peroryctidae—1 sp., Macropodidae—1 sp., Phalangeridae—1 sp. and Pseudocheiridae—1 sp.), and one rodent family (Muridae—7 spp.). Most species were encountered using camera traps, with two arboreal species detected on opportunistic night searches, while the four nights of live trapping resulted in the capture of one rodent (trapping success rate of 0.3 %). The most significant non-volant mammal species encountered was the Grey Dorcopsis *Dorcopsis luctuosa*, which has an IUCN Red List conservation status of Vulnerable because of a declining population size from over-hunting.

A total of 22 bat species was detected on the survey. Seven species of bat were captured (total 39 individuals: 35 in mist nets, 4 in harp traps comprising 38 small fruit bats and blossom bats in the family Pteropodidae, and one horseshoe bat *Rhinolophus mcintyrei*), or observed (diurnal roost camps of the Great Flying-fox *Pteropus neohibernicus*). Sixteen species of bat were detected from their echolocation calls. None of the bat species are listed by the IUCN as Threatened, or Near Threatened.

The detection of 33 native mammal species over a four-night period is indicative of a diverse and intact mammal assemblage that is worthy of conservation. The conservation of biodiversity in the Wau Creek area will be facilitated by considering 'umbrella' species such as the Grey Dorcopsis and Pig-nosed Turtle, and by engaging with local people who have a willingness to protect biodiversity on their traditional lands. Further efforts to detect species expected to occur should target arboreal non-volant species, searches for colonies of cave-roosting bats, and some identities from camera traps and bat detectors need to be confirmed by follow-up trapping and genetic work, especially taxonomically-unresolved or morphologically-similar taxa. The hunting of pigs should be promoted over native mammal species, especially the larger species such as Dorcopsis and Tree Kangaroos.

Introduction
The Kikori basin covers an area of 2.3 million hectares and comprises multiple broad-scale habitats ranging from mangrove forest in the estuarine system, to freshwater swamp forest, lowland rainforest, and montane rainforest in the central range (Leary 2004). The mammal assemblage is diverse, and has been documented from on-ground surveys, examination of museum specimens and literature searches (Leary et al. 1995; Seri et al. 1995; Leary and Seri 1997; Namo 2004). Leary (2004) summarised the mammal diversity in two ecoregions that span a large extent of southern New Guinea (as described by Wikramanayake et al. 2002)—Southern New Guinea Freshwater Swamp Forest ecosystem

('freshwater swamp forest' hereafter) and Southern New Guinea Lowland Rainforest ecosystem ('lowland rainforest' hereafter). In the lowland rainforest, a total of 68 species across the ecoregion have been documented (2 monotremes, 18 marsupials, 20 rodents, 29 bats). A compilation of mammal diversity from the Kikori basin, which extends from the lowlands up to montane habitats, documented 105 species (1 monotreme, 34 marsupials, 37 rodents, 33 bats; Namo 2004). The Kikori basin is suspected to be home to undiscovered and undescribed mammal species, especially in the relatively inaccessible limestone karst terrain where the lowland rainforest meets central range montane rainforests, so this species total is likely to be even higher.

The proposed Wau Creek Wildlife Management Area forms part of the extensive humid lowland rainforest that covers most of the lower elevations within the Kikori basin. It is partially bounded by small tributaries of Wau Creek, and the Sire River. These drain into the Kikori River that eventually enters the sea through the extensive Kikori Delta.

There has been relatively little mammal survey work undertaken in this area (Leary et al. 1995; Seri et al. 1995; Leary and Seri 1997; Leary 2004), and there are currently four mammal species predicted to be within the area that are listed as species of conservation significance by the IUCN—Lowlands Tree Kangaroo (*Dendrolagus spadix*; Vulnerable), Grey Dorcopsis (*Dorcopsis luctuosa*; Vulnerable), New Guinea Quoll (*Dasyurus albopunctatus*; Near Threatened), and a horseshoe bat (no common name) *Rhinolophus mcintyrei* (Data Deficient).

The Wau Creek area is known for recent community-based conservation work involving the Pig-nosed Turtle (*Carettochelys insulpta*; 'Piku' in local language), which has prompted a wider interest in conservation in the area. In order to support the efforts to establish a Wildlife Management Area at Wau Creek, we undertook a mammal survey there during April 2017.

Aims

The aims of this survey were to:

- Assess mammal diversity and determine the presence and status of significant species in the proposed Wau Creek Wildlife Management Area by conducting a rapid inventory survey;

- Encourage local landowners to conserve the forest and riparian habitats of Wau Creek and its biodiversity;

- Summarise information on mammal diversity to support the establishment of a Wildlife Management Area at Wau Creek.

Methods

Non-volant mammals

Several methods were employed to survey non-volant (non-flying) mammals: live trapping with Elliott box traps, camera trapping with unattended movement-triggered cameras, and by opportunistically detecting mammal species when conducting spotlighting searches at night.

Trapping was conducted for four nights between 22 and 26 April 2017, with a total trapping effort of 361 trap-nights. Traps were set along three transects near the Wau Creek research station, and a fourth, short transect was established near the Seri River at least 2.8 km directly south of the research station (Figure 1). Two sizes of Elliott box traps were used: small (37 x 10 x 10 cm) and large (15 x 15 x 46 cm). Small traps were baited with a mixture of sweet potatoes and fresh peanuts. Fresh sweet bananas and coconut sourced from the local Kikori market were added to the large traps in addition to the sweet potato and peanuts to attract larger-bodied rodents such as *Uromys* (Muridae) and bandicoots (Peroryctidae).

Data from Reconyx Hyperfire HC550/PC850 automatic 'camera traps' that were deployed at the Wau Creek site by IW at two different times are incorporated into this report. The first deployment was between 28 November and 5 December 2016 during a site reconnaissance (15 camera traps), and the second was between 22 and 26 April 2017 (20 camera traps). The location of each camera trap was recorded with a Garmin GPS unit. Details of camera trap deployment methods are described in Chapter 1.5 and their locations are illustrated in Figure 1.

An overall list of species identified in the camera trap images was compiled. Abundance cannot be estimated from the images, so instead a Relative Abundance measure was calculated to provide a rough indication of how common each species was. This is simply the proportion of camera trapping sites with one or more images of each species (e.g. a value of 0.6 indicates the species was detected at 6 out of 10 camera trapping sites).

Bat trapping

Bats were surveyed using mist nets (double-stranded nylon 'bird' mist nets), triple-bank harp traps (three rectangular frames 2 m high and 5 cm apart containing fishing line strung vertically, and positioned over a catch bag), and 'bat detectors' that record the ultrasonic echolocation calls of bats. Harp traps (two traps at a total of four sites) and mist nets (14 nets at a total of five sites) were set in the forest understorey across gullies, in the gaps amongst vegetation and on tracks to maximise the capture of bats flying through the understorey (Figure 2).

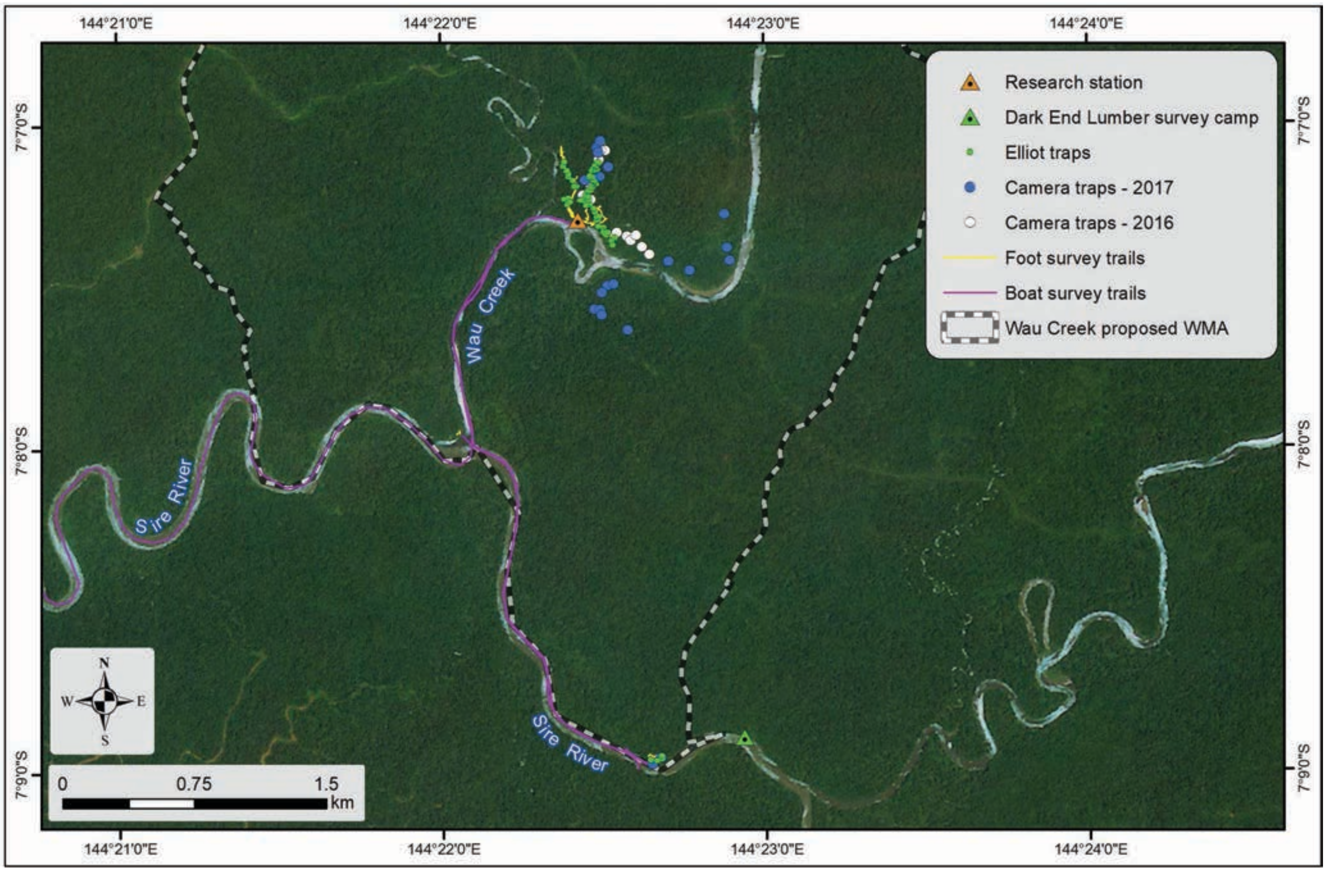

Figure 1. The locations of camera trap and Elliott trap sites within the proposed Wildlife Management Area.

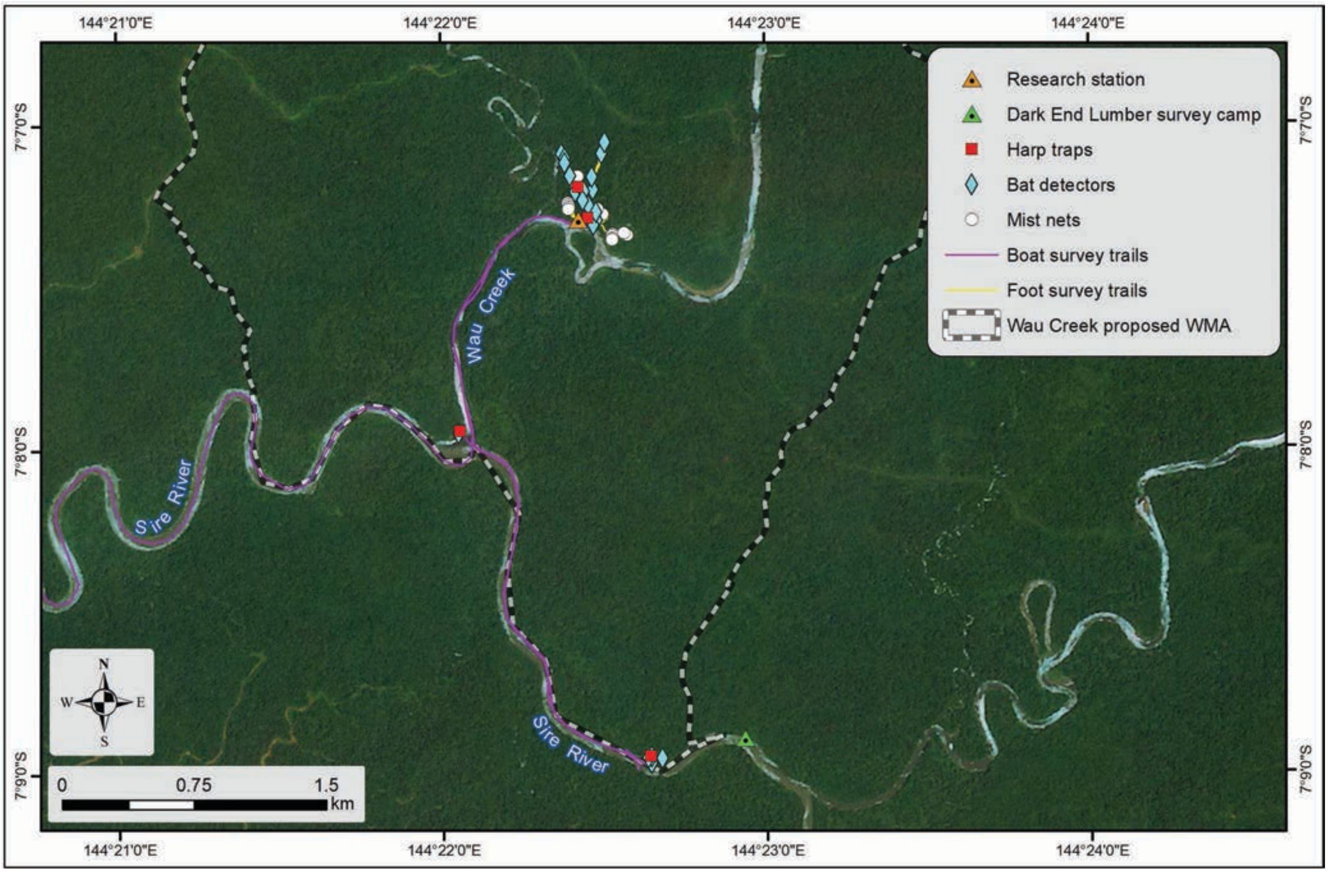

Figure 2. Deployment sites of harp traps, mist nets and bat detectors at Wau Creek.

Identification of captures and sample collection

Identifications were based on information in Flannery (1995), Bonaccorso (1998), and the unpublished notes of the authors. Nomenclature follows the IUCN Red List accounts except where these are out of date.

Most captured mammals were released after taking a small biopsy sample of skin for later genetic analysis. Biopsies were taken from the wing membrane of bats with a 4 mm dermal punch, and from the tail of rodents and small marsupials by removing <5 mm from the tail tip. A small number of voucher specimens (5 bats) was retained to aid verification of identifications. Vouchers were fixed in 10% formalin and then transferred to 70% ethanol for long-term storage. Tissue biopsy samples were preserved in 95% ethanol.

Bat echolocation recordings

Most small, insect-eating bat species can be distinguished from each other based on the frequency and pulse shape characteristics of their ultrasonic echolocation calls. Recordings of bat calls were made in high quality full spectrum WAV format over four nights (22–25 April 2017) with five Pettersson Elektronik D500X bat detectors for a total of 20 full recording nights (Figure 2). Bat detectors were waterproofed in plastic boxes, and microphones on a 3 m extension cable were attached to tree trunks c. 2.5 m high, with a funnel made from a plastic drink bottle placed over the microphone tip to protect it from moisture. The detectors were placed in a variety of habitats including adjacent to streams, within forest, along tracks, facing into clearings, and in open habitats. They were set in position before dusk and collected after dawn, and were moved to a new location each day. 'Reference' recordings were made from captured bats with a Titley Scientific Walkabout bat detector (sampling frequency 500 kHz), and also a Pettersson Elektronik D240X detector connected to a digital recorder, in order to establish a library against which to compare calls recorded by the bat detectors.

Acoustic processing of bat echolocation calls and summary of data

With high quality 'full spectrum' recordings, the datasets are typically many gigabytes, and not every sound file out of the many thousands recorded can be examined in a spectrogram. Thus, a customised, multi-step acoustic processing procedure that can filter large bat echolocation recording datasets from Papua New Guinea (Armstrong and Aplin 2014a; Armstrong et al. 2016) was applied to the recordings. This approach has been used on numerous published exploratory surveys in PNG, and details of this procedure are presented in Appendix 1.

An overall list of species identified in the recordings was compiled. Abundance cannot be estimated from recordings of echolocation, so instead a Relative Abundance measure was calculated to provide a rough indication of how common each species was. This is simply the proportion of recording sites with detections of each species (e.g. a value of 0.6 indicates the species was detected at 6 out of 10 recording sites).

Results

Non-volant mammals

At least 11 native non-volant mammal species in 10 genera from four marsupial families and one rodent family were detected in total from the data collected in both 2016 and 2017 (Table 1). In addition, one non-native species, the Pig *Sus scrofa*, was detected relatively infrequently compared to some of the other native species. The rodent family Muridae was the most species-rich with seven species, and each marsupial family was represented by only one species.

Most (eight) native species were detected through camera trapping (Table 1). Camera trapping in 2016 added only one extra rodent to the total list compiled in 2017 (Slender Rat, *Rattus verecundus*). The most commonly observed species were small bandicoots, either the Common Echymipera (*Echymipera kalubu*) or Long-nosed Echymipera (*E. rufescens*) (Plate 1A) and the White-tailed Giant Rat (*Uromys caudimaculatus*) (Plate 2C), each appearing on at least half of the cameras in both survey years (Relative Abundance of 0.5 and above). Some of the identifications from the camera trap images could not be determined unambiguously because diagnostic parts of the animal were not visible in photographs (e.g. the species of *Phalanger* in Plate 1C), or else capture was required to observe small features of the external morphology to remove ambiguity, such as for some of the rodents (Plate 2B). In these cases, the most likely options are given, with further discussion in Appendix 2.

The most significant species encountered through camera trapping was the Grey Dorcopsis (*Dorcopsis luctuosa)*, which has an IUCN Red List conservation status of Vulnerable (Leary et al. 2016a; Plate 1B). It had a Relative Abundance of 0.1 in 2016, and 0.3 in 2017.

Two species were detected by direct observation—the Lowland Ringtail (*Pseudochirulus canescens*) was detected foraging in the understorey several metres from the ground; and a Lesser Tree Mouse (*Chiruromys vates*) was detected and photographed by the herpetology team (Plate 1F). An unidentified species of Dorcopsis was also seen fleetingly during the day.

The four nights of live trapping with Elliott live traps in 2017 resulted in the capture of one individual of the Cape York Rat (*Rattus leucopus*). With the total of 361 trap-nights, this represented a trapping success rate of 0.3 %.

Further details on selected species are discussed in Appendix 2.

Table 1. List of non-volant mammals encountered at Wau Creek (?: species identity to be confirmed; IUCN: conservation status on the IUCN Red List; values: Relative Abundance values from camera trapping; LT: Elliott live trap capture; OBS: observed on a night search).

Family	Common name	Scientific name	IUCN	2016	2017
MARSUPIALS					
Peroryctidae	Common Echymipera/ and/or Long-nosed Echymipera?	*Echymipera kalubu/* and/or *E. rufescens*?	LC	0.5	0.6
Macropodidae	Grey Dorcopsis	*Dorcopsis luctuosa*	VU	0.1	0.3
Phalangeridae	Southern Common Cuscus/ and/or Ground Cuscus?	*Phalanger mimicus/* and/or *P. gymnotis*?	LC	—	0.1
Pseudocheiridae	Lowland Ringtail	*Pseudochirulus canescens*	LC	—	OBS
RODENTS					
Muridae	Uneven-toothed Rat?	*Anisomys imitator*?	LC	—	0.1
	Lesser Tree Mouse	*Chiruromys vates*	—	—	OBS
	Black-tailed Melomys	*Melomys rufescens*	LC	—	0.1
	Common Lowland Paramelomys	*Paramelomys platyops*	LC	0.1	0.1
	Cape York Rat	*Rattus leucopus*	LC	—	LT
	Slender Rat	*Rattus verecundus*	LC	0.2	—
	White-tailed Giant Rat	Uromys caudimaculatus	LC	0.5	0.5
FERAL					
Suidae	Pig, Wild Boar	*Sus scrofa*	LC	0.2	0.2
Total species			**12**	**6**	**11**

Bats

A total of 22 bat species was detected on the survey, which included six species in the family Pteropodidae and 16 species of echolocating insectivorous bat in five families (Table 2; Figure 3). An additional three species were detected in addition to those expected for the area (Appendix 3). None of the species encountered are listed on the IUCN Red List as Threatened or Near Threatened. One taxon listed as Data Deficient was present—a horseshoe bat that was renamed after a recent taxonomic revision of the *Rhinolophus arcuatus* species complex (Patrick et al. 2013), *Rhinolophus mcintyrei* (Patrick and Ruedas 2017).

Five species of bat were captured (total 39 individuals; 35 in mist nets, 4 in harp traps), and two additional species were observed. Most captured bats were small fruit bats and blossom bats in the family Pteropodidae, but one horseshoe bat *Rhinolophus mcintyrei* was also captured in a harp trap (Plate 3B).

A camp of the Great Flying-fox (*Pteropus neohibernicus*) was observed (Plate 3C, 3D), and the distinctive 'buzzing' sound of the flight of the Moluccan Naked-backed Fruit Bat (*Dobsonia moluccensis*) was also heard. Around 100 individuals of the Great Flying-fox were observed roosting in four trees opposite Waira Village, upstream from Wau Creek on the Kikori River at Kikori station. Around 50 individuals were also observed at Wau Creek.

Most echolocation call types could be attributed with confidence to a single species. However, some calls could not be associated with a species reliably because either the calls of certain species are too similar to distinguish unambiguously, or there are taxonomic issues that prevent attributions to a particular species. The most obvious example are calls that are attributable to bent-winged bats (*Miniopterus* spp.)—because identification of the members in this genus from body characters is problematic, the identification of their calls is also unreliable. These call types are also very similar to calls produced by species of Pipistrelle (*Pipistrellus* spp.) Despite these difficulties, bat detectors produced records of 15 more echolocating bat species than trapping alone. Further comments on identifications and taxonomic issues are presented in the individual species accounts that follow.

The most commonly recorded species was the horseshoe bat *Rhinolophus mcintyrei*, which was present on all recordings (Relative Abundance 1.0); and Temminck's Leaf-nosed Bat (*Aselliscus tricuspidatus*), which was represented on almost all recordings (Relative Abundance 0.9; Table 2). The small-sized bent-winged bat *Miniopterus* sp. 3 (call type *53 st.cFM*) and Wollaston's Leaf-nosed Bat (*Hipposideros wollastoni*) were also relatively common, each with Relative Abundance values of 0.7.

Further details on selected species are discussed in Appendix 2.

Table 2. Species and echolocation call types of bats recorded at all recording sites combined, with an estimate of Relative Abundance to indicate how common each was (OBS—observed only and not captured; asterisks indicate presence was expected based on information on the IUCN Red List, see Appendix 3).

Common name	Genus species	Call type	Rel Ab	Captures
PTEROPODIDAE—6				
*Moluccan Naked-backed Fruit Bat	*Dobsonia moluccensis*	—	—	OBS
*Dagger-toothed Long-nosed Blossom Bat	*Macroglossus minimus*	—	—	2
*Common Tube-nosed Fruit Bat	*Nyctimene* sp. cf. *albiventer*	—	—	1
*Green Tube-nosed Fruit Bat	*Paranyctimene* sp. cf. *raptor*	—	—	3
*Great Flying-fox	*Pteropus neohibernicus*	—	—	OBS
*Common Blossom Bat	*Syconycteris australis*	—	—	32
EMBALLONURIDAE—2				
*Raffray's Sheath-tailed Bat	*Emballonura raffrayana*	*45 i.fFM.d*	0.1	—
*Lesser Sheath-tailed Bat	*Mosia nigrescens*	*65 i.fFM.d*	0.5	—
HIPPOSIDERIDAE—5				
*Temminck's Leaf-nosed Bat	*Aselliscus tricuspidatus*	*115 sCF*	0.9	—
*Fawn-coloured Leaf-nosed Bat	*Hipposideros cervinus*	*140 sCF*	0.2	—
*Diadem Leaf-nosed Bat	*Hipposideros diadema*	*58 mCF*	0.5	—
*Maggie Taylor's Leaf-nosed Bat	*Hipposideros maggietaylorae*	*125 mCF*	0.2	—
*Wollaston's Leaf-nosed Bat	*Hipposideros wollastoni*	*89 mCF*	0.7	—
RHINOLOPHIDAE—4				
*a horseshoe bat	*Rhinolophus mcintyrei*	*70 lCF*	1.0	1
*New Guinea Horseshoe Bat	*Rhinolophus euryotis*	*52 lCF*	0.5	—
Large-eared Horseshoe Bat	*Rhinolophus* sp. cf. *philippinensis*	*47 lCF*	0.4	—
Greater Large-eared Horseshoe Bat	*Rhinolophus* sp. cf. *robertsi*	*33 lCF*	0.1	—
MINIOPTERIDAE—3				
*Unidentified bent-winged bat 1	*Miniopterus* sp. 1 'large'	*38 st.cFM*	0.3	—
*Unidentified bent-winged bat 2	*Miniopterus* sp. 2 'medium'	*45 st.cFM*	0.1	—
*Unidentified bent-winged bat 3	*Miniopterus* sp. 3 'small'	*53 st.cFM*	0.7	—
VESPERTILIONIDAE—2				
*Fly River Woolly Bat	*Kerivoula muscina*	*60 bFM*	0.1	
Unidentified Myotis	*Myotis* sp.	*30 bFM*	0.1	
Total captures				39
Total Species Richness				22

Note: All Miniopteridae are marked as expected species for the area, even though they are all unidentified, given that there are candidates listed for each of the call types in Appendix 3.

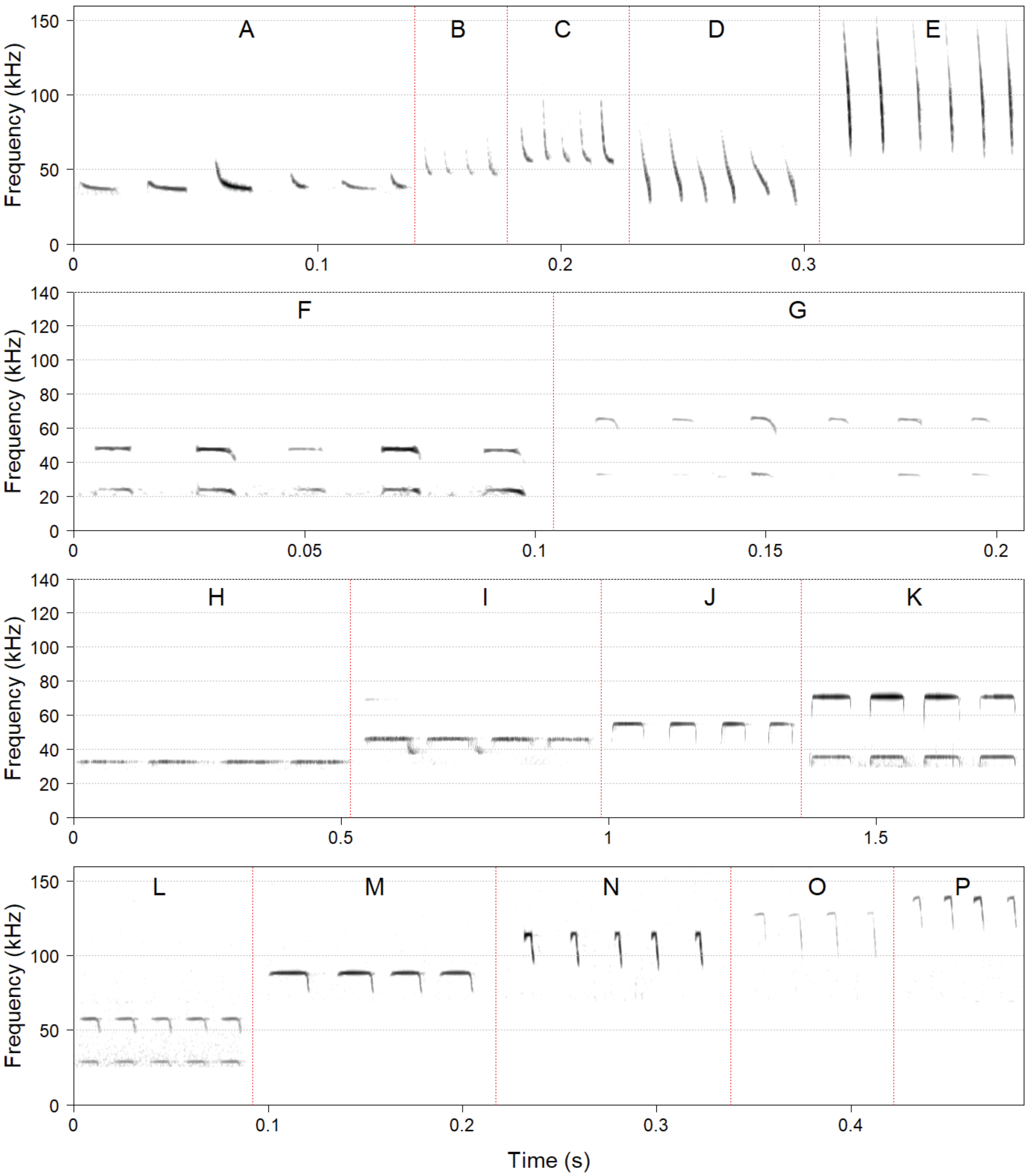

Figure 3. Examples of each echolocation call type (time is compressed between pulses; note the x-axes and y-axes are scaled differently in each plot).

A: *38 st.cFM Miniopterus* sp. 1 'large', B: *45 st.cFM Miniopterus* sp. 2 'medium', C: *53 st.cFM Miniopterus* sp. 3 'small', D: *30 bFM Myotis* sp. , E: *60 bFM Kerivoula muscina*, F: *45 i.fFM.d Emballonura raffrayana*, G: *65 i.fFM.d Mosia nigrescens*, H: *33 lCF Rhinolophus* sp. cf. *robertsi*, I: *47 lCF Rhinolophus* sp. cf. *philippinensis*, J: *53 lCF Rhinolophus euryotis*, K: *70 lCF Rhinolophus mcintyrei* , L: *58 mCF Hipposideros diadema*, M: *89 mCF Hipposideros wollastoni*, N: *112 sCF Aselliscus tricuspidatus*, O: *125 sCF Hipposideros maggietaylorae*, P: *140 sCF Hipposideros cervinus*

Discussion

The variety of approaches to surveying mammals in the proposed Wau Creek Wildlife Management Area in 2016 and 2017 (camera trapping, Elliott trapping, observational surveys, harp trapping, mist netting and recording echolocation calls) detected a total of 33 species of native mammal, with all but one of those being found during the four-night 2017 survey.

In terms of return for effort, the number of mammal species detected compares well with past surveys of similar length in similar lowland habitat. A survey at Utiti Creek (35 m elevation in the 'Southern New Guinea Freshwater Swamp Forest ecoregion'; Leary and Seri 1995, 1997) produced 17 mammal species over four nights (30 July to 4 August 1995; 18% marsupial, 35% rodents, 47% bats). Short surveys at Uro (as Veiru) Creek produced 14 species in similar habitat (20 m elevation), and eight species at Omo in the 'Southern New Guinea Lowland Rainforest ecoregion' (170 m elevation) (Leary and Seri 1997). Longer surveys in the Kikori Integrated Conservation and Development Program Area spanning a total of 40 days encountered a total of 30 non-volant species and 20 bat species (Leary et al. 1995; Seri et al. 1995).

Non-volant mammals

Camera trapping was the most successful technique used for non-volant mammals during this survey, detecting 75% (9 out of 12) of the non-volant mammal species encountered. By contrast, live-trapping using Elliott traps resulted only in a single record (a capture rate of 0.3%) of a *Rattus leucopus* captured near the Wau Creek Research Station. Such a low trap success rate is typical of studies in primary lowland forests in PNG (Aplin and Opiang 2011). For example, Anthony et al. (2008, cited in Aplin and Opiang 2011) reported a trapping success of less than 0.01% (11 individuals in almost 1800 trap-nights). This contrasts with the relatively high trapping rate of 30.8% from a long-term mark-release-recapture study at 850 m asl from just 56 trap nights (Kale 2007; Kale et al. 2012). Greater diversity at elevations over 1000 m can also contribute to higher trapping success (Aplin and Opiang 2011). It is clear from the present survey at Wau Creek that camera trapping is superior in terms of detection, but not all photographs contain enough information to make a robust identification. Furthermore, camera trapping does not provide the opportunity to confirm identifications through examination of external morphology or take samples for confirmation with genetic testing, hence the degree of uncertainty in identification discussed for some taxa (Appendix 2).

Most species that were detected with camera traps spend much of their time on the forest floor. The effort for night observational surveys was valuable given the detection of two arboreal species—the Lowland Ringtail (*Pseudochirulus canescens*) and the Lesser Tree Mouse (*Chiruromys vates*). There are likely to be other arboreal species present in the Wau Creek that remain to be detected, for example the Striped Possum (*Dactylopsila trivirgata*) and Sugar Glider (*Petaurus breviceps*) (Namo 2004), could be detected with additional night spotlighting searches and camera trap positions that are more likely to detect them.

Other species of conservation significance might be shown to be present with further effort, including the Lowlands Tree Kangaroo (*Dendrolagus spadix*) (IUCN Vulnerable), and New Guinea Quoll (*Dasyurus albopunctatus*) (IUCN Near Threatened).

Bats

Of the 34 species of bat expected to be in the Wau Creek area based on the most current information available (http://www.iucnredlist.org/initiatives/mammals; Appendix 3), 19 were encountered during this survey. In addition, three species were encountered that were not expected based on their known distributions, bringing the total number of bat species detected to 22. All of the species not recorded previously in this area were detected from their echolocation calls, and all have some level of taxonomic ambiguity (Appendix 2).

Newly-encountered species in the area include the two PNG 'phonic types' (=having different echolocation calls) of the Large-eared Bat (*Rhinolophus philippinensis*) species complex that are likely to be separate species (here referred to as Greater Large-eared Horseshoe Bat (*Rhinolophus* sp. cf. *robertsi*) and Large-eared Horseshoe Bat (*Rhinolophus* sp. cf.

philippinensis)). Until recently when bat detectors began to be employed on biodiversity surveys (Richards 2005, 2008), only one species affiliated with the '*R. philippinensis*' species complex was known from New Guinea (Flannery 1995; Bonaccorso 1998). Since that time, one or both phonic types have been recorded at the base of the P'nyang Range (Armstrong et al. 2014), near Moro (Armstrong 2017), and several other sites in PNG (K.P. Aplin and K.N. Armstrong unpublished reports). At Wau Creek the call type of *Rhinolophus* sp. cf. *philippinensis* (*47 lCF*) was moderately common (Relative Abundance 0.4), and the records of both affiliated species here significantly extend their known distributions (Sedlock et al. 2008).

The third species detected in addition to those expected for the area is the unidentified species of *Myotis*. The echolocation call type *30 bFM* encountered at Wau Creek is of lower frequency than that reported for the Maluku Myotis (*Myotis moluccarum*) (call type *40 bFM*) that is widespread across New Guinea, and might derive from a genetically distinct form first identified by Cooper et al. (2001). Capture and subsequent morphological and genetic studies are required to confirm the identity of the Wau Creek '*Myotis*'.

The remaining 15 species of bat expected for the Wau Creek area are not rare, and some could be encountered with additional effort with bat detectors and searches for cave roosts—New Guinea Sheath-tailed Bat (*Emballonura furax*), Dusky Leaf-nosed Bat (*Hipposideros ater*), Spurred Leaf-nosed Bat (*Hipposideros calcaratus*), and Eastern Horseshoe Bat (*Rhinolophus megaphyllus*). However, additional capture effort with mist nets and harp traps (ideally combined with acoustic lures; see Hill et al. 2015) will be of greater value in future mammal surveys for species whose presence is difficult to confirm based on acoustic recordings. This is particularly relevant for species in the Vespertilionidae that produce calls very similar in shape and frequency to those of medium to small-sized bent-winged bats (*Miniopterus* spp.—Hoary Wattled Bat (*Chalinolobus nigrogriseus*), New Guinea Pipistrelle (*Pipistrellus angulatus*), Papuan Pipistrelle (*Pipistrellus papuanus*), and Northern Broad-nosed Bat (*Scotorepens sanborni*).

Most of the small fruit bats expected to occur at Wau Creek were encountered there. They are important for ecosystem functioning because they pollinate a variety of rainforest plants and disperse seeds (Bonaccorso 1998). Species within the genera *Nyctimene* and *Paranyctimene* are currently difficult to identify because taxonomic studies are ongoing (Irwin 2017; K.N. Armstrong unpublished molecular data), and tissue biopsy samples from representatives of these two genera, plus *Macroglossus* and *Syconycteris*, will be used to improve our understanding of species diversity and taxonomy of these poorly understood bats.

Beyond those already expected for the area based on known distributions, it is very likely that several other species will also be present, simply because the information of range extent on many New Guinea bat species is incomplete. Bat species that fly high over the forest canopy are seldom encountered on biodiversity surveys because they are difficult to capture, and as a result there are very few records of species in the genera *Chaerephon, Otomops, Mormopterus* (=*Ozimops*), and *Saccolaimus* (Bonaccorso 1998). It is both remarkable and puzzling that there were none of these low-frequency-emitting bats recognised in the recordings, since their calls are typically loud and easy to detect, and because they often forage in open spaces above and adjacent to river systems such as the main channel of Wau Creek. While the higher-flying species can be targeted with mist nets hoisted into the canopy, this is a lot of effort if bat detectors do not first indicate their presence.

Using electronic survey tools in rapid assessments—relevant considerations

Rapid biodiversity assessments such as the present study rely on techniques that can increase the rate of encounter of mammal species in a short time period with relatively little effort or specialised skill involved in their deployment. Camera trapping and the recording of diagnostic echolocation calls with bat detectors are not limited by the many factors that influence the success of a trapping program. They simply rely on the animals coming into close proximity to the equipment. Such devices allow deployment by non-specialists, low-cost field studies, and much longer deployment periods that further increase the chance of animal encounters. Given the diversity of mammals detected in the present study area in just a few nights with mostly remote-detection (non-trapping) methods, further efforts are likely to reveal the presence of additional species, especially those that are rare, seldom-seen or difficult to identify. Such efforts are certainly desirable so that future conservation and management actions in the Wildlife Management Area consider the whole mammal assemblage. But there are two challenges that must first be resolved.

Firstly, while the camera traps and bat detectors allowed the compilation of a diverse list of taxa, there were still numerous examples where the identifications were problematic—because small diagnostic features (e.g. tail scalation patterns and nipple patterns in smaller rodents) were not visible in photographic images (e.g. making it difficult to distinguish the Common Lowland Paramelomys (*Paramelomys platyops*) from the Black-tailed Melomys (*Melomys rufescens*)); or else the identification of echolocation call types was made difficult by the similarity of certain calls amongst some species (Appendix 2). Further trapping in the short-term would therefore be especially valuable. It would reduce considerably the number of candidate species for ambiguous identifications by providing the opportunity to examine captures of these problematic taxa. Mammal diversity could then be more reliably quantified with remote methods because the most likely options for an identification in an area would be based on empirical information. In the case of species that are difficult to identify even after capture, and when there is a constraint on the collection of whole-animal vouchers for museum-based comparisons, the application of genetics-based identification will provide greater clarity from a small non-lethal biopsy sample.

Secondly, rapid assessments are not only limited by how possible it is to identify species from electronic images or acoustic recordings, they are also constrained by the state of taxonomic knowledge of some common PNG mammal groups. Mammal identification can be difficult because of the high prevalence of cryptic species—where a described species contains more than one morphologically-similar but genetically-distinct taxon. There is also a lack of published resources allowing the accurate identification of PNG mammals based on their morphology, which first requires their taxonomic resolution. There has been relatively little application of modern methods in mammal taxonomy to resolve species complexes in PNG, specifically the use of genetic markers. However, genetic markers can be used to make identifications before formal taxonomic description work. One recent ecological study on PNG vertebrates successfully used the DNA barcoding approach to ensure that taxa were identified reliably and consistently, and in some cases highlighted that some 'species' actually had taxonomically distinct forms at different elevations (on the Agogo Range and Hides Ridge; Aplin and Opiang 2017; Armstrong 2017; Armstrong and Aplin 2017a; Richards and Armstrong 2017). The application of genetic markers to identification will provide greater clarity, and also allow future recognition of the same captured taxon even if it is undescribed or completely novel.

Thus further trapping effort combined with genetic studies will help to refine the list of species known to occur at a locality, increasing the likelihood of accurate identifications by non-specialists during remote-detection surveys in the future. The strategic use of trapping, remote-detection methods, and genetics-based identification will each have an important role in a successful approach for long-term biodiversity management.

Biodiversity and conservation values

Wau Creek provides an important habitat for the Grey Dorcopsis (*Dorcopsis luctuosa*), which was detected with moderate frequency in the study area—on 13% and 25% of the camera traps in 2016 and 2017 respectively. This species is listed as Vulnerable by the IUCN because of declining populations across its range (Leary et al. 2016a). The Wau Creek area contains another IUCN Vulnerable species—the Pig-nosed Turtle *Carettochelys insculpta*, which appears to be relatively common on the Sire River (Georges et al 2008) and these two species may serve as important 'umbrella species' for conserving biodiversity at Wau Creek.

Local communities own and have all rights over most land in PNG and the Wau Creek area is one of only a few sites where local people are voluntarily conserving their biodiversity. The decision by the local landowners of Wau Creek to protect their biodiversity is extremely valuable and their long term intentions provide an optimistic view of biodiversity conservation in the proposed WMA. In addition to the IUCN Vulnerable species, the biodiversity value is also enhanced by the presence of a diverse mammal assemblage containing at least 33 species, which was evident with only a four-night survey. It may be inferred that to date it has been harvested sustainably by locals for food, as is indicated by the continued presence of the Grey Dorcopsis (Relative Abundance on camera trapping was 0.3 in 2017), and the commonness of small *Echymipera* bandicoots (Relative Abundance 0.6 in 2017).

Balancing the needs of mammal conservation, cultural traditions and subsistence

Balancing the needs of biodiversity conservation with a recognition of the importance of bushmeat to rural or remote communities is challenging (e.g. Eisemberg et al. 2011). The take of bushmeat can be considerable, with one study recording 1.2 tons of wild meat sourced mainly from 37 large bodied mammal genera, including *Dendrolagus*, *Zaglossus* and *Phalanger* (Mack and West 2005). Such a reliance on bushmeat is likely to be common, since a large proportion of PNG people live in remote locations and at the fringe of the cash economy with few options for sourcing their protein from farm or domestic stocks (Mack and West 2005). In many IUCN Red List accounts for larger PNG mammals, hunting was identified as a threatening process that causes population decline (e.g. Leary et al. 2016a).

For communities that wish to manage their land for biodiversity conservation within a formally-recognised Wildlife Management Area, they could make a commitment to stop hunting certain vulnerable species. Alternatively, recognising that a complete ban may not be desirable or achievable, they could develop a plan to manage their take sustainably, and monitor the persistence of these species.

An additional strategy for the sustainable management of species vulnerable to hunting pressure might be to encourage a greater-than-normal focus on feral pigs. The presence of pigs has several negative consequences for native biodiversity. They are destructive to the forest understorey and create significant soil disturbance, compete with native fauna for invertebrates and worms (Howarth 1985) and may also spread disease pathogens to native fauna (Hampton et al. 2004). However, their numbers are unlikely to be controllable because of the continuity of the proposed WMA with the extensive surrounding forest that would presumably be the source of continued replenishment following reductions within the WMA. By shifting a significant level of hunting pressure away from the native mammals and onto feral pigs, it could help to maintain mammal diversity and the quality of their habitat.

Even more helpful would be the reduction of wild dogs that are known to have a significant impact on some macropod populations (e.g. Leary et al. 2016b). The combination of some level of cultural change, together with active management of pigs and dogs, could be sufficient to maintain viable populations of the more sensitive species, and ensure that the area continues to meet the standards for a Wildlife Management Area. In this way, larger-bodied native mammals can serve as 'umbrella' species for the remainder of the mammal assemblage and their habitat. If the community was keen to promote the area or their management of it, then these species could also be used as 'flagship' species whose persistence demonstrates the effectiveness of their actions.

Recommendations

- Use more targeted trapping and genetic ID to resolve ambiguous identifications on a subsequent survey so that longer-term monitoring is based on verified knowledge of species presence and taxa with no ambiguity around their identification.

- Continue monitoring for mammals periodically to assess longer term patterns, using primarily camera traps and bat detectors and engaging with researchers for analysis and reporting.

- Promote the hunting of pigs over native mammal species, especially larger species such as the Grey Dorcopsis *Dorcopsis luctuosa* and the Lowlands Tree Kangaroo *Dendrolagus spadix*, and control wild and domestic dog numbers.

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Plate 1

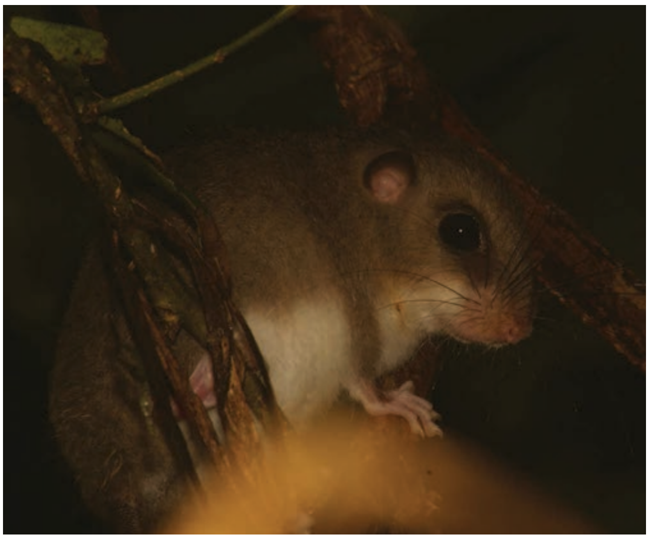
A. One of the small *Echymipera* bandicoots in the Peroryctidae

B. Grey Dorcopsis (*Dorcopsis luctuosa*)

C. Southern Common Cuscus (*Phalanger mimicus*) or Ground Cuscus (*P. gymnotis*)

D. Red morph of the Lowland Ringtail *(Pseudochirulus canescens*)

E. Uneven-toothed Rat (*Anisomys imitator)* (with a pale distal portion to the tail)



F. Lesser Tree Mouse (*Chiruromys vates*)

Plate 2

A. Common Lowland Paramelomys (*Paramelomys platyops*) with a white belly. This species is similar to the Black-tailed Melomys (*Melomys rufescens*)

B. An unidentified species of *Rattus*, distinguishable from some taxa by the darker underside

C. The White-tailed Giant Rat (*Uromys caudimaculatus*), identifiable by the characteristically pale but mottled colour of the end to the tail

D. Dagger-toothed Long-nosed Blossom Bat (*Macroglossus minimus*)

E. One of the members of the Common Tube-nosed Fruit Bat (*Nyctimene* sp. cf. *albiventer*) species complex

F. Green Tube-nosed Fruit Bat (*Paranyctimene raptor*) or an undescribed affiliated species

Plate 3

A. Common Blossom Bat (*Syconycteris australis*)

B. A horseshoe bat (*Rhinolophus mcintyrei*)

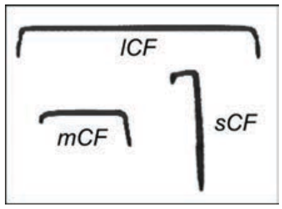
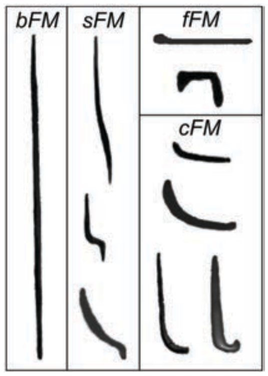
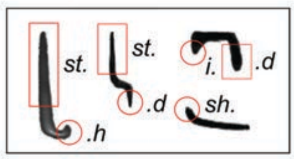
C. Diurnal roosting camp of the Great Flying-fox (*Pteropus neohibernicus*)

D. Diurnal roosting camp of the Great Flying-fox (*Pteropus neohibernicus*)

Appendix 1. Processing of bat detector recordings.

Processing first involved the recognition of bat echolocation 'call types', followed by a separate step of allocating a species identification to each of these. The 'call types' are defined based on a standardised naming scheme that has been used in many published and unpublished surveys across Papua New Guinea and Wallacea in recent years (Armstrong and Aplin 2011, 2014b; Armstrong et al. 2014, 2015a,b; Armstrong 2017; K.N. Armstrong and K.P. Aplin unpublished reports; Supplementary Table 1). The provision of illustrated examples of identified call types provides the opportunity for future verification of call identifications and retrospective correction of species names on the basis of updated information.

Supplementary Table 1. Echolocation call categories based on the shape of search-phase calls (adapted from de Oliveira 1998a,b; Corben and O'Farrell 1999; Gannon et al. 2004; Armstrong and Aplin 2011, 2014b; Armstrong et al. 2014b, 2015a,b; examples are not scaled equally). Echolocation calls generally consist of three main sections: an initial frequency sweep (IFS), followed by the main body (BST: Body Sub Type), and ending in a terminating frequency sweep (TFS). The overall call shape is represented by the codes in the form 'IFS.BST.TFS', prefixed by a value representing the mean characteristic frequency in kHz. Note that most CF pulses have a recognisable initial upward frequency sweep, and all have a terminating frequency sweep, so the IFS and TFS descriptors are not used for this Body Sub Type.

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

The WAV files were scanned for bat echolocation calls using SCAN'R version 1.7.7 (Binary Acoustic Technology) and a custom [R] statistical computing language script was then used to perform a Discriminant Function Analysis to compare bat calls from each nightly recording with data from reference calls and representative call types of Papua New Guinean bats (Armstrong and Aplin 2014b; Armstrong et al. 2014, 2015a; K.N. Armstrong and K.P. Aplin unpublished data). Verification of each call type was made from the original WAV files in a spectrogram within Adobe Audition CS6 version 5.0.2 software. Species were identified from the scored call types based on information in Armstrong and Aplin (2011, 2014b), Leary and Pennay (2011), Robson et al. (2012), Armstrong et al. (2014, 2015a), and K.N. Armstrong and K.P. Aplin (unpublished data).

Appendix 2. Species accounts—supporting information on selected species.

Brief species accounts are presented for selected species that have elevated conservation status on the IUCN's Red List, had an ambiguous identification, are part of a species complex with taxonomic issues that make identification difficult, are range extensions, or that are significant for local communities and the future management of biodiversity in the proposed Wildlife Management Area.

Order Peramelemorphia; Family Peroryctidae

Common Echymipera (*Echymipera kalubu*) (IUCN Least Concern)

Long-nosed Echymipera (*Echymipera rufescens*) (IUCN Least Concern)

The camera traps photographed at least one species of small peroryctid bandicoot, which could have been either the Common Echymipera (*Echymipera kalubu*) or the Long-nosed Echymipera (*E. rufescens*). The Common Echymipera is the most likely candidate given that it is indeed relatively common from sea level up to c. 500 m (Flannery 1995; though it extends to 1,500 metres asl; Menzies 1991). However, the Long-nosed Echymipera, while less common, is variable in coat colour and size and could be misidentified in photographs. Both species are known from the Kikori basin (Namo 2004), although Flannery (1995) indicated that *E. rufescens* has a preference for drier habitats. Small bandicoots are an important game animal for local hunters, especially in lowland parts of New Guinea, and hunting dogs may pose threats to bandicoot populations in the Wau Creek area.

Order Diprotodontia; Family Macropodidae

Grey Dorcopsis *(Dorcopsis luctuosa*) (IUCN Vulnerable)

Dorcopsis luctuosa is abundant in suitable habitat, but the IUCN lists this species as 'Vulnerable' because of a decreasing population trend, including in protected areas—it has apparently disappeared from Varirata National Park near Port Moresby. (Leary et al. 2016a). During the present survey images of the Grey Dorcopsis were captured on two camera traps. Hunting with dogs and forest degradation and clearing pose significant threats to populations of the Grey Dorcopsis so it is encouraging to document this species in the proposed Wau Creek Wildlife Management Area. Local communities should be encouraged to take a proactive approach to limiting access by dogs to the proposed WMA and surrounding areas.

Order Diprotodontia; Family Phalangeridae

Southern Common Cuscus *(Phalanger mimicus*) (IUCN Least Concern)

Ground Cuscus *(Phalanger gymnotis*) (IUCN Least Concern)

The Southern Common Cuscus *(Phalanger mimicus*) is common and distributed widely in southern New Guinea (Flannery 1995; Norris and Musser 2001; Salas et al. 2016). The individuals photographed on camera traps at Wau Creek have lighter fur than the Ground Cuscus (*Phalanger gymnotis*) so, although fur colour is variable in both *P. mimicus* and *P. gymnotis* (Flannery 1995), we tentatively assign these individuals to *mimicus*. An image of a tail resembling that of either *P. gymnotis* or *P. mimicus* was captured on one camera trap, though it is not possible to state which species it was from. Both species are recorded from nearby (Leary and Seri 1997; Leary 2004), both are listed as Least Concern by the IUCN (Leary et al. 2016c; Salas et al. 2016), and whether both occur at Wau Creek would need to be confirmed in the future.

Order Rodentia; Family Muridae

Cape York Rat *(Rattus leucopus*) (IUCN Least Concern)

Slender Rat (*Rattus verecundus*) (IUCN Least Concern)

Two species of *Rattus* were encountered on the survey. The Cape York Rat, (*Rattus leucopus*), was the only rodent captured in an Elliott trap. Its presence at Wau Creek is unsurprising because this common species is distributed widely in a variety of habitats across New Guinea (Flannery 1995).

The Slender Rat (*Rattus verecundus*) was observed on camera trap images in 2017. This species is also distributed widely across New Guinea in a range of habitats at altitudes from 150 m to more than 2700 m asl (Flannery 1995), including sites within the Kikori basin (Bosavi, Iagifu and Mt. Kemenagi; Namo 2004). Genetic studies may be required in future to confirm the identification.

Identifying *Rattus* from photographs is challenging because small diagnostic characters on the body cannot be seen. Thus, all identifications of *Rattus* made from camera trap images need to be confirmed. Other candidate species may be present at Wau Creek, including the Canefield Rat (*Rattus sordidus*), which is also found south of the central cordillera in lowland habitats (Flannery 1995). The presence of the New Guinea Rat (*Rattus novaeguineae*) is possible but much less likely given that it has only been reported from elevations between 740 to 1,520 m asl (Dickman et al. 2016).

Uneven-toothed Rat (*Anisomys imitator*) (IUCN Least Concern)

Anisomys imitator is a widespread species that occurs along New Guinea's central cordillera, and is also present near sea level in the Port Moresby area. Namo (2004) listed this species from the Iagifu Ridge near Moro. At Wau Creek the Uneven-toothed Rat (*Anisomys imitator*) was identified from camera trap images with reasonable confidence despite its morphological similarity to the White-tailed Giant Rat (*Uromys caudimaculatus*) (Flannery 1995). Both have a white-coloured distal half to their tail, but it has a mottled appearance in the White-tailed Giant Rat (compare the two individuals in Plates 1E and 2C). It was present on only one camera trap at Wau Creek and may occur at relatively low density in this lowland forest habitat.

Order Chiroptera; Family Pteropodidae

Moluccan Naked-backed Fruit Bat (*Dobsonia moluccensis*) (IUCN Least Concern)

This large fruit bat is identified easily in flight from the characteristic buzzing sound generated by the bare skin on its back and rump—which is how the species was detected on the present survey. The sound is similar to the flight of Blythe's hornbill and the vulturine parrot, but these are diurnal. The Naked-backed Fruit Bat roosts mostly in recessed shady walls of sinkholes, in caves and under shallow rock overhangs, either from the ceiling or high up on walls (Bonaccorso 1998; Churchill 2008). In general, this species is common but roosting aggregations are vulnerable to disturbance. It is not known if roosts are present at Wau Creek, or whether animals visit from elsewhere to feed in the area.

Common Tube-nosed Fruit Bat (*Nyctimene* sp. cf. *albiventer*)

Green Tube-nosed Fruit Bat (*Paranyctimene* sp. cf. *raptor*)

Tube-nosed fruit bats are recognised by their large eyes, dark and yellow spots on the skin of the wing membranes (usually on the top of wing bones) and ears, the dark stripe down its back (*Nyctimene* only; *Paranyctimene* lacks this stripe) and the long, divergent tubular nostrils. The spotting on the skin helps with camouflage as they rest amongst tree foliage during the day. At night they feed mostly in undisturbed forest on fruits, and are an important pollinator and seed disperser in the forest.

There are unresolved taxonomic issues in the genera *Nyctimene* and *Paranyctimene*. There are several cryptic taxa within the *Nyctimene 'albiventer'* complex and others are similar closely-related species that are easily misidentified (*N. certans, N. draconilla*) so we refer the Wau Creek species to *Nyctimene* sp. cf. *albiventer* pending further the outcomes of taxonomic studies. The species of *Paranyctimene* present at Wau Creek also needs genetic studies to confirm its identity.

Great Flying-fox (*Pteropus neohibernicus*) (IUCN Least Concern)

This is one of the three largest flying-fox species in the world, and can be identified in flight by its relatively slow wingbeat (1–1.5 wingbeats per second; Bonaccorso 1998). They tend to be a lighter or yellowish brown on the back compared to the darker brown of the Large-eared Flying-fox (*Pteropus macrotis*), which has longer ears and might also be present at Wau Creek. Around 100 individuals were observed roosting in four trees opposite Waira Village, downstream from Wau Creek. Around 50 individuals were also observed at Wau Creek. The Great Flying-fox tends to aggregate in large camps that are important for breeding and social interactions. Like other flying-foxes they move between camps on a regular basis, and can range many kilometres in a single night while out foraging for fruit and blossoms. They feed in the forest canopy, and are keystone ecological species that help pollinate trees and spread seeds. 'Camps' of flying-foxes tend to be vulnerable to disturbance and hunting, and severe disturbances can disrupt breeding activity and increase the mortality of young.

Order Chiroptera; Family Emballonuridae

Most small species of sheath-tailed bat (*Emballonura* spp.) are relatively common and have an IUCN conservation status of Least Concern. However, they can be vulnerable to disturbance in their roosts, especially from hunting because they aggregate into colonies that range in size from a few individuals to hundreds in some cases (Bonaccorso 1998). This includes one species detected on the survey: Raffray's Sheath-tailed Bat (*Emballonura raffrayana*) (call type *45 i.fFM.d*).

Order Chiroptera; Family Hipposideridae

Most species of hipposiderids bat are relatively common and have an IUCN conservation status of Least Concern. However, they can be vulnerable to disturbance in their roosts, especially from hunting because they aggregate into colonies that range in size from a few individuals to hundreds in some cases (Bonaccorso 1998). Such species include: Temminck's Leaf-nosed Bat (*Aselliscus tricuspidatus*) (call type *115 sCF*), Fawn-coloured Leaf-nosed Bat (*Hipposideros cervinus*) (call type *140 sCF*), Diadem Leaf-nosed Bat (*Hipposideros diadema*) (call type *58 mCF*) and Maggie Taylor's Leaf-nosed Bat (*Hipposideros maggietaylorae*) (call type *125 mCF*).

Wollaston's Leaf-nosed Bat (*Hipposideros wollastoni*) (IUCN Least Concern) Call type *89 mCF*

The *89 mCF* call type has been recorded from numerous individuals of Wollaston's Leaf-nosed Bat on the southern side of the central cordillera (K.N. Armstrong and K.P. Aplin unpublished data), but it is also at the lower frequency limit of the Fly River Leaf-nosed Bat *Hipposideros muscinus*, which generally has a call around 5 kHz higher. Bonaccorso (1998) states that Wollaston's Leaf-nosed Bat is found between 400 and 2,000 m asl in elevation, though more recently it has been stated as occurring between 30 and 2,440 m asl (Armstrong and Aplin 2017b). At low elevations, it is thought to be replaced by the Fly River Leaf-nosed Bat *Hipposideros muscinus*, which ranges between sea level and c. 750 m asl (Armstrong and Aplin 2017c). Given the overlap in both elevational range and echolocation call frequency of these two species, the capture of a specimen is required to confirm whether the *89 mCF* call is a lower frequency example of the Fly River Leaf-nosed Bat, or a lower elevational range extension of Wollaston's Leaf-nosed Bat.

Order Chiroptera; Family Rhinolophidae

Most species of rhinolophid bat are relatively common and have an IUCN conservation status of Least Concern. However, they can be vulnerable to disturbance in their roosts, especially from hunting because they aggregate into colonies that range in size from a few individuals to hundreds in some cases (Bonaccorso 1998). Such species include: the horseshoe bat *Rhinolophus mcintyrei*, New Guinea Horseshoe Bat (*Rhinolophus euryotis*), Eastern Horseshoe Bat (*Rhinolophus megaphyllus*), and Large-eared Horseshoe Bat (*Rhinolophus philippinensis*) (see comments on taxonomy below).

A horseshoe bat (*Rhinolophus mcintyrei*); Call type *70 lCF*

The Arcuate Horseshoe Bat (*Rhinolophus arcuatus*) is encountered commonly on acoustic surveys in PNG, and its presence has been reported under this name in numerous published and unpublished reports that the author KA has been involved in. When revising the conservation status of mammals in the South East Asian region, the IUCN chose to follow a taxonomic study that revised the taxonomy of this species, which split those occurring in New Guinea from the remainder in the Philippines and Indonesia and elevated them to species status (Patrick et al. 2013). The PNG representative of the *R. arcuatus* 'species complex' is now called *R. mcintyrei*, which does not have a common name. Despite its wide distribution in New Guinea, it was assessed as Data Deficient (Patrick and Ruedas 2017), but is unlikely to be facing significant threats to its persistence.

Greater Large-eared Horseshoe Bat (*Rhinolophus* sp. cf. *robertsi*); Call type *33 lCF*

Large-eared Horseshoe Bat (*Rhinolophus* sp. cf. *philippinensis*); Call type *47 lCF*

These two forms are currently regarded as 'phonic types' (=having different echolocation calls) of the Large-eared Bat (*Rhinolophus philippinensis*), which is a species complex ranging from the Philippines to northern Australia that requires thorough taxonomic revision. In both New Guinea and northern Australia, two phonic types are present together in the same habitats (in sympatry), which probably suggests they are different species. The lower frequency call type *33 lCF* was only recorded recently in New Guinea (Richards 2005, 2008), and may never have been collected. All forms are clearly recognisable by their 'over-sized' ears and noseleaf. They roost in shallow caves but do not form larger colonies like some cave-roosting bat species.

Order Chiroptera; Family Miniopteridae

Unidentified bent-winged bat (*Miniopterus* sp. 1 'large'); Call type *38 st.cFM*

Unidentified bent-winged bat (*Miniopterus* sp. 2 'medium'); Call type *45 st.cFM*

Unidentified bent-winged bat (*Miniopterus* sp. 3 'small'); Call type *53 st.cFM*

Three call types are allocated to species of bent-winged bat, with varying degrees of confidence. The *38 st.cFM* call type is similar to reference calls collected elsewhere in southern New Guinea from a large species of *Miniopterus*. The other two *st.cFM* call types with characteristic frequencies of around 45 kHz and 53kHz are likely to be from medium- and small-sized *Miniopterus*, though *Pipistrellus* is also a possibility for some examples. These two genera are very difficult to distinguish reliably, except where characteristic feeding buzzes are recorded. The reliable identification of bent-winged bats in PNG will not be possible until completion of a taxonomic study currently in progress (K.N. Armstrong and S. Wiantoro unpublished data).

All species of bent-winged bat aggregate in colonies that can number many thousands, typically females that congregate for the birth and development of young. Males also roost in caves but typically in smaller aggregations, and bats disperse to other caves outside the breeding season. Little is known about reproduction of bent-winged bats in Melanesia (Bonaccorso 1998). However, their aggregatory behaviour in caves make them vulnerable to disturbance and hunting.

Order Chiroptera; Family Vespertilionidae

Unidentified Myotis (*Myotis* sp.) (IUCN Least Concern) Call type *30 bFM*

Echolocation calls with short duration broadband sweeps beginning at 80 kHz and sweeping down to around 25 kHz are suggestive of a species of *Myotis*, but previous surveys have sometimes encountered a similar call type with a minimum frequency of 40 kHz or a few kHz lower. One species of *Myotis* is recognised as widespread across New Guinea (Maluku Myotis, *Myotis moluccarum*), which has generally been associated with calls that have a minimum frequency of around 40 kHz (K.N. Armstrong unpublished data). There is the possibility of a second uncharacterised *Myotis* species in New Guinea based on earlier genetic studies (Cooper et al. 2001), and its echolocation call is unknown.

Appendix 3. A list of bats expected and present (X) or not detected (—) from Wau Creek based on information in the IUCN Red List maps for each species.

An additional three species of bat were encountered during the survey (**Table 2**).

Common name	Scientific name	IUCN	Presence
PTEROPODIDAE			
Lesser Bare-backed Fruit Bat	*Dobsonia minor*	LC	—
Moluccan Naked-backed Fruit Bat	*Dobsonia moluccensis*	LC	X
Dagger-toothed Long-nosed Fruit Bat	*Macroglossus minimus*	LC	X
Greater Tube-nosed Fruit Bat	*Nyctimene aello*	LC	—
Common Tube-nosed Fruit Bat	*Nyctimene albiventer*	LC	X
Green Tube-nosed Fruit Bat	*Paranyctimene raptor*	LC	X
Steadfast Tube-nosed Bat	*Paranyctimene tenax*	LC	—
Large-eared Flying-fox	*Pteropus macrotis*	LC	—
Great Flying-fox	*Pteropus neohibernicus*	LC	X
Common Rousette	*Rousettus amplexicaudatus*	LC	—
Common Blossom Bat	*Syconycteris australis*	LC	X
EMBALLONURIDAE			
New Guinea Sheath-tailed Bat	*Emballonura furax*	LC	—
Raffray's Sheath-tailed Bat	Emballonura raffrayana	LC	X
Lesser Sheath-tailed Bat	*Mosia nigrescens*	LC	X
HIPPOSIDERIDAE			
Temminck's Leaf-nosed Bat	*Aselliscus tricuspidatus*	LC	X
Dusky Leaf-nosed Bat	*Hipposideros ater*	LC	—
Spurred Leaf-nosed Bat	*Hipposideros calcaratus*	LC	—
Fawn-coloured Leaf-nosed Bat	*Hipposideros cervinus*	LC	X
Diadem Leaf-nosed Bat	*Hipposideros diadema*	LC	X
Maggie Taylor's Leaf-nosed Bat	*Hipposideros maggietaylorae*	LC	X
Wollaston's Leaf-nosed Bat	*Hipposideros wollastoni*	LC	X
RHINOLOPHIDAE			
a horseshoe bat	Rhinolophus mcintyrei*	DD	X
New Guinea Horseshoe Bat	*Rhinolophus euryotis*	LC	X
Eastern Horseshoe Bat	*Rhinolophus megaphyllus*	LC	—
VESPERTILIONIDAE			
Hoary Wattled Bat	*Chalinolobus nigrogriseus*	LC	—
Fly River Woolly Bat	*Kerivoula muscina*	LC	X
Maluku Myotis	*Myotis moluccarum*	LC	—
Short-winged Pipistrelle	*Philetor brachypterus*	LC	—
New Guinea Pipistrelle	*Pipistrellus angulatus*	LC	—
Papuan Pipistrelle	*Pipistrellus papuanus*	LC	—
Northern Broad-nosed Bat	*Scotorepens sanborni*	LC	—
MINIOPTERIDAE			
Little Bent-winged Bat	*Miniopterus australis*	LC	X
Large Bent-winged Bat	*Miniopterus magnater*	LC	X
Medium Bent-winged Bat	*Miniopterus medius*	LC	X
	Total Expected		34
	Total Observed		19

* previously Arcuate Horseshoe Bat *Rhinolophus arcuatus*

Section 2. Uro Creek

Uro Creek provides access to small gardens and forest resources for the local community.

The 2017 biodiverity survey team at Uro Creek.

Heading out for a day's sampling at Uro Creek.

Uro Creek main channel near junction with Kikori River.

Forest interior on ridge adjacent to Uro Creek main channel.

A’oo Cave on A’oo Creek, site of significant bat colonies.

Major tributary of Uro Creek near Veimake.

Chapter 2.1. Flora of the Uro Creek catchment, Gulf Province, Papua New Guinea

Osia Gideon

Lowland rainforest at Veimake

Summary

This report describes the broad vegetation types and floristics of the Uro Creek catchment based on a five-day survey carried out to determine its potential as a community-based protected area. Uro Creek is located south-west of Kikori District station in Gulf Province, Papua New Guinea (PNG), and is one of the lower tributaries of the Kikori River.

Based on the PNG Forest Inventory Mapping System (FIMS), three broad vegetation types are recognized in the Uro Creek catchment. A complex, mixed swamp/swamp woodland (Fsw/Wsw) is the most dominant vegetation type, with areas of small crowned forests (Po) along the low ridges. The third category is the non-forest type with high land-use intensities (O). These vegetation types were ground-truthed against the FIMS classification and are described in this chapter.

The flora of the Uro Creek catchment is dominated by species typical of New Guinea lowland alluvial forests, especially swamp and riverine species. The area falls within the Kikori Lowlands bioregion. The area is floristically rich and the rapid taxonomic inventory reported here documented over 95 morpho-species of vascular plants, and collected 64 specimen vouchers. Noteworthy records include local endemics, new distributional records for poorly-known species, rare taxa of conservation value, species possibly new to science, and plants of value to local communities. Higher risk IUCN listed species sighted or known to occur in the area are listed and a preliminary species list for the area is presented.

Introduction

New Guinea has one of the world's richest floras, as shown by recent analyses of plant diversity on a global scale (Barthlott et al. 1996; Mutke and Barthlott 2005; Kier et al. 2005). However considering its significance as a global centre of plant diversity, the New Guinea flora remains poorly known (Gideon 2015, and references therein). Furthermore, botanical exploration within New Guinea has been very uneven, and Takeuchi (2007) reported that sampling intensity of the island's flora was 300% higher in PNG than in the Indonesian Provinces and that the holdings of the PNG National Herbarium stood at about 400,000 specimens compared to the modest 30,000 in Indonesian Papua Province (currently Papua and West Papua). There has also been considerable spatial variation in survey effort within PNG, and Takeuchi and Golman (2001) reported that the provinces that were grossly under-represented included Gulf, Northern, New Ireland, East New Britain, Manus, and Enga. Knowledge of the flora remains so poor that new species continue to be discovered and described, and many species are known only from one or very few specimens. Basic data such as species distributions, and extent of morphological variation within and between populations, are known only for a very few species.

The southern karst region of Papua New Guinea was often identified as one of the area's most in need of botanical exploration (Prance 1977; Stevens 1989; Johns 1993), and the Kikori basin and adjacent uplands was the largest of 16 'biodiversity unknowns' identified for PNG (Sekhran and Miller 1995). Recent advances in knowledge of the Kikori basin flora have resulted from two major sources: 1) biodiversity surveys commissioned by oil and gas projects in the region as part of their Environmental Impact Statements (EIS) and 2) a series of studies carried out for WWF as part of the Kikori Integrated Conservation and Development Project (KICDP).

A major contributor to these studies was W. Takeuchi (e.g. Takeuchi 2008) who carried out botanical surveys in many upland areas of the Kikori basin and adjacent areas. Other botanists who have contributed to knowledge of the flora in the Kikori basin include Lawong Balun (Unitech), Olo Gebia (WWF-Kikori), Pius Piskaut (UPNG), the orchid specialists Mark Clements (Australian National Herbarium, Canberra) and Wayne Harris (Queensland Herbarium, Brisbane), and palm specialists William Baker and Kathleen King (Royal Botanic Gardens Kew, London), and Roy Banka (PNG Forest Research Institute, Lae). Most produced reports for WWF, documenting their important discoveries (Baker 1997; Balun and Gebia 1998; Baker et al. 2000; Gebia and Balun 2000; Harris 2003).

The Kikori River basin is recognised as one of the most important areas of forest and wetlands biodiversity in the Asia/Pacific region, and WWF (2015) has produced a useful Kikori River Basin Conservation Blueprint which the local communities and PNG Government are encouraged to use to plan for development and biodiversity conservation in the area.

Uro Creek area falls within the Kikori Lowlands bioregion as defined by Crome et al. (2008), and also within WWF's broader Southern New Guinea lowland rainforest terrestrial ecoregion. The Kikori Lowlands bioregion was described as: '*The largest of the 12 bioregions, representing the floodplains of the Kikori River below 200 m elevation. The region consists of limestone plateaux, karst plains, polygonal karst and some sedimentary hills, with various types of lowland rainforest, patches of swamp forests and extensive mangroves in the delta. The region's biota is typically lowland with significant representations of riverine and swamp associated species.*'

The aims of this study were to characterise the terrestrial vegetation communities (type and condition) of the Uro Creek catchment, document species of conservation and cultural significance, especially species that are rare, threatened (i.e. nationally protected or IUCN-Listed), endemic or undescribed, and note the presence of invasive plant species, especially species known to be a major threat to natural ecosystems.

Methods

Survey Site

The flora survey reported here was carried out over a 5-day period at several sites in the Uro Creek catchment (Figure 1). Uro Creek is a tidally influenced tributary of the Kikori River, joining the Kikori about 6 km south of the Kikori District station. The dominant surface geological feature of the general area is limestone, mostly polygonal and doline karst, with littoral plains along the lower banks of the Kikori River and its lower tributaries. The Uro creek catchment has many rock-walled tidal creeks (Plate 1A).

Botanical surveys were carried out along an approximately 15 km stretch of Uro Creek and some of its larger tributaries, as well as on the ridges around Tipiowo and Eimu camp (Figure 1). The elevations worked were between 12 and 20 m asl. Surveys were carried out by the author with the able help of local assistants and ExxonMobil PNG Limited field staff.

Floristic survey methods

The botanical survey was conducted following the rapid-assessment method developed by Conservation International for their Rapid Assessment Program (RAP), which has since been adopted by most floristic surveys in PNG (Mack 1998; Beehler and Alonso 2001; Takeuchi 2008). Descriptions of plant communities follow the PNG Forest Inventory Mapping System (FIMS).

The survey consisted primarily of opportunistic collecting of vascular plants in flower and/or fruit, or fertile fronds of ferns; recording presence of species using a notebook and camera; and plot studies. One 50 X 20 m (0.1 ha) plot was established on a low ridge at Tipiowo to obtain a more quantitative estimate of species alpha diversity and forest structure.

General collecting was conducted along trails leading from pre-established camps, or by drifting along the creeks (Figure 1). Four days were spent making collections and observations along Uro Creek and its tributaries, and one day was spent establishing and studying the plot. The 'river-drift' method was very productive for general plant collecting, allowing a much larger coverage of the area surveyed than trekking on foot through the swamp forests. Flowering or fruiting trees were also more easily observed from the boat than while trekking through dense forests.

Botanical collecting focused on fertile (flowering and/or fruiting) taxa considered significant for one reason or another. These included potentially new or rare species, range extensions, unidentified species, and other species of taxonomic interest. Vouchers were retained primarily for further identification in the herbarium. Unfortunately, vouchers from larger trees could not be made because their flowers and fruit were mostly out of reach. Due to logistical constraints, in most cases only 3–5 duplicates were collected for each vouchered species. Voucher material was also photographed and detailed notes were made in the field. Most plants were identified at least to genus level in the field, and vouchers requiring additional study for identification were examined further at the National Herbarium (PNG Forest Research Institute).

Botanical specimens were dossed in ethanol (diluted to about 70%) and were shipped to Port Moresby where they were dried at the UPNG Herbarium and later freighted to the PNG National Herbarium in Lae for identification. Duplicates of vouchers will be distributed to other herbaria after final identifications have been made.

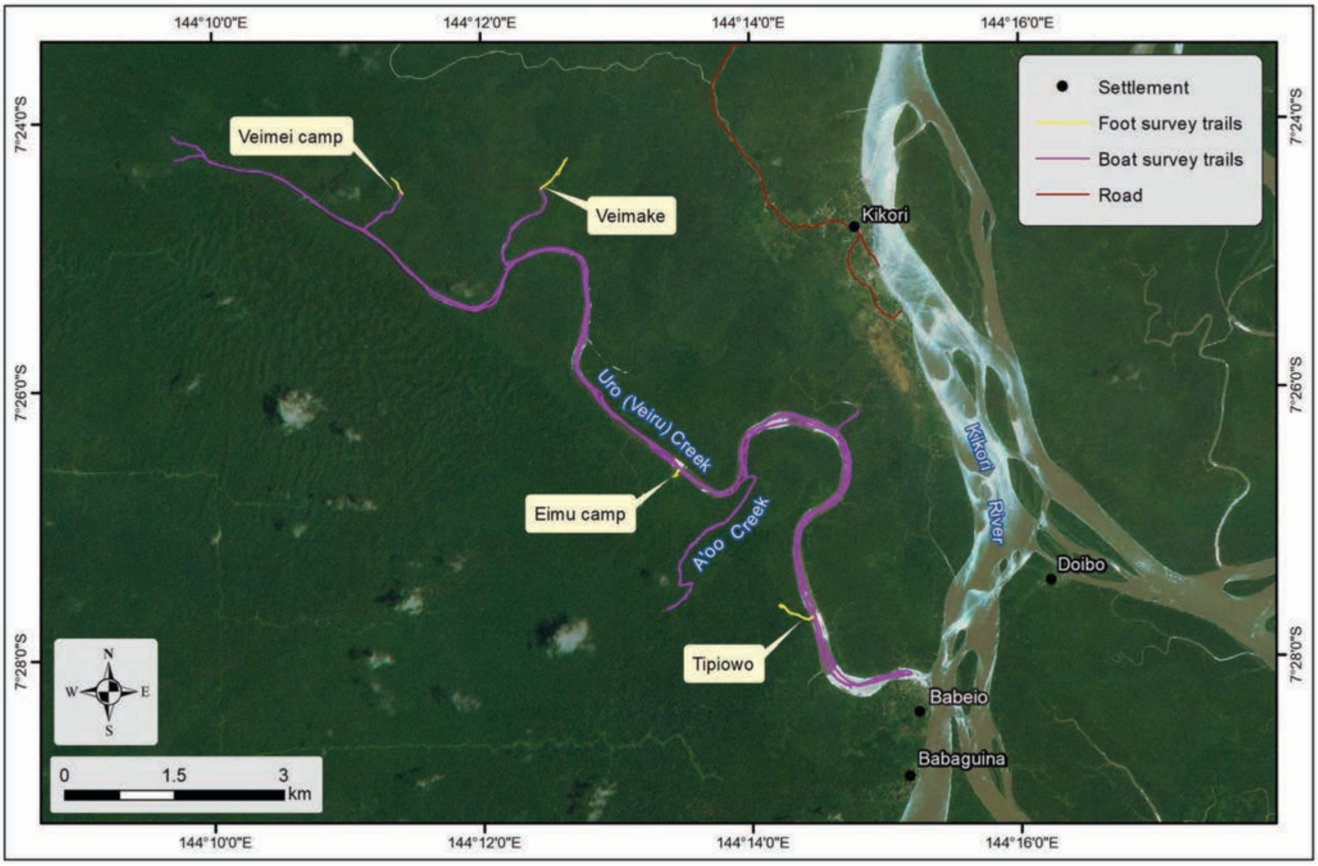


Figure 1. Sampling trails and river drift routes along Uro Creek and its tributaries.

A single plant plot was established at Tipiowo. In the plot the diameters at breast height (DBH) of all trees ≥10 cm DBH were measured to calculate basal area (BA) and estimate tree stocking and timber volume for the area. The log lengths for trees ≥50 cm DBH and tree heights were estimated to the nearest 1 m. Small plants (<10 cm DBH) in the plots were sub-sampled in 5 X 5 m quadrats. Epiphytes (mainly orchids and ferns) which mostly occur on canopy branches were not assessed.

A list of plant species at Uro Creek and nearby areas (Kopi Base Camp) based on all survey techniques is presented in Appendix 1 and noteworthy plants, including possible new species, endemics, new records, and plants of particular interest are discussed.

The area was surveyed for the presence of exotic plants, especially well-known invasive species like *Piper aduncum*, *Spathodea campanulata*, and other aquatic weeds.

Vegetation Mapping

Vegetation mapping of the area follows the PNG Forest Inventory Mapping System (FIMS), which recognises 63 major vegetation types for Papua New Guinea (Hammermaster and Saunders 1995). Most recent biodiversity surveys in PNG followed this system, which was based on Saunders (1993), mainly because it was easily applied in mapping. The system is based on aerial photography and remote sensing, and therefore gave detailed information on forest structure and species composition. Base maps used were the 1:100,000 series topographic maps provided by the PNG National Mapping Bureau. However, plot work and ground truthing often helped to provide a more reliable description of the unique forest types.

The generalised floristic lists for the different forest types and areas in Hammermaster and Saunders (1995) were collated from Paijmans (1976), various CSIRO Land Survey reports for the areas covered, and Department of Forests forestry resource surveys. Unfortunately the scale of the FIMS maps, a system generally available only in 1:250,000 scale maps, does not allow the recognition of small but distinct vegetation communities. Plant communities at the study site were therefore ground-truthed against the FIMS classification and are described below.

Results

Forest types in the Uro Creek catchment

Hammermaster and Saunders (1995) recognized 17 vegetation types within the broad Aramia/Kikori and Kerema forest zones. The Kikori River forms the boundary between the Aramia/Kikori zone to the west and Kerema to the east, and Uro Creek falls within the Aramia/Kikori forest zone. The vegetation along Uro Creek and in surrounding areas includes a mixture of typical lowland rainforest types, swamp forests, and mangroves further downstream. Parts of the northern and western areas of the catchment were logged under the Turama Block 1 Forest Management Agreement (FMA).

Saunders (1993) recognized only two main vegetation types for the area: small crowned forests (**Ps**) and other non-vegetation and areas dominated by land-use (**O**). Although FIMS recognized as a many as eight vegetation complexes for Uro Creek and the surrounding area, ground truthing during this survey indicated that some adjustments are required to properly classify the vegetation. The following vegetation types and complexes are recognized and described below: small to medium crowned forest on uplands (**Hm/Hs**), small crowned forests on alluvial plains and fans (**Ps**), mixed freshwater/woodland swamp forests (**Fsw/Wsw**), and other non-vegetation and high land-use intensities (**O**). Other vegetation types, such as **Fsw, G, Fsw/G, Hm/Hs/Fsw,** occur further away from Uro Creek and are not described here.

The vegetation types recognized are described below:

Hm/Hs – Small to medium crowned forest on uplands

Hm/Hs forest is quite common within the Aramia-Kikori forest zone, especially in low karst country such as that found around Kikori. It occurs on the hills on the eastern side of Uro Creek but much of this forest type was not accessible during the survey so it was not investigated in detail. However, the 0.1 ha study plot was established within this vegetation type so a brief description can be provided based on general observations made there.

The canopy height is about 25–35 m, with few emergents to 40 m, and 70–80% crown closure. Tree species composition is very mixed and dominant canopy trees include *Pometia*, *Cryptocarya*, *Pouteria*, *Pimeliodendron*, *Cryptocarya*, *Rhus*, *Elaeocarpus*, *Pterocarpus*,*Terminalia*, and *Dysoxyllum*. Understory tree species include *Myristica*, *Cryptocarya*, *Ficus*, *Myristica*, *Celtis*, *Trichospermum*, *Aglaia*, and *Dysoxyllum*. Presence of pioneer species such as *Rhus taitensis* and *Trichospermum* indicates human impacts on the forest. Rattans are rare, but other palms such as *Hydriastele*, *Cystostachys* and *Licuala* are conspicuous. The forest floor is generally open and herbaceous plants are not common, but gingers are conspicuous (especially *Alpinia* and *Pleuranthodium*) and terrestrial ferns such as *Selaginella*, *Marratia* and *Asplenium* are common, especially along regularly used trails.

Ps – Small crowned forest on plains and fans (below 1,000 m altitude)

Ps was once a dominant vegetation type in the Uro Creek area, but a substantial area of this vegetation type has been converted to non-forest categories through various types of land-use, particularly gardening and some logging. The forest has a dense even canopy of medium to small crowns, is 20–30 m in height, and usually lacks emergents. Species composition is very mixed, and there are different suites of species found in the low lying areas and on ridges. Species composition is similar to **Hm** (see Chapter 1.1), and common tree species (which were not all observed at Uro Creek) include *Pometia pinnata*, *Pterocarpus indicus*, *Terminalia*, *Canarium*, *Calophyllum*, *Syzygium*, *Elaeocarpus*, *Pouteria*, *Dillenia* and *Dysoxyllum*. Understory tree species include *Myristica*, *Horsfieldia*, *Harpulea*, *Barringtonia*, *Euodia*, *Semecarpus* and *Ficus*. Palms are common in the forest, with tall *Cyrtostachys loriae* and *Hydriastele* species reaching the forest canopy or higher. Other palms in the understory include *Licuala*, *Orania*, *Heterospathe*, *Hydriastele* and rattans (*Calamus*, *Korthalsia*). Herbaceous plants on the forest floor include gingers (*Alpinia*, *Pleuranthodium*, *Hornstedtia scottiana*), aroids (*Alocasia*, *Cyrtosperma*, *Homalomena*, *Schismatoglottis*) and terrestrial ferns (*Selaginella*, *Cyclosorus*, *Nephrolepis*, *Microsorium*, *Marratia*, *Asplenium*).

Fsw/Wsw – Mixed swamp forest/Swamp woodland

A mixed freshwater swamp and swamp woodland forest complex (**Fsw/Wsw**) is the dominant vegetation type along Uro Creek, occurring in the regularly inundated areas along the river banks (Plate 1B). FIMS recognized this vegetation type as **Wsw/M**, but mangroves are so insignificant along Uro Creek that **Fsw/Wsw** is a better description of this vegetation type. Saunders (1993) included most of this distinct vegetation type with the non-forested areas category (**O**), while Paijmans (1975) recognized it as **Wsw**. The forest is dense, irregularly structured, and the canopy height reaches up to 30 m. In many places the soil consists of a thin living organic root mat overlying the limestone pavement.

Tree species composition is very mixed, but dominant taxa include *Myristica* spp., *Horsfieldia* spp., *Calophyllum suberosum*, *Palaquium*, *Pouteria*, *Terminalia* spp., *Elaeocarpus multisectus*, *Semecarpus*, *Vatica*, *Neuburgia*, *Campnosperma*, *Bischofia javanica*, *Fagraea* and other tree species. The forest structure and floristics is determined by drainage, soil type and inundation. Trees typically have stilt roots or sprawling surface roots, probably in response to a fluctuating water table; high buttresses are not common here. Herbs and small shrubs are rare on the forest floor.

The family Myristicaceae appears quite dominant in this vegetation type, being represented by several species. *Elaeocarpus multisectus* is common in advanced regrowth, where it is easily recognized by its smooth round crown. Sago palm (*Metroxylon sagu*) is also common, as well as other palms (*Cyrtostachys loriae*, *Hydriastele costata*, *Hydriastele* sp., *Licuala* spp.). *Pandanus* species are dominant along the creek banks, forming pure communities in areas. A number of mangrove species (*Sonneratia*, *Bruguiera*, *Heritiera*) are present along the river banks, but are not sufficiently dominant to form a proper mangrove vegetation.

O – Other non-vegetation and areas dominated by land-use

This vegetation category includes a range of plant communities affected by land-use. Within this broad category, as demarcated in Saunders (1993), are small remnant pockets of **Ps**, **Hm**, **Fsw**, **Wsw** and other plant communities. However regrowth vegetation, at various stages of succession, dominated this broad category. Almost all of these disturbed areas are of anthropogenic origin, mostly old gardens and logged areas. Secondary or regrowth vegetation includes various stages of forest succession, from bare ground after disturbance to almost mature forests of **Ps**, **Hm**, **Fsw** or **Wsw**. Species composition changes through the different stages of succession.

Examples of this non-vegetation category were abandoned gardens or failed vanilla farms observed at Tipiowo, Eimu and Veimake camps. These regrowth communities are initially dominated by herbaceous garden weeds, grasses and creepers. In more advanced stages light demanding woody plants, especially species of Euphorbiaceae (*Macaranga*, *Mallotus*, *Omalanthus*, *Endospermum*, *Melanolepis*), *Ficus*, *Premna*, *Cordyline*, *Dracaena*, *Trichospermum*, *Rhus taitensis*, *Gymnostoma papuana*, *Octamyrtus* and *Commersonia bartramia*, are common. The creepers (*Merremia*, *Canavallia*, *Pueraria*, *Mucuna*, *Trichosanthes*, *Faradaya*, *Entada*, *Cissus*, *Ampelocissus*, *Cayratia*) usually persist into the later stages of succession. Terrestrial ferns such as *Nephrolepis* and *Cyclosorus* form dense undergrowth, and a few gingers (*Hornstedtia scottiana*, *Amomum*) and palms (*Hydriastele*, *Cystostachys*) are also present. In later stages of succession the usual long-lived pioneer tree species, such as *Neolamarckia cadamba*, *Endospermum*, *Gymnostoma papuana*, *Canarium*, *Pometia pinnata*, *Euodia*, *Artocarpus*, *Litsea*, etc., become more dominant.

The flora of Uro Creek

Uro Creek has a flora typical of that described for the Southern New Guinea Lowland Rain Forests terrestrial ecoregion. The ecoregion's low relief with many large rivers results in frequent inundations. The most extensive habitats are lowland alluvial and hill forests. These forests have irregular, multi-tiered canopies with many emergents, and a dense understory containing shrubs, herbs and lianas. Palms are also common, with emergent and understory taxa (Paijmans 1976). The ecoregion is botanically poorly known compared to other lowland areas in New Guinea (Johns 1993). Regrettably, it is under serious threat from logging, as some of the largest logging concessions are located in this ecoregion.

One 0.1 ha plot was established and assessed at Tipiowo camp. Because only one plant plot was studied, forest structure and tree diversity can only be discussed in general terms. Comparisons are made with other studies in New Guinea, although plot sizes of the other studies vary greatly, ranging from 0.1 ha (present study) to 2.4 ha. Tree density and diversity from available studies, including two plots at Wau Creek established during the 2017 survey, are summarised in Table 1.

Table 1. Tree density, species diversity and basal area from various study sites in New Guinea

Study Site	Sample Size (ha)	Altitude (m)	No. of Species	No. of stems ≥ 10 cm dbh/ha	Basal Area (m^2/ha)	Reference
Wau Creek Plot 1	**0.1**	**24**	**42**	**790**	**48**	**Present study**
Wau Creek Plot 2	**0.1**	**24**	**35**	**640**	**28**	**Present study**
Uro Creek	**0.1**	**12**	**24**	**380**	**30**	**Present study**
Crater Mtns., Simbu Province	1.0	850–1350	228	693	37.1	Wright et al. (1997)
Si River, Lakekamu Basin, Gulf Province	1.0	60	93	392	49.32	Oatham and Beehler (1997)
Nagore N, Lakekamu Basin, Gulf Province	1.0	70	149	426	37.67	Oatham and Beehler (1997)
Nagore S, Lakekamu Basin, Gulf Province	1.0	70	178	482	28.72	Oatham and Beehler (1997)
Alluvial, Lakekamu Basin, Gulf Province	1.0	175	182	575	28.46	Reich (1998)
Hill, Lakekamu Basin, Gulf Province	1.0	260	156	759	32.04	Reich (1998)
Woodlark Is., Milne Bay Province	0.52	10–150	142	608	30.4	Gideon (2010)
Nakanai Mtns, E New Britain Province	1.4	200–1600	382	216	67.5	Balun et al. (2000)
Hill Forest,	2.4	n/a	n/a	526–652	30.8	Paijmans (1970)
Alluvial Forest	0.8	n/a	n/a	430	n/a	Paijmans (1970)
Foja Foothills, Memberamo, W Papua	?vars. sizes	?	127	598	32.4	Van Heist et al. (2010)
Ayawasi, W Papua	2.2	?	415	805	35.8	Polak (2000)

Extrapolating from the raw data, the basal area (BA) for the Uro Creek forests is estimated to be about 30 m^2/ha, and an average merchantable timber volume of about 195 m^3/ha. The tree density for stems ≥ 10 cm dbh was about 380 trees/ha, and for trees ≥ 50 cm dbh about 40 trees/ha. The most common trees in the plot, with more than 10% dominance were *Aglaia* (16%), *Dysoxyllum* (13%), and *Myristica* (10%). In contrast the most common tree species in the 0.2 ha Wau Creek plots were *Myristica* (11%), *Ficus* (8%), *Dysoxyllum* (6%) *and Macaranga* (6%). All genera with more than 5% dominance at Uro Creek are shown in Table 2. Commercial size trees (> 50 cm dbh) were about 40 trees/ha.

The presence of pioneer tree species (*Myristica, Cryptocarya, Pimeliodendron, Elaeocarpua*) in the plot indicates disturbance. The plot was established on a low ridge above Tipiowo camp, along a track regularly used by the locals for hunting and harvesting of timber for house building.

Table 2. The dominant tree genera in the Uro Creek forests (≥ 5% dominance)

Family	Species	Number of Trees	Dominance (%)
Meliaceae	*Aglaia* (2–3 spp.)	6	15.8
Meliaceae	*Dysoxyllum* (2 spp.)	5	13.2
Myristicaceae	*Myristica* (3 spp.)	4	10.5
Lauraceae	*Cryptocarya* (2 spp.)	3	7.9
Euphorbiaceae	*Pimeliodendron amboinicum*	3	7.9
Burseraceae	*Protium macgregorii*	3	7.9
Elaeocarpaceae	*Elaeocarpus* (1 sp.)	2	5.3
Annonaceae	*Polyalthia* (1 sp.)	2	5.3
Myrtaceae	*Syzygium* (2 spp.)	2	5.3

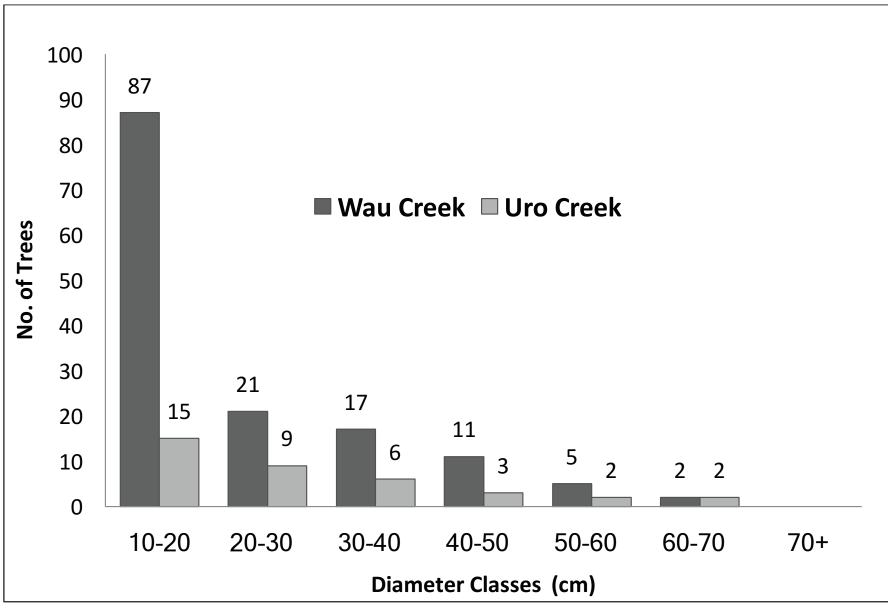


Figure 2. Tree size class distribution (trees ≥ 10 cm DBH) for Uro Creek. Wau Creeks is also shown for comparison

The size class distribution curve for the area shows the typical L-shape for mixed tropical rain forests (Figure 2). A large proportion of the trees (63%) are in the lower diameter classes (10–30 cm DBH), with only 12% of trees reaching merchantable size classes (50+ cm DBH). While the sample size is small compared to other studies, the raw data and extrapolations from these fall within the general ranges for New Guinea (Table 1), and also from other tropical regions of the world (Paijmans 1970, 1976; Wright et al. 1997; Oatham and Beehler 1997; Reich 1998).

Table 3. Number of taxa recorded from the Uro Creek plant plot

Taxa Group	Families	Genera	Species
Dicotyledons	17	20	27
Monocotyledons	4	5	5
Gymnosperms	0	0	0
Pteridophytes	1	1	1
	22	**26**	**33**

During the five day biodiversity survey at Uro Creek 64 plants, representing approximately the same number of morpho-species, were collected. Unfortunately, most large trees in flower or fruit were not sampled because fertile material was out of reach; sadly such species are not well represented in existing collections. Most trees in plots were only identified to genus level. The number of families, genera and species censused in the plots are presented in Table 3.
The 0.1 ha plot at Uro Creek yielded 33 morpho-species in 26 genera and 22 families. Most genera were represented by a single species, with only a few genera represented by more than three morphospecies (Table 2), a pattern characteristic of tropical forests. The most abundant tree genera were *Myristica, Aglaia, Dysoxyllum*, *Syzygium* and *Cryptocarya,* together representing about 12 morpho-species and about 50% of the trees censused. In contrast at Wau Creek plots the most abundant tree genera were *Myristica, Ficus, Dysoxyllum*, *Macaranga, Cryptocarya* and *Elaeocarpus,* representing about 25 morpho-species or 46% of the trees censused. The plant species list generated for the Uro Creek and Kopi Base Camp, based on actual collections, sightings, and photographs, and censused in the plots totalled 95 morpho-species (Appendix 1).

In a study at Dark End Lumber eco-forestry project area (about 50 km NE of Uro Creek), Gebia and Balun (2000) assessed two 0.04 ha plots and recorded 32 and 34 trees in the two plots. Extrapolating from their figures, the tree density for the area is around 400 stems/ha, which falls at the higher end of the range reported for New Guinea (Table 1). They recorded the presence of over 160 plant species, in 112 genera and 61 families. The floristic diversity figures are much higher than most similar studies, which is attributed to the sampling protocols applied. They sampled all plants greater than 5 cm DBH and all epiphytes up to 10 m high, whereas most studies censused only trees greater than 10 cm DBH and epiphytes were usually not censused. In another sample (0.2 ha plot) near Gobe at 50 m elevation, Gebia and Balun (2004) recorded 145 species.

Even though a considerable effort has been made over the last 20 years to improve the level of understanding of the biological diversity of the Kikori lowlands, there is no doubt that more work is still required, especially studies on the flora and invertebrates. The kind of intensive plant collecting carried out by Takeuchi (2008) in the upstream region of the PNG LNG project should be replicated in the Kikori lowlands. There has been much speculation about the characteristics of the flora of the Southern New Guinea Lowlands, and this can only be confirmed by detailed floristic studies using both plots and general collecting, and such a program should be undertaken by botanists with extensive New Guinea experience.

A number of noteworthy plant species were encountered in the Uro Creek catchment and these are discussed below.

Noteworthy plants

Noteworthy plant species encountered at Uro Creek and along the Kikori River include potential new species, local endemics, range extensions, and several other taxa of conservation value.

Araceae (Aroids)

***Cryptocoryne ciliata* (Roxb.) Fisch. ex Wydle (Uncertain taxonomy, locally rare)**

Cryptocoryne ciliata occurs from East India to New Guinea, and occurs in tidal brackish mud and mangrove communities. In New Guinea it occurs mostly in the south. A single collection was made at Veimake Camp. It is a clumping herb up to 70 cm tall, leaves oblong-lanceolate to linear lanceolate; inflorescence on a very short peduncle, lower spathe about 2 cm and upper part about 30 cm long, warty, with hair-like segments. Two varieties are recognized, *C. ciliata* var. *latifolia* and var. *ciliata*. Aroid specialist J. Bogner suggested the New Guinea population looks different from the rest of the species and possibly represents an endemic subspecies. Although, widely distributed, and its conservation status has been assessed as Least Concern, this species is locally rare. Another species endemic to Kiunga (Western Prov.), *C. dewitii* might also occur in the Kikori area, in similar habitat.

Arecaceae (Palms)

***Brassiophoenix drymophloeoides* Burret (Range extension)**

The genus *Brassiophoenix* contains two species, both of which are endemic to PNG. *Brassiophoenix drymophloeoides* is a slender, solitary palm reaching 5–10 m, with large, fishtail-shaped leaflets and a narrow, bluish-green crown shaft. A single plant was seen from the boat about 6 km downstream from where the Sire River joins the Sirebi River. W. Baker (Baker 1111) collected it previously from the Morere logging concession. It was not sighted at Uro Creek, but is likely to be present in the area, and is probably widespread but uncommon in the Kikori area. This species was previously only known from Central, Milne Bay and Oro Provinces. It has not been assessed by the IUCN.

***Heterospathe macgregorii* (Becc.) H.E. Moore (Limited distribution; see Plate 1B–C in Chapter 1.1)**

A beautiful rheophytic palm that is abundant in parts of the Kikori lowlands. It forms dense clumps along the river banks, especially on limestone. Stems are 5–7 m tall, often crooked, and lean over the water. It is very conspicuous with its red ripe fruits bunches. One collection was made at A'oo Creek, a branch of Uro Creek, and the species appears to be common throughout the Kikori River and other tributaries, including the Sirebi River (pers, observ.). Baker et al. (2000) reported that the species is conspicuous on the Kikori and Sirebi rivers, but less frequent on the Mubi River. It is now known to occur in Gulf (Kikori lowlands), Western, and Southern Highlands (Mubi River) Provinces. Other collections from the Kikori lowlands are W. Baker 651, W. Baker 1090 and K.J. White NGF10714. *Heterospathe macgregorii* is only known from southern New Guinea, from the Fly River in the west to the Kikori Lowlands including Mubi River in the east. Its conservation status has not been assessed by the IUCN.

***Hydriastele apetiolata* Petoe & W.J. Baker (Limited distribution)**

A moderately slender, clustering palm to 6 m tall, leaves to 125 cm long; sheath 60 cm long, crownshaft 120–150 cm long. A specimen was collected at Uro Creek, above Tipiowo camp. The species was recently described by Petoe et al. (2018), and was previously only known from two localities in southern New Guinea: Timika in Indonesian Papua Province and the Kopi-Kikori road in Gulf Province (Baker et al. 1103). Its conservation status has not been assessed by IUCN.

***Hydriastele* sp. nov. (in press, W. Baker, pers. comm.) (Plate 1C)**

This was the most conspicuous palm seen in the Kikori lowlands. It is a tall, slender solitary palm, reaching up to 30 m. The leaves are long and strongly curved. It was seen growing on limestone outcrops and on vertical cliff faces, including in the gorge along the Sirebi River and on islands of limestone outcrop along the Kikori River. Baker et al. (2000) identified this species as *Gronophyllum* sp. 1 in their report, which was vouchered by the specimen Baker 1096. They reported that the species was very common in the Kikori lowlands as well as in the lower montane forests of Southern Highlands Province. Upon enquiring with William Baker on the identity of this species, I was informed that it is currently being described as a new species. The only threat appears to be from local harvesting for its timber.

***Hydriastele flabellata* (Becc.) W.J. Baker & Loo *(syn. Nengella flabellata Becc.)* (New province record; see Plate 1D–E in Chapter 1.1)**

A small, very slender, clustering palm 2–4 m tall, leaves 30–80 cm long (including petiole). It was seen and collected near the Wau Creek research station. It was not sighted at Uro Creek, but is very likely to be present in the area in suitable habitats. This species was previously known from Western and Southern Highlands Provinces, and a few other areas in New Guinea, but had not previously been documented from Gulf Province. SHP: Kutubu patrol area, Waro (Takeuchi 7284 and Takeuchi 7312); Kantobo (Baker et al. 643); Mt Bosavi, Wasaso (Baker et al. 611); Mt. Bosavi, northern side (Jacobs 9470). Although *H. flabellata* is widespread, it is not common. Its conservation status has not been assessed by the IUCN.

***Orania archboldiana* Burret (Poorly known species) (Plate 1D–E)**

A solitary, moderately large palm to 12 m tall. Leaves 2.5–3 m long, leaflets 40/side, arranged in several planes giving a plumose appearance. Inflorescence branched twice, 27 branches. Fruits spherical, 3–4 cm diameter. This species is known from seven southern New Guinea localities. A collection was made at Veimake Camp, Uro Creek, and the species no doubt occurs elsewhere in the Gulf. William Baker collected it along the Kopi–Kikori road (Baker 1104). The genus was recently monographed by Keim and Dransfield (2012), in which they suggested its conservation status as NT, but the species has not been formally assessed by the IUCN.

Pinanga rumphiana **(Mart.) J. Dransf. & Govaerts (syn.** ***P. punicea*** **(Blume) Merr.) (Limited distribution in PNG)**
Pinanga rumphiana is the only species of this large Southeast Asian genus of about 130 species that reaches New Guinea, where it has been found in the border provinces of West Sepik and Western; it was recently collected at Kikori in Gulf Province (Baker et al. 2000). My collection was from the upper reaches of Uro Creek, where the top of the creek divides into two branches. It is a solitary palm, up to 10 m tall, with leaves up to 2.5 m long and regularly arranged leaflets; the inflorescence is branched to 1-order. The voucher Baker et al. 1091 was collected on the bank of the Kikori River near Kopi Base Camp. The Kikori location is the eastern-most locality for the genus and species (Baker et al. 2000). Its conservation status has not been assessed by the IUCN and this should be done as soon as possible because of the species' restricted distribution in PNG, and because its habitat is mostly under large logging concessions in the three border provinces.

Begoniaceae

Begonia sharpeana **F. Muell. (Limited known distribution; see Plate 1F in Chapter 1.1)**
This beautiful begonia was first collected from the Aird Hills by Theodore Bevan (trader and natural history collector) in 1887 and was sent to Dr Ferdinand Mueller, Government Botanist in Melbourne (Australia), who described it in 1889. Even though the species has been known for over 100 years, less than 10 collections exist. This was a species I have wanted to see in the field for a long time. It was previously only known to grow in limestone crevices around Kikori/Aird Hills, and the 2017 collection from the gorge along the Sirebi River extends the species' known range upstream. It was not seen at Uro Creek but probably occurs in the catchment because suitable steep, limestone habitats occur there. For me, seeing and collecting this interesting species in the field was the highlight of the trip.

Begonia sharpeana is an interesting species, not only because it is beautiful with usually reddish blotches on the upper surface of the leaves, but it is the only New Guinea species to belong to the *Begonia* section *Baryandra*. Until recently it was placed in the section *Diploclinium* (with 7 other New Guinea species) but molecular evidence suggests it belongs to section *Baryandra* which otherwise contains only species from the Philippines and Borneo (Rubite et al. 2013). *Begonia sharpeana* is only known from limestone habitats in the Kikori lowlands, and with this restricted distribution its conservation status needs to be assessed as a matter of urgency.

Gesneriaceae

Cyrtandra **sp. nov. (New to science; see Plate 2A in Chapter 1.1)**
This probable new species was only seen and collected at Wau Creek but it is likely to be present at Uro Creek in similar habitats. The soft-stemmed treelets of this new species occur on the forest floor with few spreading branches. Leaves are obovate, thick and fleshy, and break easily. The flowers are borne in thick clusters amongst the leaves near the top of the stem. Flowers are cream, with brown longitudinal strips. Bracts and sepals are also cream. The species was not sighted at Uro Creek, but is possibly present throughout the Kikori lowlands.

Cyrtandra is a large genus of about 800 species, ranging from Southeast Asia to the Pacific, with centres of diversity in Borneo, Philippines and New Guinea. The New Guinea species have not been critically studied taxonomically and most species are poorly represented in herbarium collections. However, there is growing interest in the phylogeny of the genus and some regional studies have been undertaken elsewhere; and hopefully the New Guinea taxa will eventually receive some attention. This species is most probably new to science. Most collections of this genus at the National Herbarium have not been identified to species level, but I am confident that this species is new and possibly has a narrow range.

Rubiaceae

***Ixora valetoniana* Mouly & B. Bremer (syn. *Versteegia grandifolia* Valeton) (First record for PNG; see Plate 2B in Chapter 1.1)**

This is a rare pachycaul treelet to 3 m high. Leaves are large, sessile, broadly obovate to oblanceolate, 30–110 cm long and 10–30 cm wide. Flowers/fruit cauliflorous, corolla red to pink, tube c. 2 mm long, glabrous. Fruits are globose, 3–3.5 X 3–3.5 cm, ripening bright red, pulp fleshy. This species was previously known from just three collections (Branderhorst 320, Kanehira & Hatusima 12396 and Versteeg 1039) from Papua Province, Indonesian New Guinea (Ridsdale et al. 1972). The species was collected at both Wau Creek and Uro Creek, and is apparently quite common. The Wau and Uro Creek collections are the first records from PNG and also the first after more than 70 years. Its conservation status has not been assessed.

***Ixora* sp. nov. (New to science; see Plate 2C in Chapter 1.1)**

This is a small dioecious pachycaul treelet to 1 m high, common on the forest floor at Wau Creek and a single plant was sighted at Lake Kutubu. It was not sighted at Uro Creek but probably occurs there; a similar looking plant was collected there but final confirmation of its identification is required. Leaves are sessile, elliptic to obovate. Flowers/fruit axillary, male inflorescence many flowered, female few flowered. Fruits are green, ovoid, ridged. This species is probably endemic to the Kikori River basin and it may have a very narrow range.

Zingiberaceae

***Pleuranthodium racemigerum* (F.Muell.) R.M.Sm. (syn. *Psychanthus racemigera* (F.Muell.) R.M. Smith). (Range extension; see Plate 2D in Chapter 1.1)**

A flowering specimen collected at Veimei Camp, Uro Creek probably belongs to this species, which was originally described from Queensland, Australia. The pseudostem is 1–1.5 m tall, leaf blades are sessile and glabrous, and inflorescences are pendulous, breaking out just below the top of the pseudostem. Flowers are cream, but fruits were not seen at Uro Creek. Fruiting material collected at Wau Creek probably belongs to this species (see Chapter 1.1).

Until now, *Pleuranthodium racemigerum* was considered an Australian endemic, one of the few species of the genus that occur outside of New Guinea. However, should this tentative identification of the Kikori basin material be confirmed, the species' range will be shown to extend into New Guinea. Smith (1987) suspected that this species might also be present in New Guinea, but this has never been confirmed. The species probably occurs elsewhere in the Kikori lowlands. The distribution of the species is poorly known, but it probably occurs throughout the southern lowlands. Its conservation status has not been assessed.

***Riedelia* sp. nov. 2 (New species; see Plate 2F in Chapter 1.1)**

This species was seen and collected only once, along the banks of Wau Creek. Although it was not sighted at Uro Creek, it is likely to be present there because suitable habitats are present. It is an epiphytic species, occurring about 6 m from the ground. Pseudostems up to 1 m. Leaves dark glossy green above and paler below. Inflorescence up to 30 cm long, unbranched, the axes bright red. Flowers curved, pink to pale reddish, corolla pinkish. The plants are easily seen when in flower because of the bright red inflorescence axes and pinkish flowers. Only a single plant was seen and collected.

Although the genus *Riedelia* is so poorly known that a large part of the collections at the PNG National Herbarium in Lae remain undetermined beyond the genus level, this probably represents a new species. Epiphytic *Riedelia* species are common at higher elevations, but they are rare in the lowlands and I have only seen them twice, at Woodlark Island and here. At this stage this plant is tentatively considered to be a new species. The distribution of the species is unknown; it might be locally rare in the Kikori lowlands.

IUCN listed species

The International Union for Conservation of Nature (IUCN) Red List of Threatened Species is widely recognised as the most authoritative global assessment of the conservation status of species (Lamoreux et al. 2003, Rodrigues et al. 2006). It provides up to date taxonomic, conservation and distribution information on taxa that have been assessed using the IUCN Red List Categories and Criteria.

As a country so disproportionately blessed with rich biodiversity, PNG needs to take a strong and committed approach to ensuring that species under threat are properly assessed and rated to help with conservation planning and priority setting. To date only the vertebrates have been comprehensively assessed, while assessment and listing of PNG's rich plant life has barely begun. As of 2017, 573 PNG species had been assessed by the IUCN (see Table 4 in Chapter 1.1), and 73% of these are in the lower risk categories (NT, LC, DD) (IUCN 2017). Several recent revisions of plant taxa have made recommendations regarding the IUCN conservation status of the species under consideration, but formal assessments of these species have not been completed (e.g. many palm taxa: Heatubun et al. 2018, Petoe et al. 2018).

Two species listed by the IUCN as Vulnerable, and two as Near Threatened, were identified at Wau Creek or are likely to occur there (Table 4). These are all widespread species that occur throughout the PNG lowlands and most also extend outside of New Guinea.

Table 4. Plants with an IUCN status greater than LC that were confirmed as present at Uro Creek or likely to be present in the area

Family	Species	IUCN Category	Threat	Notes
Cycadaceae	*Cycas scratchleyana*	NT	Regarded as Near Threatened due to the threat of habitat loss.	Widespread in eastern PNG (Central, Gulf, Milne Bay, and Western Provinces), also in Papua (Indonesia) and Australia. Not sighted at Uro Creek or Wau Creek, but collected at Mena Creek east of these localities (Womersley NGF 46475).
Fabaceae	*Intsia bijuga*	VU	Extensively exploited for its high value timber	Africa to Pacific. Widespread in New Guinea, sighted at Uro Creek. It is certainly present in the Wau Creek area as well.
Fabaceae	*Pterocarpus indicus*	VU	Extensively exploited for its high value timber	India to Vanuatu. Sighted at both Wau Creek and Uro Creek.
Flindersiaceae	*Flindersia amboinensis*	NT	Threatened due to logging	Maluku and New Guinea (sporadic). Sighted and collected fruits on the forest floor at Uro Creek. Very likely to be present at Wau Creek as well.

Weedy and invasive species

Invasive species are considered one of the greatest threats to biodiversity, second only to habitat destruction. By definition, invasive plants are "those species that are not native to the ecosystem under consideration and whose introduction causes or is likely to cause economic or environmental harm." Increasing international trade and travel have greatly increased the chances of introducing invasive species.

Uro Creek is easily accessed by the Babeio community, as well as the settlements around Kikori station. Canoes and motor boats were seen travelling up and down the creek every day, fishing, hunting, or making sago. There was some evidence of gardening along the creeks although the fluctuating water table rendered many areas unsuitable for gardening. In addition to localised impacts by landowners, there has been extensive conventional logging close to Uro Creek. These disturbance regimes are a potential source for the introduction and establishment of weedy and invasive plants through movement of logging equipment and personnel. However, there was little evidence of such introductions along Uro Creek. None of the well-known PNG invasive plants, such as *Piper aduncum, Chromolaena odorata* (Siam weed), *Spathodea campanulata* (African tulip), *Lantana amara*, and the water weeds *Eichhornia crassipes* (water hyacinth) and *Salvinia molesta* were sighted along Uro Creek and its tributaries. However, the search for invasive species was neither extensive nor intensive, and it is possible that some invasive species were not detected, especially in areas close to villages and previously logged areas. Locals were interviewed for the presence of any of these invasive species, but none confidently reported sighting any of them.

Merremia peltata was sighted at Uro Creek and elsewhere along the Kikori River, and although it is considered as invasive it is an indigenous species and part of the ecosystem. *Mimosa pudica* was not sighted in the area, but is possibly present near the villages. Siam weed (*Chromolaena odorata*) is probably already present in the area, but was not sighted during the survey. It occurs throughout PNG and in North Queensland, and also throughout Southeast Asia.

Biodiversity and conservation values

Uro Creek catchment provides numerous resources for the local community who access it to fish, hunt and harvest sago; and the surrounding lowland rainforests were logged some years ago. However apart from the logging, other human impacts are insignificant. There were few gardens along the creek because it is swampy and not suitable for gardening. Despite this, should the area be set aside for conservation purposes, decisions need to be made soon and a management plan developed to protect the area from damage to the local ecosystems.

The mixed swamp forest/swamp woodland forest along Uro Creek is typical of Southern New Guinea freshwater swamp forests, and probably harbours a number of ecologically sensitive habitats. However the study reported here was not intensive and further studies are encouraged, in order to gain a better understanding of Uro Creek's vegetation and flora and to identify unique and ecologically sensitive habitats.

Although no new species were discovered from the area, a number of the potentially new species reported from Wau Creek probably occur at Uro Creek in similar habitats. In addition, there were several important records of species with high biodiversity values. These include documentation of the rare *Ixora valetoniana* (first record for PNG), and the second collection of a recently described rare species of palm (*Hydriastele apetiolata*), which is only known from Timika in Indonesian Papua Province and Kikori in PNG. Two plants from A'oo Creek that were tentatively identified as *Dimorphanthera* (Ericaceae), require further study but are certainly interesting records becauses the family is rarely found at this low elevation and in this type of habitat. The new palm species, *Hydriastele* sp. nov. (in press), is a dominant feature of limestone outcrops in the area. Although the locally endemic *Begonia sharpeana* was not sighted at Uro Creek it is most certainly present in the area in suitable habitats (limestone outcrops) because the type locality is Aird Hills, only 13 km east of Uro Creek. This is a species of high conservation value for the area.

The wetlands of the Kikori lowlands have significant freshwater ecosystems, which have important flora and fauna habitats, particularly for local endemics. These ecosystems are vulnerable to the impacts of environmental change and need special care and attention. Any intentional or accidental introduction of alien species of flora and fauna into the area can pose a significant threat to local ecosystems and biodiversity.

Uro Creek certainly warrants further studies to fully understand and appreciate its biodiversity values, especially if the area is going to be set aside for conservation purposes. Is there a need for another WMA or other protected area in the Kikori lowlands? The answer is definitely 'yes.' Although the Neiru/Aird Hills WMA is only 13 km east Uro Creek, it is a limestone outcrop surrounded by freshwater swamp and mangrove forests. In contrast Uro Creek is not only a representative of fresh water swamp forests of the area, but also of other lowland rainforests on plains and fans. These lowland forests on plains and fans have been targeted by loggers in the Kikori lowlands, and any opportunity to save what remains of these forests should be supported. Therefore, a community based protected area within this vegetation zone would protect an important area of forest that is currently under significant threat.

Recommendations

The brief botanical survey reported here is clearly inadequate to fully understand and appreciate the plant life of the area. However, the survey provides some guidance for future botanical studies.

The following recommendations are offered to guide future surveys:

- Future studies should explore the mixed swamp forests and surrounding low hills more intensively than was possible during the five days survey.

- Give adequate time to opportunistic collecting of the flora, and if possible make multiple visits in different seasons to ensure plants missed during previous visits are collected.

- Identify any unique habitats or ecologically sensitive areas and survey these habitats adequately for potentially unique species, which should add to the area's floristic coverage and known biodiversity values.

- An effort should be made to protect as much of the Uro Creek catchment as possible, incorporating all remaining areas of unlogged forest and representative tracts of all vegetation types and ecosystems present.

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Appendix 1. List of plants collected, sighted or recorded from the plot at Uro

Plate 1

A. Rock-walled upper tributary of Uro Creek

B. Swamp forests along Uro Creek

C. *Hydriastele* sp. nov.

D. *Orania archboldiana* at Veimake Camp

E. *Orania archboldiana* at Veimake Camp

F. Forest interior at Tipiowo

Creek and around Kopi Base Camp

Note: ? = the plant could not be identified any further

Family	Species	Location	OGG Field Number	Plot or Sighting	Comments
Anacardiaceae	*Semecarpus* sp.	Uro Creek			
Apocynaceae	*Cerbera* sp.	Uro Creek		Plot	
Apocynaceae	*Orchrosia* sp.	Uro Creek	OGG 070		
Araceae	*Alocasia hollrungii*	Uro Creek			
Araceae	*Cryptocoryne ciliata*	Uro Creek	OGG 116		water plant
Araceae	*Cyrtosperma carrii*	Uro Creek	OGG 104		
Araceae	*Rhaphidophora* sp.	Uro Creek	OGG 073		
Araceae	*Schismatoglotis* sp.	Uro Creek		Plot	
Araliaceae	*Osmoxylon geelvinkianum*	Uro Creek	OGG 093		
Araliaceae	*Schefflera* sp.1	Uro Creek			
Araliaceae	*Schefflera* sp. 2	Kopi			
Araliaceae	*Schefflera* sp. 3	Uro Creek	OGG 106		
Araliaceae	*Schefflera* sp. 4	Uro Creek		sighting	
Arecaceae	*Cyrtostachys* sp.	Uro Creek		Plot	
Arecaceae	*Cyrtostachys loriae*	Uro Creek			
Arecaceae	*Hydriastele apetiolata*	Uro Creek	OGG 058		
Arecaceae	*Hydriastele costata*	Uro Creek			
Arecaceae	*Hydriastele* sp.	Uro Creek			
Arecaceae	*Hydriastele* sp. nov.	Uro Creek			W. Baker informs me that it is being described as a new species (in press)
Arecaceae	*Licuala* sp. 1	Uro Creek	OGG 098		
Arecaceae	*Licuala* sp. 2	Uro Creek		sighting	
Arecaceae	*Orania archboldiana*	Uro Creek	OGG 111		
Arecaceae	*Pinanga rumphiana*	Uro Creek	OGG 118		vernacular name: Biri
Arecaceae	*Ptychococcus paradoxus*	Uro Creek			cultivated in Babeio village, reported common by WJ Barker et al. 2000
Bignoniaceae	*Tecomanthe dendrophila*	Uro Creek	OGG 062		
Burseraceae	*Canarium acutifolium*	Kopi			
Burseraceae	*Canarium acutifolium*	Uro Creek	OGG 087		
Burseraceae	*Protium macgregorii*	Uro Creek		Plot	
Casuarinaceae	*Gymnostoma papuana*	Uro Creek		sighting	
Clusiaceae	*Calophyllum suberosum*	Uro Creek	OGG 112		
Clusiaceae	*Garcinia* sp.	Uro Creek		Plot	
Cyatheaceae	*Cyathea* cf. *contaminans*	Uro Creek			
Dennstaedtiaceae	*Microlepia* sp.	Uro Creek	OGG 110		
Elaeocarpaceae	*Elaeocarpus multisectus*	Uro Creek	OGG 081		

Family	Species	Location	OGG Field Number	Plot or Sighting	Comments
Ericaceae	*Dimorphanthera* (sp. 1?)	Uro Creek	OGG 079		Family rarely found in the lowlands
Ericaceae	*Dimorphanthera* (sp. 2?)	Uro Creek	OGG 080		Family rarely found in the lowlands
Euphorbiaceae	*Macaranga* sp. 1	Uro Creek	OGG 063		
Euphorbiaceae	*Macaranga* sp. 2	Uro Creek	OGG 075		
Fabaceae	*Derris* sp. 1	Uro Creek	OGG 088		
Fabaceae	*Derris* sp. 2	Uro Creek	OGG 092		
Flacourtiaceae	*Casearia* sp.	Uro Creek	OGG 107		
Flagellariaceae	*Flagellaria indica*	Uro Creek		Plot	
Flindersiaceae	*Flindersia amboinensis*	Uro Creek			Fruit seen on forest floor (ID confirmed)
Gnetaceae	*Gnetum costatum*	Uro Creek	OGG 057		
Lauraceae	*Cryptocarya* sp.	Uro Creek		Plot	
Lecythidaceae	*Barringtonia* sp. 1	Uro Creek	OGG 076		
Lecythidaceae	*Barringtonia* sp. 2	Uro Creek	OGG 084		
Loganiaceae	*Fagraea berteroana*	Uro Creek	OGG 115		
Loganiaceae	*Neuburgia* sp.	Uro Creek	OGG 114		
Loganiaceae	?	Uro Creek	OGG 074		
Lorathaceae	*Amyema* sp.	Uro Creek	OGG 077		
Lorathaceae	?	Uro Creek	OGG 078		
Malvaceae	*Brownlowia argentata*	Uro Creek	OGG 056		
Marantaceae	*Phrynium* sp.	Uro Creek	OGG 105		
Marattiaceae	*Marratia* sp.	Uro Creek	OGG 061		
Meliaceae	*Chisocheton*	Uro Creek	OGG 083		
Moraceae	*Antiaris toxicaria*	Uro Creek		Plot	
Myrsinaceae	*Ardisia* sp.	Uro Creek	OGG 091		
Myrtaceae	*Asteromyrtus symphyocarpa*	Uro Creek		sighting	cultivated in Babeio village
Myrtaceae	*Octamyrtus insignis*	Uro Creek			
Myrtaceae	*Syzygium* sp. 1	Uro Creek	OGG 071		
Myrtaceae	*Syzygium* sp. 2	Uro Creek	OGG 086		
Myrtaceae	*Syzygium* sp. 3 (white ridged fruit)	Uro Creek	OGG 113		
Orchidaceae	*Dendrobium* sp.	Uro Creek	OGG 117		
Pandanaceae	*Freycinetia* sp.	Uro Creek	OGG 068		
Pandanaceae	*Pandanus* sp. (common river pandan)	Uro Creek	OGG 120		Common river pandan, forming pure communities
Phyllanthaceae	*Baccaurea papuana*	Uro Creek	OGG 095		vernacular name: Mamuru, edible fruit
Piperaceae	*Piper* sp. (free fruits)	Uro Creek	OGG 102		
Poaceae	*Bambusa* sp.	Uro Creek		Plot	
Rubiaceae	*Amaracarpus* sp.	Uro Creek			
Rubiaceae	*Atractocarpus decorus*	Uro Creek	OGG 082		

Family	**Species**	**Location**	**OGG Field Number**	**Plot or Sighting**	**Comments**
Rubiaceae	*Gardenia* sp.	Uro Creek	OGG 090		
Rubiaceae	*Ixora valetoniana*	Uro Creek	OGG 096		vernacular name: Amauri'kara
Rubiaceae	*Ixora* sp. 1	Uro Creek	OGG 069		
Rubiaceae	*Ixora* sp. 2	Uro Creek	OGG 059		
Rubiaceae	*Lasianthus* sp. 1	Uro Creek	OGG 065		
Rubiaceae	*Lasianthus* sp. 2	Uro Creek	OGG 103		
Rubiaceae	*Mussaenda bevani*	Uro Creek	OGG 089, OGG 101		
Rubiaceae	*Mussaenda scratchleyi*	Uro Creek	OGG 066		
Rubiaceae	*Psychotria* sp. 1	Uro Creek	OGG 064		
Rubiaceae	*Psychotria* sp. 2	Uro Creek	OGG 109		
Rubiaceae	*Timonius* sp.	Uro Creek	OGG 100		
Sapotaceae	*Pouteria* sp.	Uro Creek	OGG 119		
Selaginellaceae	*Selaginella* sp.	Uro Creek		Plot	
Sonneratiaceae	*Sonneratia lanceolata*	Uro Creek			
Ulmaceae	*Celtis* sp.	Uro Creek		Plot	
Urticaceae	*Elatostema* sp.	Uro Creek		Plot	
Winteraceae	*Belliolum* sp.	Uro Creek	OGG 067		
Zingiberaceae	*Alpinia* sp. (large green fruit)	Uro Creek	OGG 072		
Zingiberaceae	*Alpinia* sp. (yellow flower)	Uro Creek	OGG 099		
Zingiberaceae	*Alpinia* sp. (single red fruit)	Uro Creek	OGG 108		
Zingiberaceae	*Hornstedtia scottiana*	Uro Creek			
Zingiberaceae	*Pleuranthodium racemigerum*	Uro Creek	OGG 094		
Zingiberaceae	*Pleuranthodium* sp. (Kopi)	Kopi			
?	?	Uro Creek	OGG 085		Vine

Chapter 2.2. Butterflies of the Uro Creek catchment, Gulf Province, Papua New Guinea

Chris Müller and Pagi Toko

A male of *Lamprolenis nitida* (Nymphalidae), guarding its territory.

Summary

The biodiversity of the Kikori Delta in Gulf Province, Papua New Guinea, is incompletely known. As part of a program to document the biodiversity and conservation values of the Kikori basin we surveyed butterfly species at Uro Creek in the upper Kikori delta. One hundred and seventeen butterfly species were documented at Uro Creek over a five day period. One species of *Perpheres* (Lycaenidae) is undescribed and 20 species were recorded from Gulf Province for the first time. The previously unknown life histories of six butterfly species were also documented.

The lycaenid butterfly *Hypochrysops lucilla*, which was previously known only by the holotype male from Aroa River in Central Province and a female from Haia in Chimbu Province, was recorded at Eimu Camp. *Morphopsis biakensis,* a species previously known only from five specimens from PNG, all in East Sepik Province, and a small number from Indonesian Papua Province, was recorded at Tipiowo. The IUCN Endangered Southern Tailed Birdwing Butterfly (*Ornithoptera meridionalis*) was observed at Tipiowo and Veimake. Together with the Common Birdwing (*O. priamus*) these butterflies are reared by some local communities elsewhere in PNG as a source of income and a sustainable ranching program could be viable in the Uro Creek area.

Uro Creek has considerable conservation values, with a diverse butterfly fauna that includes poorly known and conservation significant species. Such conservation values, and potential threats to them, are outlined and recommendations for retaining and potentially utilising the butterfly diversity are provided.

Introduction

Butterflies are the best studied of all invertebrates (Kerr 2001; Dincă et al. 2011), and the majority of species have probably been discovered and described (Kitching et al. 2001). However new species continue to be discovered in New Guinea, where nearly 1000 described butterfly species are known, approximately 840 of which have been recorded from Papua New Guinea (PNG) (Tennent 2006). The New Guinea butterfly fauna has high levels of endemism (approximately 40%) and includes some spectacular radiations, such as the genera *Delias* and *Philiris* which together make up nearly 25% of the total fauna. The iconic Birdwings of the genus *Ornithoptera* reach their greatest diversity in New Guinea.

There have been few entomological surveys conducted within the Kikori basin. Alfred Meek and William Brandt, the two historically most prolific butterfly collectors in PNG, who surveyed in PNG during the late 1800's and early 1900's and during the 1950–60's, respectively, and who made substantial contributions to our knowledge of the PNG butterfly fauna, did not make any collections in Gulf Province. This lack of biodiversity data led Hartshorn et al. (1993) to recommend that biodiversity inventories be generated for the region, and in July 1994 the World Wildlife Fund (WWF) carried out surveys of several taxa at 33 sites across the middle and lower Kikori basin (Hartshorn et al. 1994, 1995). During that survey, 32 butterfly species were documented from sites which included primary forest at Lake Kutubu-Moro and the Kopi-Kaiam lowlands. Although this butterfly inventory was presented in unpublished reports, the results were not included in published checklists.

Butterflies are recognised as valuable environmental indicators, owing to their rapid and sensitive responses to subtle habitat or climatic changes and as analogies for the diversity and responses of other wildlife (Brereton et al. 2011). Kerr et al. (2000) showed that butterflies could be used to predict species diversity among Hymenoptera at a number of study sites in the USA. Despite all of this, in PNG only the Birdwings and some species in the subfamily Danainae have been officially assessed using IUCN criteria and thus the conservation status of PNG butterflies is insufficiently known.

In this report we present the results of a survey of butterflies in the Uro Creek catchment. The main aims of the survey were to record and characterise butterfly diversity, distribution, abundance and life histories with particular attention to new, rare and/or threatened species, migratory species and exotic pest species. Another objective of the survey was to identify significant butterfly communities and habitats, species of community/cultural significance and potential threats to butterfly biodiversity.

Methods

Surveying

Active surveys involved 3–4 surveyors (CM, PT and 1–2 assistants) searching for butterflies along pre-existing walking tracks, and along new trails established in the forest through as many different habitats as possible. Survey coverage is shown in Figure 1.

Butterflies were identified visually in the field often using binoculars or, when field identification was not possible (e.g., for cryptic, less easily discernible species), voucher specimens were collected using long handled nets and stored in glassine envelopes with the preservatives paradichlorobenzene and chloro-m-chresol for subsequent identification.

Two legs from each voucher were stored separately as dried tissue samples in vials for potential DNA sequence analysis. Surveys were conducted between approximately 0800 to 1630 hrs between 26–30 April, 2017, except on one day when surveying continued until dark (1900 hrs) to assess crepuscular species. Temperature and humidity was measured 24 hours a day during the survey (min/max stored in the memory), using a Platinum S Hygrometer that was positioned in shade at various locations during the day and on the research vessel deck (under cover) at night. Daily temperatures ranged from 23.1–29.6°C (average daily minimum of 23.4°C; average daily max of 28.8°C) and daily humidity ranged from 76–100% (average daily minimum of 81.3 and average daily max of 100%).

Fruit baits

Because some nymphaline butterflies, particularly in the subfamilies Amathusiinae and Satyrinae are attracted to fruit we sampled these groups using fruit traps. Three fruit traps containing fermented pineapple, banana and pawpaw that had been stored for three days in air-tight plastic bags were placed at various heights from 0.5 to 10 m above the forest floor (Plate 1D) and remained in place for the duration of the survey, without being moved. Bait was replaced twice during the survey at Uro Creek. Butterflies enter the trap, which is open at the bottom, and become trapped in the enclosed upper portion.

Paper lures

Many adult hesperiid (skipper) butterflies, and some butterflies of the families Lycaenidae and Nymphalidae, imbibe moisture and presumably nutrients from bird droppings. These species are attracted to small pieces of white paper, cut roughly circular to imitate droppings and placed on the upper sides of leaves in various micro-habitats. Paper lure baits consisted of approximately 10 pieces of paper placed within a ~0.5 m radius on the upper surfaces of leaves in the forest understorey. The lures normally cover a single bush or several adjacent bushes and once attracted the butterflies generally 'feed' for long periods, such that twice daily checks of the baits are adequate. Figure 2 shows the location of paper lure baits set up at Uro Creek.

Identification

Where identification was uncertain, type specimens of certain butterfly taxa were examined in the Australian National Insect Collection, Canberra, Australian Museum, Sydney and the Natural History Museum, London.

Conservation status

Species of conservation significance are those classified as Threatened, Near Threatened or Data Deficient by the IUCN (IUCN 2017), those Protected under PNG law and species that are new to science (discovered for the first time during this survey) or undescribed (previously known from one or more sites but remaining without a name).

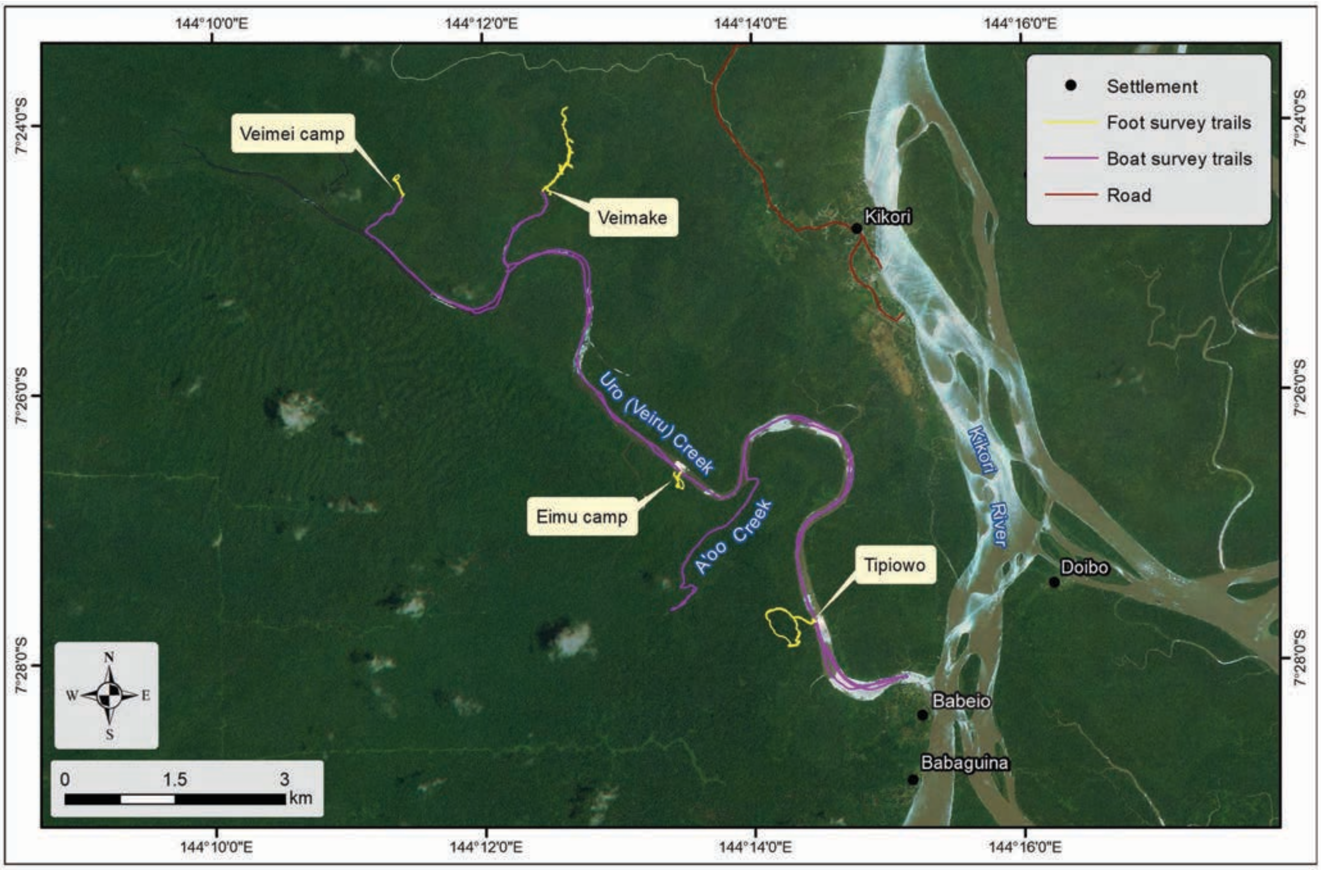

Figure 1. Map of Uro Creek, showing locations of the survey for butterflies.

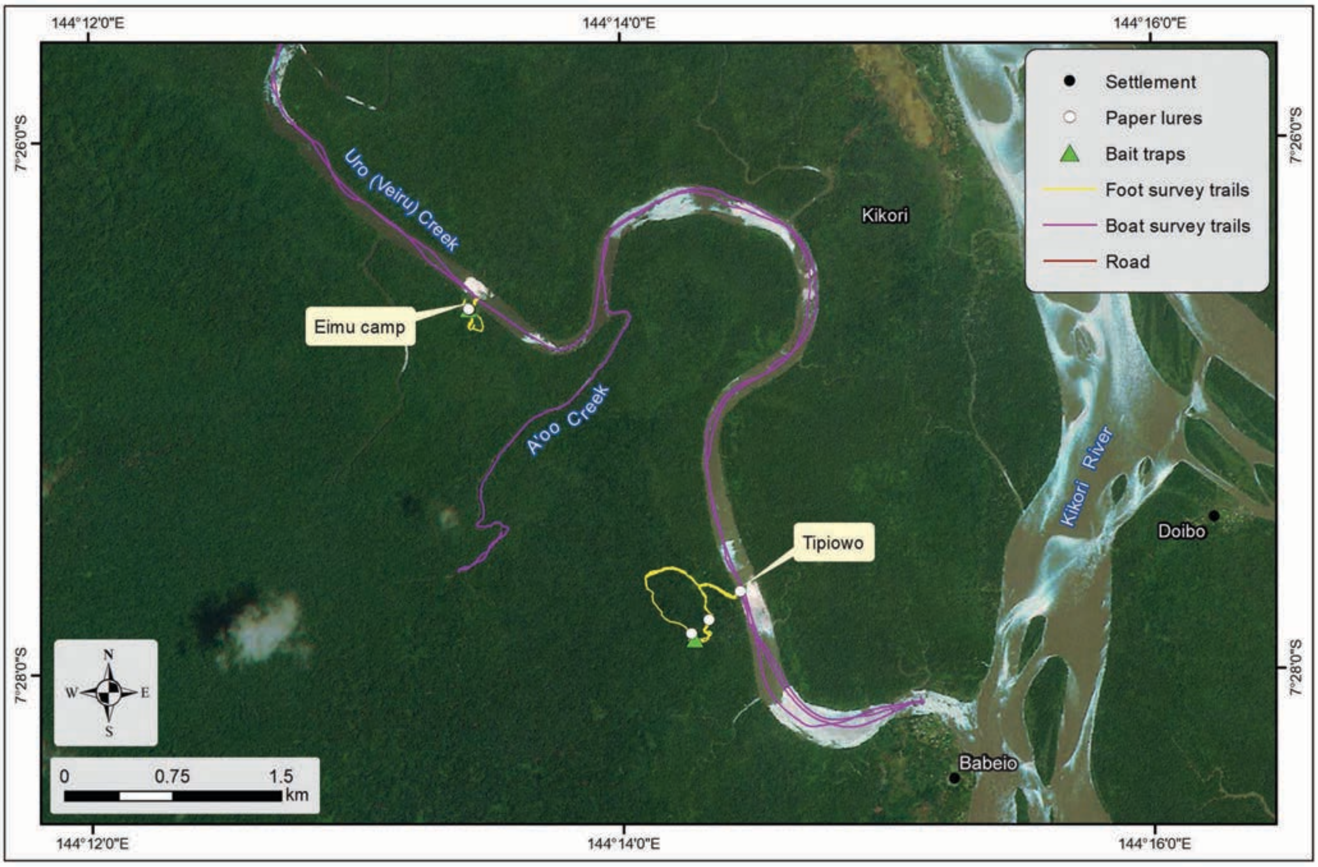

Figure 2. Map of Uro Creek, showing locations of bait traps and paper lures (excluding Veimake camp)

Taxonomy and nomenclature

Nomenclature in this report follows that of Parsons (1998). Only a few butterflies in New Guinea have common names, so this report generally uses standard scientific names and draws only occasionally on Australian references to common names (Braby 2000).

Results

A total of 117 butterfly species was recorded over a five-day period at Uro Creek (Appendix 1), one of which is undescribed and another is IUCN Endangered. Twenty species were recorded from Gulf Province for the first time, some of which were also encountered at Wau Creek during the same survey program. The previously unknown life histories of six butterfly species were documented for the first time (Table 2). Conservation significant species are listed in Table 1, and a selection of species are illustrated in Plates 1–2.

Species accounts

This section presents brief accounts for butterfly species that are undescribed, IUCN-listed, Protected under PNG law, of cultural importance, or for which significant distributional records apply.

Undescribed species

***Perpheres* sp. (Lycaenidae)**

This undescribed species of *Perpheres* has a unique wing shape, pattern and colour. It differs from *P. perpheres*, the only other member of the genus, in having extensive blue and white colouration on the underside of the wings. The female is largely blue on the upperside (vs black and white in *P. perpheres*). *Perpheres perpheres* is widespread in the lowlands of mainland Indonesian New Guinea and the western half of Papua New Guinea, and there is only fairly minor morphological variation in a large series of that taxon examined suggesting that these differences do not reflect clinal variation. The early stages of this species were located on *Ziziphus* sp. (Rhamnaceae) at Uro Creek. It was also found at Wau Creek during the 2017 surveys there.

Conservation significant species

***Ornithoptera meridionalis* (Papilionidae)**

Although the smallest species in the genus *Ornithoptera*, this birdwing is still a large butterfly, the male's wingspan reaching up to 99 mm and the female's up to 124 mm. Males are green and black with a thin spatulate tail to the narrow hindwing, while females are predominantly brown and cream. According to Parsons (1998), the larvae feed exclusively on the vine *Pararistolochia meridionaliana*. Males are rarely observed, probably because they fly only short distances while females are more wide-ranging. This is typical of other Birdwings.

This butterfly is endemic to mainland New Guinea, with all but one dubious record from south of the central cordillera. It is primarily a lowland species, although there are records as high as 700 m asl in the Lake Kutubu area. *Ornithoptera meridionalis* inhabits the margins of advanced secondary and primary forest, and suitable habitat is widespread in the Uro Creek area where females were observed on two occasions at Tipiowo flying through thick vegetation presumably in search of oviposition sites. It was also observed at Wau Creek during the 2017 surveys.

This species is classified as Endangered by the IUCN (Gimenez Dixon 1996) and is protected by the PNG Fauna (Protection And Control) Act 1966. It is also listed on CITES Appendix II.

Table 1. Significant butterfly species recorded at Uro Creek.

Common Name	Scientific Name	Undescribed Species	IUCN	PNG Fauna Act	Cultural importance
-	*Perpheres* sp.	x			
Southern Tailed Birdwing	*Ornithoptera meridionalis*		EN[1]	P[2]	x

[1]IUCN status EN = Endangered.

[2]Status under the PNG Fauna (Protection and Control) Act. P = Protected

Other significant records

***Chaetocneme caristus* (Hesperiidae)**

Parsons records *C. caristus* from Aru Island (Indonesia) and from southern mainland New Guinea; mainland Papua (Indonesia) and Western, Central and Milne Bay Provinces, as far east as Tagula Island. There are no previous records from Gulf Province. A single male was recorded at a paper lure on dusk at Veimake.

***Chaetocneme tenuis* (Hesperiidae)**

One individual of this crepuscular species was recorded at Veimake where it was attracted to paper lures at dusk. In PNG, Parsons (1998) records this taxon only from Central, Northern, Morobe, Western and East Sepik Provinces. It was also found at Wau Creek during the 2017 survey there. The new records fill a major gap in the known distribution of this species.

***Mimene caesar* (Hesperiidae)**

Mimene caesar was previously known only from a handful of specimens from the Kumusi River (Morobe Province), Western Province and Central Province (Parsons 1998). At Uro Creek males were fairly common at paper lures around midday in swampy (mostly Sago) areas. The Uro Creek records fill a major gap in the known distribution of this species.

***Mimene celiaba* (Hesperiidae)**

This species was previously known only from six specimens collected at the type locality at Kiunga (Western Province) and the Eilanden and Utakwa rivers in southern Papua Province, Indonesia (Parsons 1998). At Uro Creek a single male was taken at a paper lure in similar habitats occupied by *M. caesar*, thus representing the first record for Gulf Province.

***Notocrypta flavipes* (Hesperiidae)**

Parsons (1998) records *N. flavipes* only from Central, Madang and East Sepik Provinces in PNG. The species was fairly common at all Uro Creek sites, in particular on hilltops where males contested for territories in small clearings. The Uro Creek records fill a major gap in the known distribution of this species.

***Ocybadistes flavovittatus* (Hesperiidae)**

This species is common throughout much of eastern Australia, where it frequents gardens and open spaces. In PNG, *O. flavovittatus* is recorded from Western, East Sepik, Central and Milne Bay Provinces (Parsons 1998), so the Uro Creek record represents a significant range extension. It is likely that this species has been overlooked and is probably more widespread in mainland NG.

***Telicota argeus* (Hesperiidae)**

Telicota argeus was recorded by Parsons (1998) from a handful of specimens from Central, Western Highlands and East Sepik Provinces but also on some Bismarck islands. Specimens recorded from Veimake, taken at paper lures, appear to be the first record of the species from Gulf Province.

***Telicota ixion* (Hesperiidae)**

Several males of this species were encountered at paper lures. *Telicota ixion* belongs to a species complex in which morphological differences between taxa are slight. However examination of comparative material in the Australian National Insect Collection, indicates that the Uro Creek population represents this taxon. *Telicota ixion* was previously recorded in PNG from Central, Morobe, Madang and Northern Provinces, and from the d'Entrecasteaux and Bismarck islands. It was also found at Wau Creek during the 2017 surveys. The Uro Creek and Wau Creek records represent a major westerly range extension for this species and the first record for Gulf Province.

***Arhopala wildei* (Lycaenidae)**

Arhopala wildei appears to be rare in PNG and had previously only been reported from Madang, Morobe and Western Highlands Provinces as well as some Milne Bay islands. At Uro Creek it was recorded along a flooded tributary of the main creek channel in riparian vegetation. This appears to be a new record for Gulf Province.

***Danis phroso* (Lycaenidae)**

Recorded in PNG by Parsons (1998) from Western, Western Highlands, Morobe, Central and Northern Provinces, *D. phroso* (Plate 1B) was fairly common at Uro Creek, and this record fills a major gap in its known distribution. Adults form part of a mimicry ring, in which the adults have black and green bands on the underside.

***Dicallaneura ribbei* (Lycaenidae)**

Dicallaneura ribbei has been reported only from Western, East Sepik, Madang, Central, Northern and Milne Bay Provinces. Two individuals were recorded from Eimu Camp, on the closed canopy crests of low ridges near a tributary of Uro Creek. These appear to be the first records of this species in Gulf Province.

***Hypochrysops lucilla* (Lycaenidae)**

This species was known previously only from the holotype male and a single female (Lane and Edwards 2004). A single male was taken on an open hilltop on a low ridge bordering a tributary of Uro Creek. This species forms part of a mimicry ring comprising lycaenids with green and black banded undersides.

***Philiris harterti* (Lycaenidae)**

Early stages of this butterfly were recorded in deep shaded forest near the forest floor at Tipiowo, feeding as larvae on *Litsea guppyi* (Lauraceae). Larvae and pupae are both extremely well camouflaged, concealed in troughs made by the former on stems of the foodplant. An adult was also observed at Tipiowo in a clearing created by a tree fall. Sands (1981) and Parsons (1998) recorded this species in PNG only from Milne Bay, Northern, Central, Morobe and Western Provinces. It was also found at Wau Creek during the 2017 surveys. The Uro Creek and Wau Creek records fill a major gap in the species' known distribution.

***Dolleschallia bisaltide* (Nymphalidae)**

Dolleschallia bisaltide is a widespread species that occurs throughout much of the Indo-Pacific, from Sri Lanka and India through South-East Asia to New Guinea and eastern Australia. However, there are few records from PNG, where it is recorded only from West Sepik, East Sepik and Central Provinces. A single individual was recorded in a large clearing at Veimake, Uro Creek. This species was also encountered at Wau Creek during the 2017 survey there.

***Euploea netscheri* (Nymphalidae)**

Parsons (1998) considered *E. netscheri* (Plate 2D) to be very localised in the western half of mainland PNG (Western, East Sepik, Western Highlands, Madang Provinces). Several specimens were observed at Uro Creek, mostly in swampy areas at Veimake, where a female was observed to oviposit on a species of *Tylophora* (Apocynaceae). The resultant larva (Plate 1E) failed to reach 4th instar. This species was also encountered at Wau Creek during the 2017 survey there.

***Morphopsis biakensis* (Nymphalidae)**

Morphopsis biakensis (Plate 1C) was previously only known in PNG from five specimens collected in East Sepik Province (Parsons 1998) so the Uro Creek record appears to be the first on the southern side of the central cordillera in PNG.

***Taenaris dioptrica* (Nymphalidae)**

Taenaris dioptrica was previously only known from a few specimens from West Sepik, East Sepik, Madang and Western Provinces (Parsons 1998). The species was fairly common at all sites surveyed at Uro Creek, being readily attracted to fruit baits. This species was also encountered at Wau Creek during the 2017 survey there.

***Taenaris gorgo* (Nymphalidae)**

The nominate subspecies of *T. gorgo* is known from a number of localities in the northern half of mainland New Guinea, but the subspecies *yulei*, which was documented at Uro Creek, is known only from Central Province (Aroa River and Kokoda Trail) (Parsons 1998). This butterfly was observed at Veimake on one occasion and appears to be the first record of this subspecies outside of Central Province (see Plate 2G in Chapter 1.2).

Life history records

During the field survey at Uro Creek the life histories of 25 species were recorded in the field and their food plants noted (see Table 2). Several of these had not previously been recorded and are hence noteworthy (e.g., *Perpheres* sp., *Jamides aetherialis*, *Jamides nemophilus*, all Lycaenidae; *Euploea netscheri* (Plate 1E, 2D) *Harsiesis hygea*, both Nymphalidae; the latter species' food plant was also documented at Wau Creek).

Table 2. Food plants recorded for butterfly fauna at Uro Creek.

Taxon	Food plant species	Food plant family
Tagiades japetus	*Dioscorea* sp.	Dioscoraceae
Badamia exclamationis	*Terminalia catappa*	Combretaceae
Hasora hurama	*Derris* sp.	Leguminaceae
Toxidia inornatus	*Centotheca latifolia*	Poaceae
Notocrypta waiguensis	*Alpinia* sp.	Zingiberaceae
Notocrypta flavipes	*Alpinia* sp.	Zingiberaceae
Sabera caesina	*Alexandria* sp.	Arecaceae
Cephrenes augiades	*Alexandria* sp.	Arecaceae
Arrhenes marnas	Grass sp.	Poaceae
Atrophaneura polydorus	*Aristolochia* sp.	Aristolochiaceae
Graphium agamemnon	*Haplochistus* sp.	Annonaceae
Papilio ambrax	*Citrus* sp.	Rutaceae
Catopsilia pomona	*Cassia* sp.	Fabaceae
Eurema hecabe	*Albizia* cf. *fulva*	Fabaceae
Philiris harterti	*Litsea guppyi*	Lauraceae
Philiris helena	*Macaranga* cf. *aleurotoides*	Euphorbiaceae
Philiris moira	*Ficus* sp.	Moraceae
Perpheres sp.	*Zizyphus* sp.	Rhamnaceae
Psychonotis caelius	*Alphitonia* cf. *petriei*	Rhamnaceae
Jamides aetherialis	*Pongamia pinnata*	Fabaceae
Jamides nemophilus	*Pongamia pinnata*	Fabaceae
Euploea netscheri	*Tylophora* sp.	Apocynaceae
Harsiesis hygea	*Bambusa* sp.	Poaceae
Cyrestis acilia	*Ficus* sp.	Moraceae
Vindula arsinoe	*Adenia* cf. *heterophylla*	Passifloraceae

Discussion

The 2017 surveys at Uro Creek and Wau Creek are the most significant surveys of butterflies carried out to date in the Kikori lowlands. Total diversity at these sites was similar (117 species vs 109 species at Wau Creek) with moderately high overlap of species. However a number of species were found only at one or the other of the two sites (compare Appendix 1 with Appendix 1 in Chapter 1.2), reflecting differences in habitat between these areas. The WWF species inventory of Kikori Basin butterflies assembled by Hartshorn et al. (1994) lists just 32 species and does not indicate which of the three main sites visited (Agogo Forest, Moro/Kutubu, Kopi/Kikori) they were recorded from. In contrast the survey at Uro Creek documented 117 species including all but one listed by Hartshorn et al. (1994). That species, *Mycalesis valeria* (misspelled *valeriana*), is very similar to the congener *M. pernotata* which was recorded nearby at Wau Creek during the 2017 surveys.

Butterfly diversity at Uro Creek is similar to that reported from similar altitudes elsewhere in PNG (Lake Hargy Caldera and Hargy Oil Palm sites in West New Britain, with a total of 74 species) (D. Miller, pers. comm., 2010) and the lower Waria Valley, Morobe Province with 102 species (Dawson et al. 2009). However none of those surveys recorded undescribed or conservation-listed species, in contrast to the survey at Uro Creek. Several species were recorded from only a few individuals so it is likely that the Uro Creek butterfly inventory will continue to grow slowly with increased survey effort. Important habitats at Uro Creek include Sago swamps, which support a population of the poorly known *Mimene celiaba*, and hilltops (especially adjacent to Eimu Camp) where several other poorly known species (*Dicallaneura ribbei*, *Hypochrysops lucilla*, and *Perpheres* species) were encountered.

Biodiversity and conservation values

The forests at Uro Creek have considerable conservation value, providing important habitat for a moderately diverse and poorly known butterfly fauna containing a number of conservation listed, rare and poorly known species. Extensive areas of forest at Uro Creek remain intact, although gardening and logging activities have degraded some areas. Sago swamps and associated mosaics with other forest types are particularly important habitats for many butterflies of the family Hesperiidae. Stands of sago were both plentiful and generally intact at Tipiowo and several hesperiids were recorded in this habitat including *Mimene celiaba*, a rare species not recorded elsewhere during the survey. Given the large number of new distribution records documented during this survey, it is likely that a number of additional species remain to be documented in the area.

Recommendations

- A significant proportion (48/117, i.e., 41%) of butterfly species were recorded only from single individuals at Uro Creek suggesting that additional surveys may detect other rare or seasonally abundant species. In particular, a more thorough understanding of the distribution, seasonality and abundance of the endangered *Ornithoptera meriodionalis*, as well as potential threats to the species, at Uro Creek could be confirmed with additional targeted survey effort.

- Habitat loss and degradation are the most significant threats to the butterfly fauna at Uro Creek so it is important that clearing of forest be minimised. Minimising habitat loss will also reduce the opportunity for invasive plant and animal species to take a hold. Invasive weeds are present locally at Uro Creek, particularly along the water ways and overgrown logging roads. Aggressive invasive ant species (whose establishment is often accompanied with human settlement) can have a dramatic negative impact on native ants and other native species (e.g., Berman et al. 2013). Impacts on native ants can in turn have significant impacts on butterfly species that rely on symbiotic ant - early butterfly stage relationships for successful reproduction.

- Given the closure of the Insect Farming and Trading Agency (IFTA), and the Wau Ecology Institute which supplied Birdwing butterflies that were 'ranched' (reared under controlled conditions) in 2009, there may be an opportunity for local communities to obtain export permits to trade in insects. Two *Ornithoptera* birdwing species that have been successfully reared elsewhere in PNG for commercial purposes (i.e., the sale of specimens), were recorded during this survey: *Ornithoptera priamus* and *O. meridionalis*.

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Plate 1

A. Riparian habitat in tributary of Uro Creek

B. Male *Danis phroso*

C. *Morphopsis biakensis* male on tree trunk

D. Bait trap in clearing at Veimake Site

E. Hitherto unknown larva of *Euploea netscheri*

F. Larva of *Cyrestis acilia*

Plate 2 *Euploea* (Crow) butterflies known or expected to occur at Uro Creek

A. *Euploea alcathoe* (from Lake Kutubu)

B. *Euploea alcathoe* (female) (from Lake Kutubu)

C. *Euploea leucostictos*

D. *Euploea netscheri*

E. *Euploea phanareta*

F. *Euploea stephensii* (from Kiunga)

G. *Euploea sylvestor*

H. *Euploea wallacei*

Scale bar = 20 mm

Appendix 1. Butterfly species recorded at Uro Creek.

Family	Subfamily	Taxon	English Name
Hesperiiidae	Pyrginae	*Chaetocneme caristus*	
Hesperiiidae	Pyrginae	*Chaetocneme tenuis*	
Hesperiiidae	Pyrginae	*Tagiades japetus*	Black and White Flat
Hesperiiidae	Pyrginae	*Tagiades trebellius*	
Hesperiiidae	Coeliadinae	*Badamia exclamationis*	Migratory Awl
Hesperiiidae	Coeliadinae	*Hasora celaenus*	
Hesperiiidae	Coeliadinae	*Hasora hurama*	Broad-Banded Awl
Hesperiiidae	Coeliadinae	*Hasora khoda*	Narrow banded Awl
Hesperiiidae	Coeliadinae	*Hasora subcaelestis*	
Hesperiiidae	Trapezitinae	*Toxidia inornatus*	
Hesperiiidae	Hesperiinae	*Arrhenes marnas*	
Hesperiiidae	Hesperiinae	*Arrhenes tranquilla*	
Hesperiiidae	Hesperiinae	*Cephrenes augiades*	
Hesperiiidae	Hesperiinae	*Kobrona rasta*	
Hesperiiidae	Hesperiinae	*Mimene basalis*	
Hesperiiidae	Hesperiinae	*Mimene caesar*	
Hesperiiidae	Hesperiinae	*Mimene celiaba*	
Hesperiiidae	Hesperiinae	*Notocrypta flavipes*	
Hesperiiidae	Hesperiinae	*Notocrypta renardi*	
Hesperiiidae	Hesperiinae	*Notocrypta waiguensis*	Banded Demon
Hesperiiidae	Hesperiinae	*Ocybadistes flavovittatus*	
Hesperiiidae	Hesperiinae	*Pelopidas lyelli*	
Hesperiiidae	Hesperiinae	*Sabera caesina*	Black and White Swift
Hesperiiidae	Hesperiinae	*Telicota ixion*	
Hesperiiidae	Hesperiinae	*Telicota melanion*	
Hesperiiidae	Hesperiinae	*Telicota subha*	
Hesperiiidae	Hesperiinae	*Telicotaargeus*	
Papilionidae	Papilioninae	*Atrophaneura polydorus*	Red-Bodied Swallowtail
Papilionidae	Papilioninae	*Graphium agamemnon*	Green-Spotted Triangle
Papilionidae	Papilioninae	*Graphium wallacei*	
Papilionidae	Papilioninae	*Ornithoptera meridionalis*	Ornithoptère Méridional
Papilionidae	Papilioninae	*Ornithoptera priamus*	Common Birdwing
Papilionidae	Papilioninae	*Papilio aegeus*	Orchard Swallowtail
Papilionidae	Papilioninae	*Papilio ambrax*	Ambrax Swallowtail
Papilionidae	Papilioninae	*Papilio euchenor*	
Papilionidae	Papilioninae	*Papilio ulysses*	Ulysses
Pieridae	Coliadinae	*Catopsilia pomona*	Lemon Migrant
Pieridae	Coliadinae	*Eurema hecabe*	Large Grass Yellow
Pieridae	Coliadinae	*Eurema puella*	Broad-Margined Yellow
Pieridae	Coliadinae	*Gandaca butyrosa*	
Pieridae	Pierinae	*Cepora perimale*	Common Gull

Family	**Subfamily**	**Taxon**	**English Name**
Pieridae	Pierinae	*Delias gabia*	
Pieridae	Pierinae	*Delias lara*	
Pieridae	Pierinae	*Elodina hypatia*	
Lycaenidae	Riodininae	*Dicallaneura ribbei*	
Lycaenidae	Curetinae	*Curetis barsine*	Sunbeam
Lycaenidae	Lycaeninae	*Anthene lycaenoides*	Pale Cilated-blue
Lycaenidae	Lycaeninae	*Anthene seltuttus*	Dark Ciliated-blue
Lycaenidae	Lycaeninae	*Arhopala centaurus*	Dull Oakblue
Lycaenidae	Lycaeninae	*Arhopala herculina*	Large Oakblue
Lycaenidae	Lycaeninae	*Arhopala micale*	Bright Oakblue
Lycaenidae	Lycaeninae	*Arhopala nobilis*	
Lycaenidae	Lycaeninae	*Arhopala thamyras*	
Lycaenidae	Lycaeninae	*Arhopala wildei*	
Lycaenidae	Lycaeninae	*Candalides ardosiacea*	
Lycaenidae	Lycaeninae	*Candalides cupreus*	
Lycaenidae	Lycaeninae	*Candalides margarita*	
Lycaenidae	Lycaeninae	*Catochrysops amasea*	Cobalt Pea Blue
Lycaenidae	Lycaeninae	*Catochrysops panormus*	Pale Pea Blue
Lycaenidae	Lycaeninae	*Danis phroso*	
Lycaenidae	Lycaeninae	*Erysichton lineata*	Dusky Blue
Lycaenidae	Lycaeninae	*Everes lacturnus*	
Lycaenidae	Lycaeninae	*Hypochlorosis antipha*	
Lycaenidae	Lycaeninae	*Hypochrysops lucilla*	
Lycaenidae	Lycaeninae	*Hypolycaena phorbas*	Common Tit
Lycaenidae	Lycaeninae	*Jamides aetherialis*	
Lycaenidae	Lycaeninae	*Jamides allectus*	
Lycaenidae	Lycaeninae	*Jamides amarauge*	Shining Cerulean
Lycaenidae	Lycaeninae	*Jamides celeno*	
Lycaenidae	Lycaeninae	*Jamides coritus*	
Lycaenidae	Lycaeninae	*Jamides nemophilus*	
Lycaenidae	Lycaeninae	*Nacaduba kurava*	White Line Blue
Lycaenidae	Lycaeninae	*Nacaduba pactolus*	
Lycaenidae	Lycaeninae	*Nacaduba subperusia*	
Lycaenidae	Lycaeninae	*Perpheres* sp.	
Lycaenidae	Lycaeninae	*Philiris harterti*	
Lycaenidae	Lycaeninae	*Philiris helena*	
Lycaenidae	Lycaeninae	*Philiris moira*	
Lycaenidae	Lycaeninae	*Psychonotis caelius*	Small Green-Banded Blue
Nymphalidae	Danainae	*Danaus affinis*	Black and White Tiger
Nymphalidae	Danainae	*Euploea leucostictos*	
Nymphalidae	Danainae	*Euploea netscheri*	
Nymphalidae	Danainae	*Euploea phaenareta*	
Nymphalidae	Danainae	*Euploea sylvestor*	Two-brand Crow

Family	Subfamily	Taxon	English Name
Nymphalidae	Danainae	*Euploea wallacei*	Wallace's Crow
Nymphalidae	Danainae	*Ideopsis juventa*	
Nymphalidae	Morphinae	*Morphopsis biakensis*	
Nymphalidae	Morphinae	*Taenaris catops*	Catops Owl
Nymphalidae	Morphinae	*Taenaris dimona*	
Nymphalidae	Morphinae	*Taenaris dioptrica*	
Nymphalidae	Morphinae	*Taenaris gorgo*	
Nymphalidae	Morphinae	*Taenaris myops*	
Nymphalidae	Satyrinae	*Harsiesis hygea*	
Nymphalidae	Satyrinae	*Lamprolenis nitida*	
Nymphalidae	Satyrinae	*Melanitis amabilis*	
Nymphalidae	Satyrinae	*Mycalesis cacodaemon*	
Nymphalidae	Satyrinae	*Mycalesis duponchelii*	
Nymphalidae	Satyrinae	*Mycalesis mucia*	
Nymphalidae	Satyrinae	*Mycalesis phidon*	
Nymphalidae	Satyrinae	*Mycalesis shiva*	
Nymphalidae	Satyrinae	*Mycalesis terminus*	Orange Bush Brown
Nymphalidae	Satyrinae	*Orsotriaena medus*	
Nymphalidae	Apaturinae	*Cyrestis acilia*	
Nymphalidae	Nymphalinae	*Cethosia cydippe*	Red Lacewing
Nymphalidae	Nymphalinae	*Cirrochroa regina*	Red Yeomen
Nymphalidae	Nymphalinae	*Cupha prosope*	Rustic
Nymphalidae	Nymphalinae	*Dolleschallia bisaltide*	
Nymphalidae	Nymphalinae	*Dolleschallia noorna*	Leafwing
Nymphalidae	Nymphalinae	*Hypolimnas antilope*	
Nymphalidae	Nymphalinae	*Hypolimnas bolina*	Common Eggfly
Nymphalidae	Nymphalinae	*Junonia hedonia*	Chocolate Soldier
Nymphalidae	Nymphalinae	*Lexias aeropa*	Orange-Banded Plane
Nymphalidae	Nymphalinae	*Neptis praslini*	Yellow-eyed Aeroplane
Nymphalidae	Nymphalinae	*Pantoporia consimilis*	Orange Aeroplane
Nymphalidae	Nymphalinae	*Pantoporia venilia*	Cape York Aeroplane
Nymphalidae	Nymphalinae	*Parthenos tigrina*	
Nymphalidae	Nymphalinae	*Vindula arsinoe*	Cruiser

Chapter 2.3. Dragonflies and damselflies (Odonata) of the Uro Creek catchment, Gulf Province, Papua New Guinea

Stephen Richards, Pagi Toko and Günther Theischinger

Archibasis crucigera

Summary
We report the results of a survey of dragonflies and damselflies at Uro Creek in Gulf Province, Papua New Guinea (PNG). Twenty five species of odonates were encountered in five days, including 10 species of damselflies (Zygoptera) and 15 species of dragonflies (Anisoptera). Three species, including one in the argiolestid genus *Metagrion*, one in the coenagrionid genus *Pseudagrion* and one in the platycnemidid genus *Idiocnemis*, are undescribed. These species were previously known from several other sites in Gulf Province but remain unnamed. All are associated with clear-flowing streams in forest.

Although less diverse than the odonate community at Wau Creek, the Uro Creek area provides important habitat for a moderately diverse and poorly known fauna that includes several undescribed species. Small streams isolated from the tidal influence of the main Uro Creek channel are particularly important habitats for this odonate assemblage.

Introduction
More than 600 species of dragonflies and damselflies are currently known from the New Guinea region extending from the islands off western New Guinea to the Solomon Islands in the east (Michalski 2012; Kalkman and Orr 2013; Orr and Kalkman 2015). About half of the species are endemic to the region and the greatest diversity occurs on mainland New Guinea (Michalski 2012). This impressive diversity is certainly an underestimate because recent fieldwork in remote areas has revealed numerous new species in the forested interior of mainland New Guinea. (e.g. Englund and Polhemus 2007; Kalkman et al. 2013; Orr et al. 2012, 2014; Theischinger and Richards 2012a,b, 2013, 2015, 2016).

Two surveys of the Kikori basin during the 1990s reported by Polhemus (1995) and Richards (2000) provided important information about the region's odonate fauna but sampling effort across the basin remains patchy. The survey by Polhemus spanned most of the Kikori catchment, extending from the foothills of the central cordillera around Moro to the coastal lowlands. Sampling focused on damselflies, and dragonflies were not assessed during that survey. However Polhemus sampled several streams in the vicinity of Uro Creek, providing useful information of the damselfly fauna of this area. The survey reported by Richards (2000) incorporated both damselflies and dragonflies and included a montane site on Mount Sisa and a lowland site at Dark End Lumber, a patch of forest adjacent to the proposed Wau Creek Wildlife Management Area ~40 km to the NE of Uro Creek.

Here we report the results of a short (5-day) but intensive survey of odonates in the lowland forests at Uro Creek in Gulf Province, Papua New Guinea.

Methods
The survey at Uro Creek was conducted by four people (SR, PT and two local assistants) between 28 April and 02 May 2017. Most survey effort was focused at Eimu Camp, Veimake and the area between Tipiowo and Mabu (Figure 1). Searches were conducted along forest trails where adult odonates were observed with close-focus binoculars or collected with a long-handled net during daylight (normally 10 am to ~4.30 pm) from around freshwater habitats including the main channel of Uro Creek (Plate 1A), smaller streams in closed forest (Plate 1B), and forest pools and seepages. Additional observations were made from boats along the banks of Uro Creek. Figure 1 illustrates the trails accessed and boat-based surveys undertaken during the 2017 survey. Voucher specimens of species requiring further examination were treated with acetone for about 12 hours, sun-dried, and subsequently stored in labelled envelopes. Larvae were not sampled because larval stages of most New Guinea odonates cannot be assigned confidently to species.

Identifications are based largely on Michalski (2012), which summarises the papers on New Guinean odonates published by M. A. Lieftinck between 1933 and 1978, with reference also to Theischinger and Richards (2006a,b), Gassmann and Richards (2008), Theischinger and Richards (2008), Kalkman and Orr (2013) and Orr and Kalkman (2015). Comparative odonate material in existing public collections was also examined where necessary.

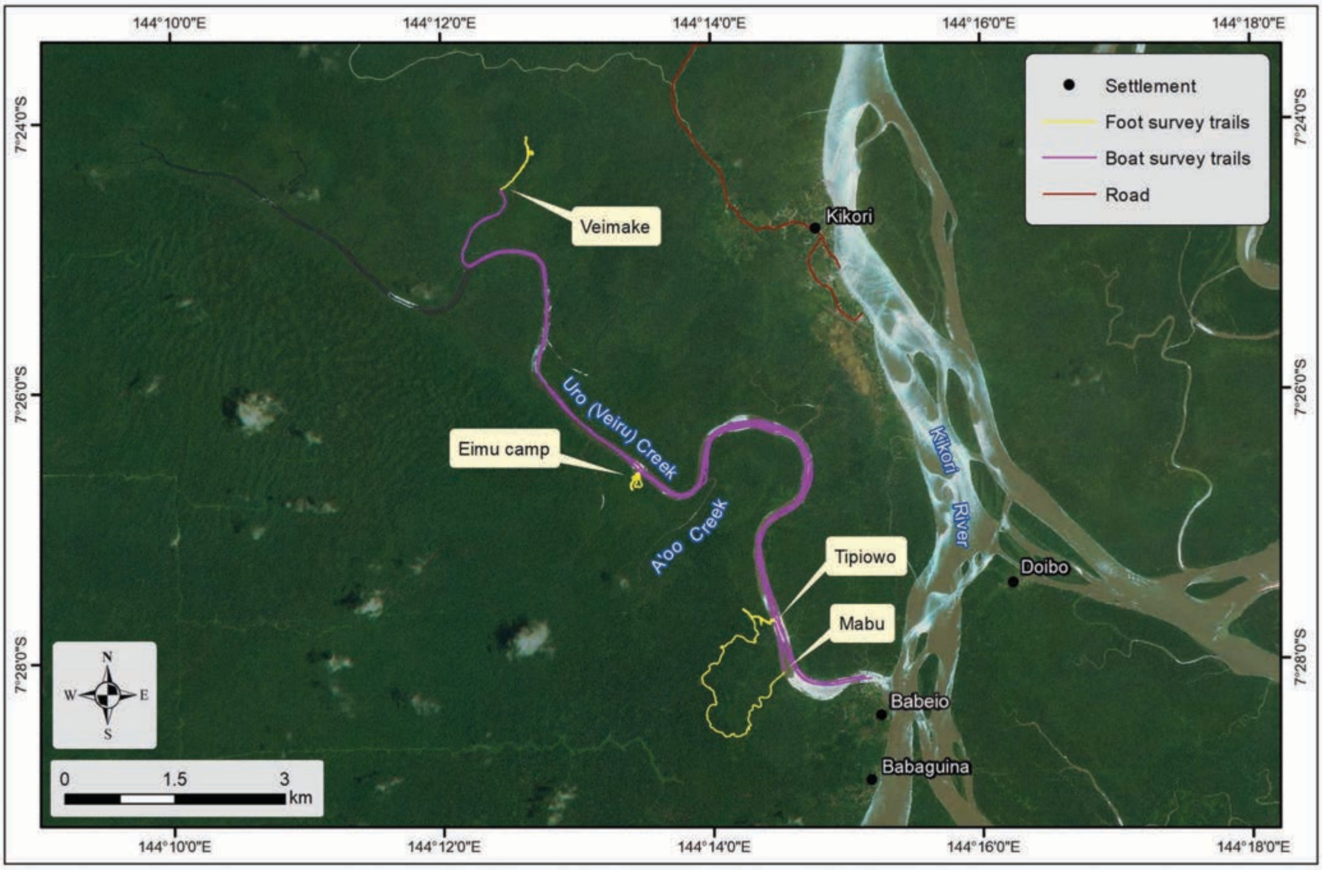

Figure 1. Map of odonate survey coverage in the Uro Creek catchment.

The conservation status of each species was taken from the IUCN Red List (IUCN 2017): LC = Least Concern; DD = Data Deficient; NE = Not Evaluated. Species are referred to as 'new to science' if they were discovered for the first time during this survey, and as 'undescribed' if they are unnamed but were previously know from other sites.

The general vegetation structure of the area is described in Chapter 2.1, and only those habitat features relevant to odonates are mentioned further here.

Results and discussion

Twenty-five species of odonates were encountered in five days, including 10 species of damselflies (Zygoptera) and 15 species of dragonflies (Anisoptera). Three species, including one in the argiolestid genus *Metagrion*, one in the coenagrionid genus *Pseudagrion* and one in the platycnemidid genus *Idiocnemis*, are undescribed. These species were previously known from several other sites in Gulf Province but remain unnamed. All are associated with clear-flowing streams in forest. Only widespread libellulid and corduliid dragonflies were found along the main channel of Uro Creek and its tidally influenced adjacent channels including *Nesoxenia mysis*, *Neurothemis* spp., *Pantala flavescens* and the dusk-flying *Hemicordulia continentalis* and *Zyxomma* sp. Several large aeshnid dragonflies were also observed hawking over the main river channel at dusk but identification to genus or species was not possible and these are not considered further.

No species classified by the IUCN in a category above Least Concern was documented.

A list of species encountered during the survey is presented in Appendix 1, species accounts for each of the undescribed species are presented below, and representative species are illustrated in Plates 1 and 2.

Significant species

Undescribed species

Three species collected at Uro Creek are undescribed (previously known but not yet named). Brief accounts for each of these species are provided below.

Family Argiolestidae: *Metagrion* sp.

A moderately large and robust damselfly that, unlike most damselflies, perches with the wings spread flat. This species has a dark thorax with narrow anterior yellow markings, and differs from *M. trigonale* in having segment 9 of the abdomen entirely dark (Plate 1C) (vs pale). During the 2017 surveys this species was found only at Uro Creek where adults perched on low vegetation adjacent to small, clear-flowing streams draining steep ridgelines (and so remote from tidal influence). It is unnamed but is known to occur at several other sites in the southern lowlands of PNG.

Family Coenagrionidae: *Pseudagrion parafarinicolle*

A small, dark and moderately robust damselfly that, although very similar to *P. farinicolle* differs from that species by several features of the male appendages. Males become distinctly pruinose (covered with a waxy film) on the thorax as they mature (see Plate 1D in Chapter 3.3). During the 2017 surveys this species was found along disturbed, sunny sections of small streams remote from tidal influence at both Uro Creek and Lake Kutubu. It was previously known from several other sites in Gulf Province and was formally described during preparation of this report (Theischinger et al. 2018).

Family Platycnemididae: *Idiocnemis* sp.

A small species of the damselfly genus *Idiocnemis* with a banded abdomen and a distinct pattern on the thorax (Plate 1D), is undescribed. This species was previously known from the Lakekamu Basin ~240 km to the SE of Uro Creek, and from Dark End Lumber immediately adjacent to Wau Creek ~ 40 km to the NE, and is currently being described (Gassmann and Richards in press). During this survey it was also found at Wau Creek. At Uro Creek it was found only along small, clear-flowing streams remote from tidal influence, where adults perched in dappled sunlight in low riparian vegetation.

General comments

The odonate fauna of Uro Creek is moderately diverse and contains an important assemblage of stream-dwelling damselflies, including three species that are currently undescribed. Each of these is known only from the Gulf Province lowlands of south-central PNG and two of them (*Metagrion* sp. and *Pseudagrion* sp.) were not encountered at Wau Creek.

Unfortunately the difficulty of accessing primary forest on the ridge systems along Uro Creek from boats biased our survey effort towards the rather depauperate assemblage of common, widespread species that occupy river banks and associated open waterbodies. These species also tended to dominate in disturbed forest and gardens on the few ridges and areas of dry land where ready access from the river has concentrated gardening and settlement activities. It is important to note however, that despite human encroachment on the forest near the main river channel, and the impact of logging over large areas of the catchment, extensive areas of undisturbed forest persist in the Uro Creek area and the area retains high conservation value for a number of undescribed and poorly known odonate species and other flora and fauna.

During WWF's 1994 biodiversity survey of the Kikori Basin, Polhemus (1995) reported a total of four species of damselflies from four sites along Uro Creek (as Veiru Creek) so this study increases the known fauna substantially. Furthermore the total diversity of dragonflies reported here is similar to that recorded at a lowland rainforest site in the Lakekamu Basin, approximately 240 km to the SE of Uro Creek (17 species at Lakekamu vs 15 at Uro Creek; Richards et al. 1998), even though survey effort was much lower at Uro Creek (5 days vs 23 days). However the diversity of damselflies was lower at Uro Creek than at Lakekamu (10 species vs 17 species), probably because the Uro Creek survey area (Figure 1) was dominated by the main channel of Uro Creek and its associated smaller channels, which are influenced by tides.

Tidal waterways are less attractive to stream-dwelling damselflies than small freshwater forest streams and pools because of their increased salinity and the diverse assemblages of predatory fish that normally inhabit them. It is likely that improved access to additional small streams in the catchment that are isolated from the tidal influences of the main Uro Creek channel will reveal a more diverse damselfly fauna than we encountered during this survey.

Biodiversity and conservation values

The Uro Creek catchment encompasses a wide range of ecosystems, including hill forest on limestone, alluvial forest, and a variety of swamp forest types and riverine wetlands. This complex of diverse, interconnecting terrestrial and aquatic landscapes undoubtedly supports a rich odonate fauna that remains incompletely documented due to constraints on accessing much of the unlogged forest on higher ridges from boats. Despite this limitation, our results suggest that the habitat with highest conservation value for damselflies at Uro Creek is small, clear-flowing streams in forest that are remote from tidal influence. These streams support a small but unique assemblage of forest interior species including three that are undescribed and currently known only from a small area of south-central PNG. These forest interior species were absent from disturbed habitats, and from open riverbanks and other exposed wetland environments so minimising disturbance to small clear-flowing streams draining the ridges adjacent to Uro Creek, and their riparian habitats, is important to ensure the long-term survival of this important group of aquatic insects.

Recommendations

Maintaining the current diversity of odonates at Uro Creek, and ensuring the long-term survival of stream-dwelling forest interior species in particular, will require actions to minimise the future impacts of logging and forest degradation. The local landowners at Babeio have demonstrated a strong intent to protect the forests in this area and the following activities are recommended in order to maintain or enhance the conservation values of the Uro Creek catchment:

- Initiate and pursue a process to formalise a community-based protection area that includes as much of the habitat complexity within the Uro Creek catchment as possible and prevent logging from occurring within this area.

- Incorporate within this area as much as possible of the unlogged forest remaining within the catchment.

- Prevent or minimise activities (such as collection of firewood and felling of trees on stream banks for gardens) that damage or degrade riparian vegetation along small forest interior streams, particularly those in unlogged forest that are remote from tidal influence.

- Because odonates are useful indicators of both habitat quality and potential impacts of climate change (Clark and Samways 1996; Ott 2010), promote further research into the local odonate fauna with a focus on documenting odonate diversity and community structure across the complex network of interconnected habitat types present in the catchment.

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Plate 1

A. Main channel of Uro Creek

B. Small stream at Veimake

C. Undescribed *Metagrion* species

D. Undescribed *Idiocnemis* species

E. *Gynacantha mocsaryi*

F. *Hemicordulia continentalis*

Plate 2

A. *Papuagrion occipitale*

B. *Lyriothemis meyeri*

C. *Nesoxenia mysis*

D. *Neurothemis decora*

E. *Orthetrum sabina*

F. *Tholymis tillarga*

Appendix 1. List of odonate species documented at Uro Creek

Species	IUCN
Damselflies	
Argiolestidae	
Metagrion sp. 1.	NE
Coenagrionidae	
Archibasis crucigera	LC
Papuagrion occipitale	NE
Pseudagrion parafarinicolle	NE
Teinobasis debeauxi	NE
Teinobasis pulverulenta	NE
Platycnemididae	
Idiocnemis australis	NE
Idiocnemis sp. 1.	NE
Nososticta rosea	NE
Platystictidae	
Drepanosticta dendrolagina	NE
Dragonflies	
Aeshnidae	
Gynacantha mocsaryi	LC
Corduliidae	
Hemicordulia continentalis	LC
Libellulidae	
Brachydiplax duivenbodei	LC
Diplacina erigone	NE
Lyriothemis meyeri	LC
Nesoxenia mysis	NE
Neurothemis decora	NE
Neurothemis stigmatizans	LC
Orthetrum sabina	LC
Orthetrum serapia	LC
Orthetrum villosovittatum	LC
Pantala flavescens	LC
Protorthemis coronata	NE
Tholymis tillarga	LC
Zyxomma sp.	LC*
Total number of species = 25	

*Not identified to species but all members of this genus known from southern PNG are classified as LC.

Chapter 2.4. Herpetofauna of the Uro Creek catchment, Gulf Province, Papua New Guinea

Stephen Richards

Juvenile Green Python (*Morelia viridis*)

Summary

I report the results of a survey of frogs and reptiles in the Uro Creek catchment in Gulf Province, Papua New Guinea (PNG). Twenty-seven species of native herpetofauna were encountered including 14 frogs and 13 reptiles. The introduced Cane Toad (*Rhinella marina*) was also encountered in cleared areas along Uro Creek. At least one, and probably two, species of frogs are undescribed; each of these is known only from a small area in south-central PNG. One species of treefrog, *Litoria sauroni*, is classified as Data Deficient by the IUCN owing to its poorly-known distribution and habitat requirements, and the large Pig-nosed Turtle (*Carettochelys insculpta*) is classified as Endangered owing to unsustainable harvesting over at least some of its range. The New Guinea Giant Softshell Turtle (*Pelochelys bibroni*) is known to occur in the local waterways but was not encountered during this survey.

At least one sighting of a juvenile crocodile appears to represent the Estuarine Crocodile (*Crocodylus porosus*) and Freshwater Crocodiles (*C. novaeguineae*) likely occur in smaller tributaries in the area. Although only a moderately diverse herpetofauna was documented, this largely reflects the limited survey time available and constraints on access to many forest habitats because the survey was predominantly boat-based. The fauna at Uro Creek is likely to be substantially more diverse than was documented because the catchment constitutes a complex of interconnected ecosystems containing numerous forest types. This is reflected in the high ecological diversity of the herpetofauna assemblage that was encountered, including mangrove, freshwater, and terrestrial species. Better access to a broader range of forest types in the catchment is likely to confirm that they provide habitat for a more diverse assemblage of frog and reptile species than was detected during this survey.

Introduction

The herpetofauna of Papua New Guinea is exceptionally diverse, with the total number of frog and reptile species known from the region currently nearing 700 (Allison and Tallowin 2015). This number is expected to increase substantially as recent taxonomic revisions of the fauna and exploration of remote regions have revealed numerous new species, particularly in the frog families Hylidae (now Pelodryadidae) and Microhylidae (e.g. Kraus and Allison 2009; Richards et al. 2009; Günther et al. 2012; Günther and Richards 2011, 2016), the gecko genus *Cyrtodactylus* (e.g. Rösler et al. 2007; Oliver et al. 2008; Oliver et al. 2012, 2016) and the snake genus *Stegonotus* (Ruane et al. 2017).

Existing knowledge about the frogs and reptiles of the Kikori basin is derived largely from a series of surveys sponsored by the World Wildlife Fund (WWF) between 1995 and 2003. These covered habitats including mangroves, lowland, hill, and montane forest, and resulted in a number of unpublished flora and fauna inventories (e.g. Hartshorn 1995; Richards 2000, 2002b; Richards and Allison 2003) and a guide to the frogs of the Kikori basin (Richards 2002a). One of the sites surveyed for herpetofauna by WWF (Richards 2000), Dark End Lumber (DEL), is located adjacent to the proposed Wau Creek Wildlife Management Area just 40 km NE of Uro Creek and a number of herpetofauna records from Kopi Base Camp are also provided in Richards (2002a–c). Description of the large green treefrog *Litoria sauroni* by Richards and Oliver (2006) was based partly on material collected at DEL. In addition, an assessment of the diversity and conservation status of freshwater turtles in the Kikori River basin was produced by Georges et al. (2008a).

Despite these efforts, survey coverage within the basin remains patchy and herpetofaunal communities are incompletely documented. Here I report the results of a herpetofauna survey conducted at several sites along Uro Creek near Babeio in Gulf Province, Papua New Guinea in 2017.

Methods

Field methods

The survey at Uro Creek was conducted by three people (SR and two local assistants) between 28 April and 02 May 2017. Most survey effort was focused at Eimu Camp, Veimake and the area between Tipiowo and Mabu (Figure 1). Night surveys were conducted only at Eimu (two nights) and Veimake (one night). Field methodology closely followed the protocols proposed by Catenazzi et al. (2016) for rapid herpetofauna assessments in tropical environments. We conducted intensive searches for frogs and reptiles along a network of existing trails. During the day we searched for heliothermic (basking) reptiles along trails through forest, in clearings, and on stream banks. Small lizards were collected by hand or were stunned with a large rubber band. Large lizards and snakes were collected by hand. Non-basking reptiles were sampled by searching in deeply shaded forest, during rain, or at dusk. We searched for nocturnal reptiles, including geckos, by walking along forest trails at night with a headlamp. We searched for frogs at night by conducting visual-encounter and aural surveys along streams, and in and around small ponds. Because a large proportion of New Guinea's frogs have life cycles that are independent of freestanding water, we also conducted extensive visual and aural searches along trails in forest away from water.

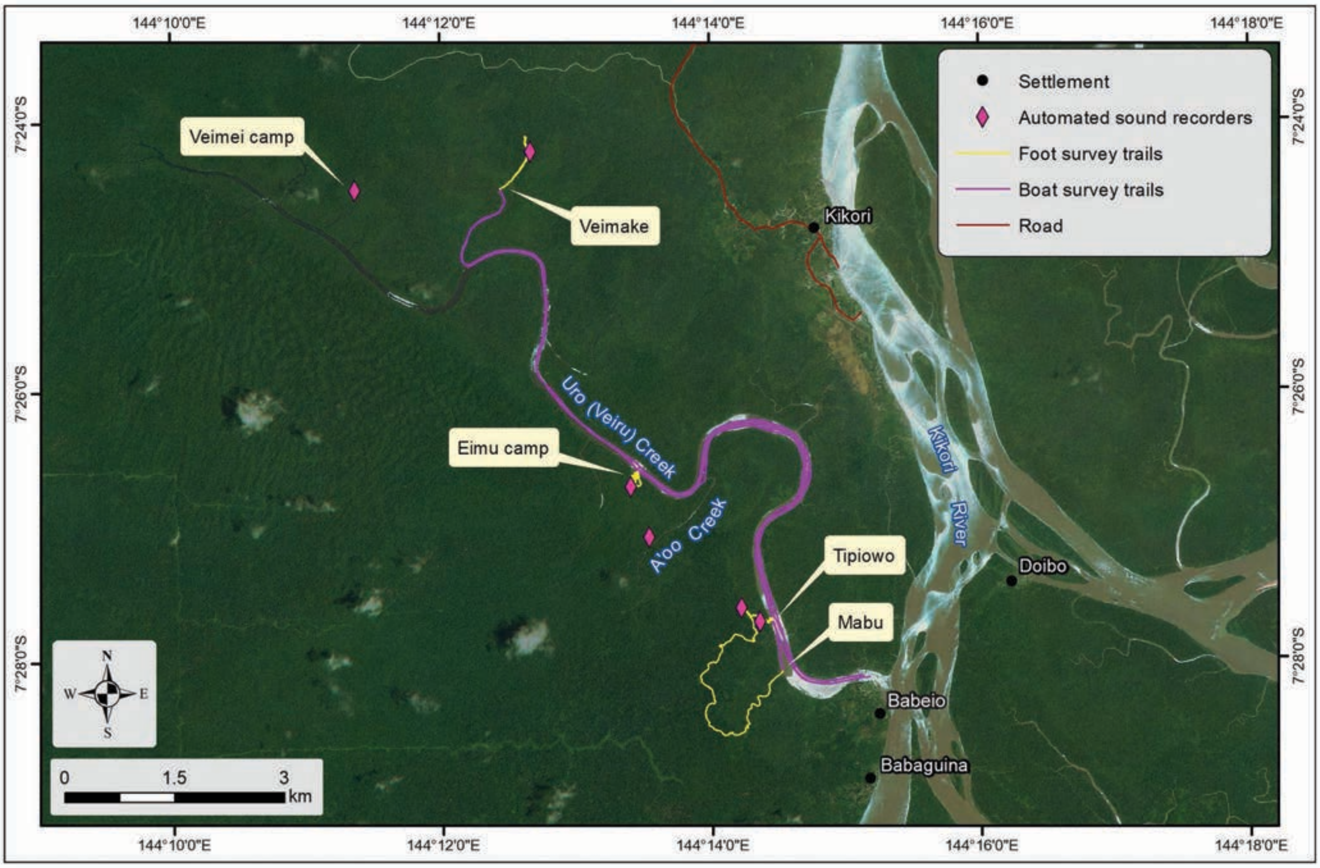

Figure 1. Herpetofauna survey coverage at Uro Creek

Frog calls are an important diagnostic character that assists greatly with species identification so whenever possible I recorded the advertisement calls of frogs during night surveys with a Marantz PMD-661 Solid-state Recorder and a Sennheiser ME66 microphone. I also deployed three automated sound recorders (SongMeter SM3) at six locations selected to sample the acoustic environment in different habitats occupied by frogs (Figure 1). SongMeter recordings were screened for the calls of notable species, including frogs not detected during active survey periods, using Adobe Audition software. Screening followed the protocols described by Richards and Armstrong (2017), and species detected by automated recorders were incorporated into the species list.

Representatives of most species were photographed alive and a small number of voucher specimens were retained for more detailed examination and identification. Voucher specimens were euthanized by submersion in chlorotone (for amphibians and small reptiles), or with lethal injection of chlorotone for larger reptiles. Specimens were fixed in 10% formalin solution, and then stored in 70% ethanol. Samples of liver tissue for DNA analyses were extracted from representative specimens and stored in 95% ethanol. Voucher specimens will be deposited in the Papua New Guinea National Museum and Art Gallery, Port Moresby, and the South Australian Museum, Australia.

The conservation status of each species was taken from the IUCN Red List (IUCN 2017): LC = Least Concern; DD = Data Deficient; NE = Not Evaluated. Species are referred to as 'new to science' if they were discovered for the first time during this survey, and as 'undescribed' if they are unnamed but were previously know from other sites.

The general vegetation structure of the area is described in Chapter 2.1, and only those habitat features relevant to herpetofauna are mentioned further here. A map illustrating the trails accessed and placement of automated sound recorders during this survey is presented in Figure 1.

Results and discussion

Twenty-seven species were encountered during the three surveys including 14 frogs and 13 reptiles. At least one species of frog is undescribed, and another is also likely to be. The calls of a canopy-dwelling frog are tentatively referred to *Litoria sauroni*, a large green treefrog classified as Data Deficient by the IUCN owing to its poorly-known distribution and habitat requirements. The large freshwater Pig-nosed Turtle (*Carettochelys insculpta*) was observed on several occasions during boat-based surveys. It is classified as Endangered by the IUCN owing to unsustainable harvesting over at least some of its range. The IUCN Vulnerable New Guinea Giant Softshell Turtle (*Pelochelys bibronii*) also occurs at Uro Creek but was not observed during this survey. The species status of a sea snake in the genus *Hydrophis* that was captured by a local fisherman near Eimu Camp remains unclear. It belongs to a taxonomically complex group of sea snakes but may represent a species new to science.

The predominantly boat-based survey at Uro Creek documented a moderate diversity of frog and reptile species, but survey effort was limited by lack of access to a wide range of terrestrial forest habitats and the true diversity of herpetofauna in the area is certainly much higher.

Species accounts for significant species are presented below, biodiversity values of the Uro Creek catchment are discussed, and representative species and their habitats are illustrated in Plates 1–2.

Undescribed and other significant species

Undescribed species

One species of the microhylid genus *Xenorhina* encountered at Uro Creek is undescribed (unnamed but previously known from other sites). The status of one other species, a frog of the microhylid genus *Hylophorbus*, is unclear. The call of a *Hylophorbus* species recorded at Uro Creek differs from that recorded at Wau Creek in having more notes produced at a faster rate. However no specimens were captured so, until a specimen is obtained the status of the *Hylophorbus* species at Uro Creek remains in doubt.

Xenorhina sp. 1. (Plate 1C)

A moderately large (~45 mm), semi-fossorial (burrowing) frog with extremely short legs, a narrow snout and small eyes. This species lives under moist leaf litter on the forest floor where males call from small depressions in the soil under dense litter, or from within burrows in the humus layer itself. Occasionally a male will call from a semi-exposed position in the upper surfaces of the litter layer. The call consists of a long series of soft, hooting notes that increases in both pitch and intensity during the call sequence. *Xenorhina* sp. 1 is undescribed but it is known from several localities in the southern foothills of Papua New Guinea spanning both the Kikori and Purari River catchments in Gulf Province. It is listed as *Xenorhina* sp. by Richards (2002a).

Species listed by IUCN

The conservation status of most frog and reptile species known from PNG has been evaluated by the IUCN for inclusion in the IUCN Red List. No species listed by the IUCN as Critically Endangered were encountered at Uro Creek but one species that is listed as Endangered, and one as Data Deficient, were documented.

One frog species encountered at Uro Creek, *Litoria sauroni*, is listed by the IUCN as Data Deficient.

Litoria sauroni

This is a very large (to 70 mm SVL), bright green treefrog with a rounded snout, prominent white folds on the arms and legs, extensively webbed hands, and a distinctively coloured eye. It is part of the taxonomically difficult *Litoria graminea* species complex and was only recently described as a species distinct from *L. graminea* by Richards and Oliver (2006) based in part on specimens from Dark End Lumber, approximately 40 km NE of Uro Creek.

This species is currently known only from several sites in Gulf Province where males call at night from high in the forest canopy. Males were heard calling even during extremely dry conditions. *Litoria sauroni* is listed as Data Deficient 'since it has only recently been described, and there is still very little known about its extent of occurrence, area of occupancy, status and ecological requirements' (Richards 2008).

The Pig-nosed Turtle is listed by the IUCN as Endangered.

***Carettochelys insculpta* (Pig-nosed Turtle)**

This is a large (to > 55 cm carapace length and 22 kg) freshwater turtle known only from the southern lowlands of New Guinea and several drainages in the Northern Territory of Australia (Georges and Rose 1993). Several individuals of this species were observed when they briefly came to the water surface during boat-based surveys along Uro Creek. A full species account is presented in Chapter 1.4.

Other significant species

***Hydrophis* sp. (Plate 1E).**

A single specimen of a hydrophiine sea snake of the genus *Hydrophis* was observed at Uro Creek. This animal was captured adjacent to Eimu Camp in the main channel of Uro Creek by a local fisherman. The animal was photographed, a small tissue sample was taken for DNA analysis, and it was subsequently released. Examination of the images, and analysis of the tissue sample, by an expert in sea snake taxonomy suggests that this animal is a member of the taxonomically complex *Hydrophis elegans* group of sea snakes – it could be the poorly known *Hydrophis vorisi*, a species previously known from only two specimens from Western Province (O'Shea 1996) or it could be a species new to science (K. Sanders, personal communication). Further studies on the genetics of this group are required to determine the taxonomic status of this interesting snake which has cultural significance for the local community.

General comments

The total of 27 species documented at Uro Creek is lower than that reported from other lowland sites in PNG. For example 51 species, including 23 frogs and 28 reptiles were documented at Wau Creek just ~40 km to the NE of Uro Creek (Chapter 1.4), and 74 species including 30 frogs and 44 reptiles were documented in the Lakekamu Basin in the Gulf Province lowlands east of the Kikori basin (Allison et al. 1998). However several factors must be considered when making these comparisons. First, at Wau Creek data were accumulated over three survey periods between 2015 and 2017, resulting in a substantially greater survey effort than was possible at Uro Creek (5 days). Similarly, survey effort at Lakekamu continued for 6 weeks (Allison et al. 1998) vs 5 days at Uro Creek. Furthermore, the survey at Uro Creek was substantially boat-based, with limited time available for comprehensive land-based activities, particularly at night. This constrained the ability to produce a comprehensive inventory of terrestrial amphibians and reptiles.

Biodiversity and conservation values

The Uro Creek catchment supports alluvial forest, hill forest on limestone and on non-limestone sediments, a variety of freshwater swamp forest types (mixed swamp forest, sago/pandanus swamp woodland) and tidally influenced mangroves. This diversity of interconnected habitats supports an ecologically diverse range of herpetofauna species including elapid sea snakes (Hydrophiinae) and 'mangrove snakes' (Homalopsidae), estuarine and freshwater crocodiles, freshwater turtles, terrestrial lizards and snakes, and litter- and canopy-dwelling frogs.

Although the species diversity documented at Uro Creek is lower than that recorded at Wau Creek approximately 40 km to the NE, the ecological diversity of the Uro Creek herpetofauna is substantially greater than that encountered at Wau Creek and Lake Kutubu (Chapters 1.4 and 3.4). This is reflected in the presence at Uro Creek of a number of reptile groups that are absent from those sites (ie mangrove snakes and sea snakes). Furthermore, it is likely that with improved access to terrestrial forest habitats remote from tidal influence, the diversity of reptile species in particular will be revealed as much higher than currently documented.

The forests and waterways at Uro Creek also provide habitat for a number of undescribed or conservation significant species including the canopy-dwelling frog *Litoria sauroni*, which is known only from several scattered locations in the Gulf Province lowlands, and at least one (and possibly two) undescribed microhylid frogs (Appendix 1). Other significant species include the Estuarine Crocodile, a sea snake of the genus *Hydrophis* that is possibly new to science, and populations of the Pig-nosed Turtle and New Guinea Giant Softshell Turtle (though the latter was not encountered during this survey).

Recommendations

Maintaining the diversity of herpetofauna at Uro Creek will require that forests within the Uro Creek catchment are as much as possible protected from future logging. Importantly, the demonstrated intent of local landowners to conserve the Uro Creek environment will underpin conservation activities within the catchment. Specific recommendations to maintain the biodiversity and conservation values of the Uro Creek herpetofauna are:

- The local community should be encouraged to establish a community-based protected area in the Uro Creek catchment that incorporates all remaining areas of unlogged forest and to capture significant areas of representative tracts of all forest types present within the catchment.

- Forest within the proposed protected area should be protected from future logging.

- Additional surveys are required that provide access to forest areas remote from tidal influence to better document the herpetofauna biodiversity values of the catchment.

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Plate 1

A. Riparian vegetation along Uro Creek

B. Forest interior at Uro Creek

C. *Xenorhina* sp. 1 (from Western Province)

D. *Elseya rhodini*

E. *Hydrophis sp., a culturally significant snake for local communities at Uro Creek*

Plate 2

A. *Litoria infrafrenata*

B. *Litoria prora*

C. *Asterophrys turpicola*

D. *Rhinella marina*

E. *Candoia aspera*

F. *Fordonia leucobalia*

Appendix 1. List of frog and reptile species encountered at Uro Creek and their IUCN status

Frogs	**IUCN Status**
Microhylidae	
Asterophrys turpicola	LC
Choerophryne crucifer	NE
Copiula guttata	LC
Hylophorbus sp.	NE
Mantophryne lateralis	LC
Metamagnusia slateri	LC
Oreophryne oviprotector	NE
Oreophryne pseudunicolor	NE
Sphenophryne cornuta	LC
Xenorhina sp. 1	NE
Pelodryadidae	
Litoria infrafrenata	LC
Litoria prora	LC
Litoria sauroni	DD
Ranidae	
Papurana daemeli	LC
Total number of native frog species = 14	
Bufonidae	
Rhinella marina	
Reptiles	
Scincidae	
Carlia aenigma	LC
Emoia caeruleocauda	LC
Emoia longicauda	NE
Scincidae	
Carlia aenigma	LC
Emoia caeruleocauda	LC
Emoia longicauda	NE
Boidae	
Candoia aspera	NE
Homalopsidae	
Fordonia leucobalia	LC
Elapidae (Hydrophiinae)	
Hydrophis sp.	NE
Pythonidae	
Morelia viridis	LC
Carettochylidae	
Carettochelys insculpta	VU
Chelidae	
Elseya rhodini	NE
Crocodylidae	
Crocodylus porosus	LC
Total number of reptile species = 13	

Chapter 2.5. Avifauna of the Uro Creek catchment, Gulf Province, Papua New Guinea

Iain A. Woxvold

Sclater's Crowned Pigeon at Uro Creek

Summary
Birds were surveyed at Uro Creek in the lower Kikori River basin in Gulf Province, Papua New Guinea, during 27 April–3 May 2017. Survey methods included active searches, camera trapping, mist netting and automated sound recording. The results of bird surveys conducted at Uro Creek by Ian Burrows in October 1995 are combined with those of the present study. One hundred and twenty-six bird species have been recorded. Twelve conservation listed species have been recorded, including two birds listed by the IUCN as Vulnerable (Pesquet's Parrot (*Psittrichas fulgidus*)) or Near Threatened (Sclater's Crowned Pigeon (*Goura sclaterii*)) and 12 species that are Protected under Papua New Guinean law. Local records of Sclater's Crowned Pigeon extend the known geographic range of this IUCN listed species. The Uro Creek catchment supports an ecologically diverse ecosystem-complex that includes a variety of well-connected forest types. The forest bird community is therefore both species rich and displays a high level of beta diversity. Existing avian conservation values are discussed and recommendations for their future enhancement are proposed.

Introduction
New Guinea and its satellite islands support the world's highest concentration of endemic birds (Gregory 2013). The region is exclusively home to seven bird families (Melanocharitidae, Paramythiidae, Cnemophilidae, Melampittidae, Rhagologidae, Eulacestomidae, Ifritidae) and to most species of bird-of-paradise (Paradisaeidae), bowerbirds (Ptilonorhynchidae), Australasian robins (Petroicidae), cassowaries (Casuariidae) and owlet-nightjars (Aegothelidae). Of nearly 800 bird species recorded in the New Guinea region, nearly half are found nowhere else (365/779 species: Pratt and Beehler 2015).

Rates of endemism are highest in New Guinea's montane environments, its lowland biotas having stronger affinities with those of neighbouring regions. The southern lowlands of New Guinea form part of the northern rim of the Australo-Papuan continental shelf, and accordingly support a comparatively high proportion of Australian taxa (Gressitt 1982). In general, these affinities are strongest at higher taxonomic levels (genera and above) and within the seasonally dry and coastal environments that characterize much of northern Australia and parts of southern mainland Papua New Guinea (the Trans-Fly and around Port Moresby). By contrast, the lowland rainforests of southern mainland Papua New Guinea support a comparatively high proportion of regional-endemic forest bird species.

In western mainland Papua New Guinea, the Hegigio-Kikori River system drains some of New Guinea's wettest forest environments, from the Southern Fold Mountains of Hela and Southern Highlands Provinces through Gulf Province and into the Gulf of Papua. In western Gulf Province, the Kikori River flows south through predominantly karstic landforms of the Kikori-Lake Kutubu Karst Area to the estuarine swamps and mangrove plains of the expansive Kikori River delta (Löffler 1977; Bryan and Shearman 2008). At the head of the delta, Uro Creek (appearing as Veiru Creek on the 1970s 1:100,000 Kikori (no. 7783) topographic mapsheet) reaches west approximately 20 km into the karst foothills at the southeast end of the Darai Karst Plateau.

Landowners have expressed interest in establishing a community based protected area in the Uro Creek catchment. As part of a broader multi-disciplinary biodiversity study, this report outlines the results of bird surveys undertaken in the Uro Creek area in 2017.

The Uro Creek environment
Uro Creek is located near the eastern end of the South Papuan Lowlands Endemic Bird Area (EBA) as defined by BirdLife International (Stattersfield et al. 1998):

> "This EBA includes the south-west lowlands and foothills bordering the Snow and Star mountains from the Mimika River (in the Indonesian province of [Papua]) to the drainages of the Kikori and Purari rivers (in Papua New Guinea)" (Stattersfield et al. 1998, p. 556).

In a local regional context, Uro Creek lies within the 'Kikori-Purari' biogeographic region identified by Beehler (1993) for warm-blooded vertebrates (mammals and birds). This biogeographic region is contained within the Gulf Province lowlands (not above 500 m asl) and extends from the Turama River east to the Vailala River.

The landforms, geology, climate and vegetation of the Uro Creek area are summarised in detail in the Report Summary.

Existing Data

In the late 1980s commercial reserves of oil and gas were discovered in Southern Highlands Province in the uplands of the Kikori River basin. In partnership with industry leaders (a joint venture led by Esso Highlands Limited, then operator of the PNG LNG Project), in 1994 WWF initiated the Kikori Integrated Conservation and Development Project (KICDP), currently termed the Kikori Basin Conservation Program, aimed at preserving biodiversity within the Kikori drainage (Leary et al. 1996; McCall and Flemming 2000). Since then, the avifauna of the Kikori lowlands has been surveyed by a number of experienced ornithologists, including Ian Burrows, Jared Diamond, David Bishop and Roger Jaensch.

Within the Uro Creek catchment, birds were surveyed by Ian Burrows (1995) from 28 February to 3 March 1995 as part of a multidisciplinary set of flora and fauna studies conducted on behalf of the WWF KICDP (Burrows 1995). Burrows surveyed birds along waterways and in forest environments, including swamp forest and hill forest on limestone karst, visually, audially and with the use of mist nets. The location of the WWF 'Veiru' Creek camp is not known. The results of the 1995 survey are combined with those of the present study.

Based on Burrows' results, a few months later Phil Gregory visited Uro Creek to view the New Guinea Flightless Rail *(Megacrex inepta*), an elusive inhabitant of lowland swamp forests and "one of the great New Guinea mystery birds" (Gregory 1996, p. 38).

Numerous additional surveys have been conducted in comparable lowland environments elsewhere within the lower Kikori basin (within 40 km of the Uro Creek catchment at elevations below 150 m asl)—in the Sirebi River catchment near Omo village (Burrows 1995) and at Wau Creek and the Sire River (Diamond and Bishop, Undated A; Woxvold, Chapter 1.5); at various sites along the lower Kikori River and its tributaries upstream from the deltaic zone (Utiti Creek, Pinini Creek, Iviri, Kopi and Kikori: Burrows 1995; Diamond and Bishop, Undated A, B; Jaensch and Watkins, Undated; Leary, Undated A, B; Leary and Seri, Undated); and in the Kikori delta (Diamond and Bishop, Undated A, B; Jaensch and Watkins, Undated). The results of these surveys provide context for a broader understanding of the Uro Creek bird community.

Methods

Birds were surveyed by IW at Uro Creek during 27 April–3 May 2017.

Birds were surveyed by boat (motorised tender) along all navigable sections of Uro Creek and the tributary A'oo Creek and parts of three other tributaries (Figure 1). Five sites were selected for land-based survey:

- Tipiowo—hill forest and sago swamp woodland on non-calcareous sediments. Located near the site of a former settlement (Karatiowa on the 1970s topographic mapsheet), surveyed habitats included secondary forest in a number of old garden areas.
- The A'oo cave area—swamp woodland/mangrove complex on tidally inundated karst alongside A'oo Creek.
- Eimu camp—a mosaic of cleared areas, hill forest and regenerating secondary forest on non-calcareous sedimentary hills and swamp woodland/mangrove.

- Veimake—swamp woodland/mangrove complex near the access creek, with interior hill forest on non-calcareous sediments, in complex with a subordinate freshwater swamp forest component in low lying areas. The site of a former village (occupied during the 1930s–1940s according to local informants) still regularly visited by local landowners, surveyed habitats included clearings and advanced secondary forest. Hill forest in the northeast had been logged approximately 10 years prior (in 2005–2006 according to local informants).

- Veimei camp—swamp woodland/mangrove complex near the access creek, with interior unlogged alluvial forest.

Accommodation on most nights was based on a boat moored at Babeio village at the mouth of Uro Creek, with land-based survey sites accessed daily by tender. One night was spent at Veimake on 1 May 2017.

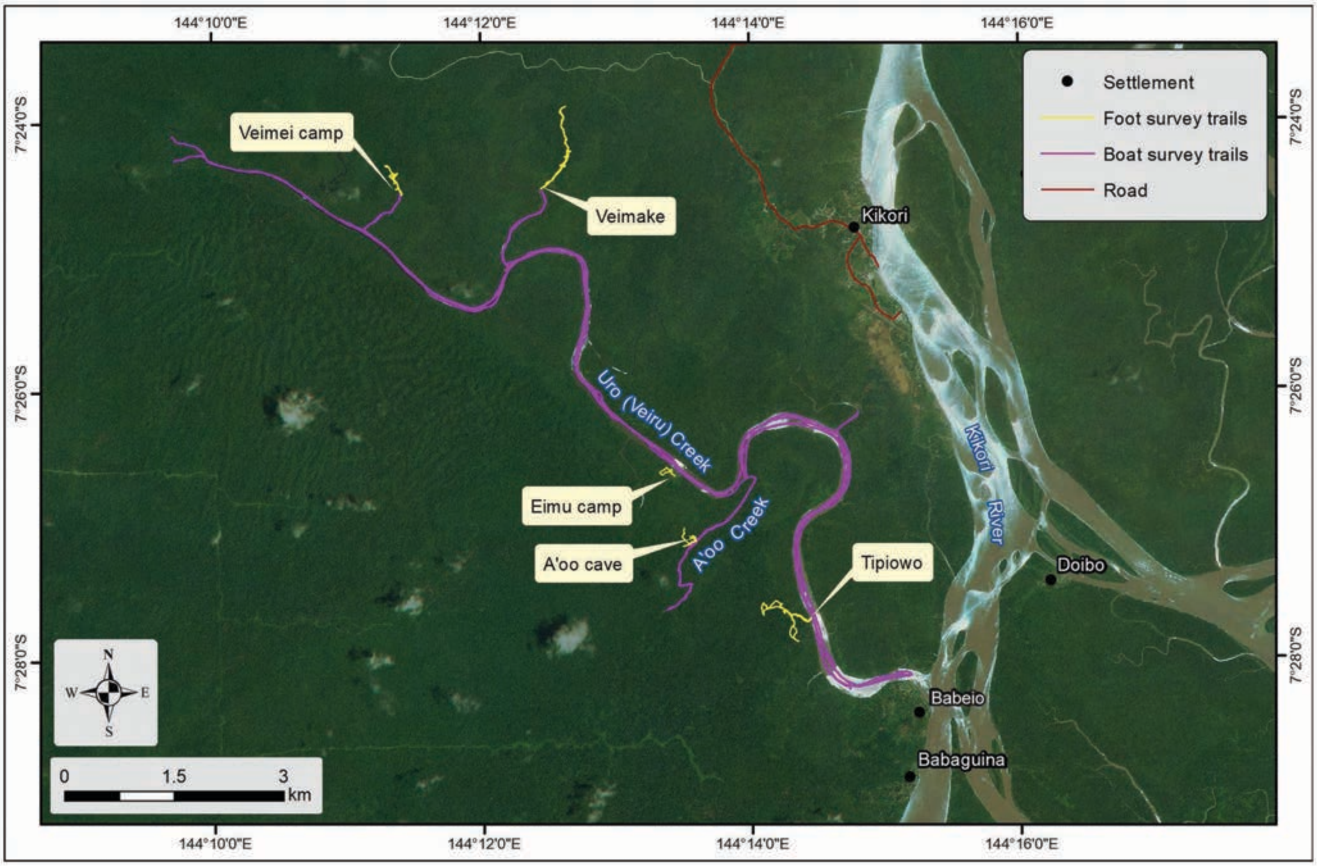

Figure 1. Bird survey coverage at Uro Creek.

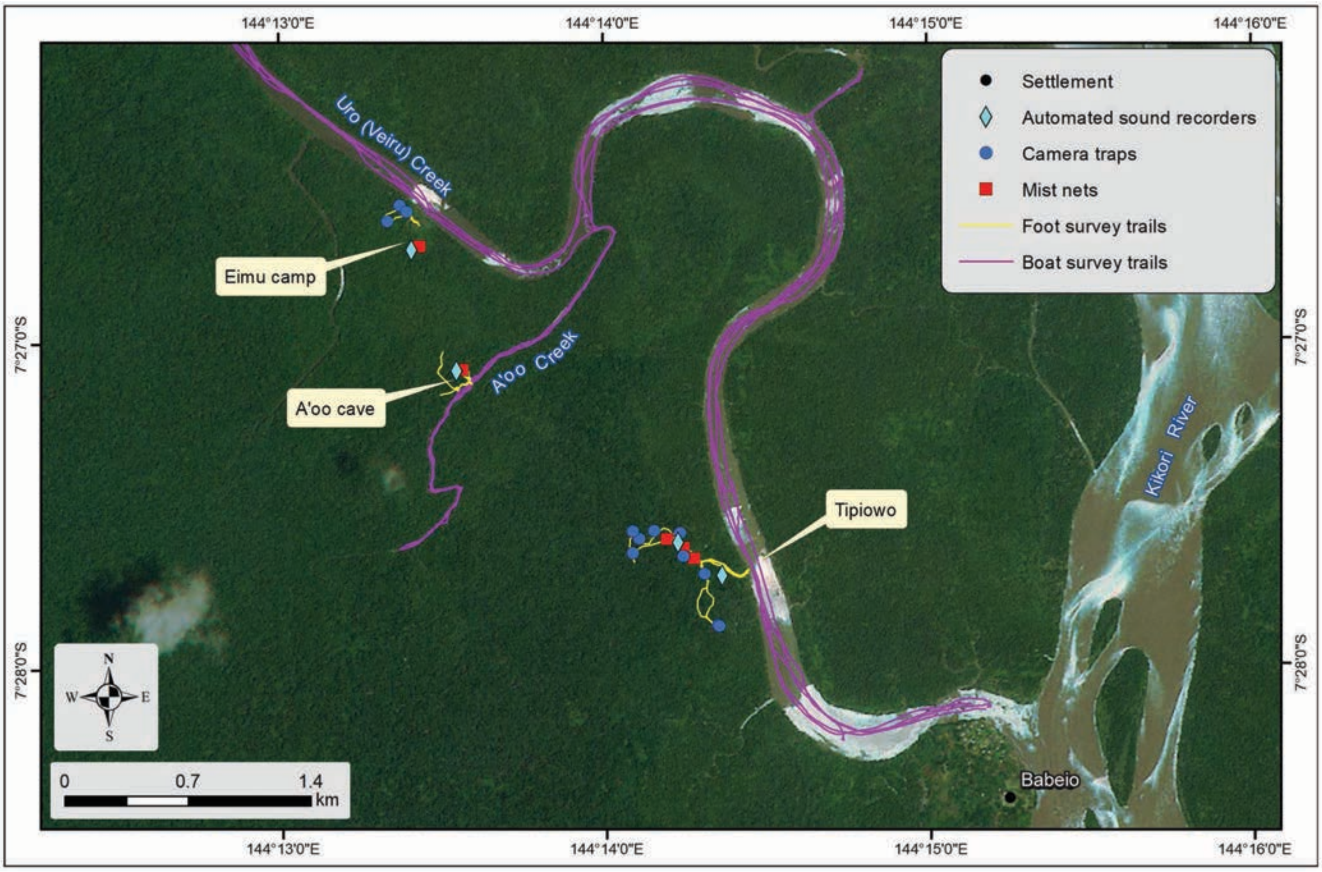

Figure 2. Detail of bird survey coverage, southeast Uro Creek catchment.

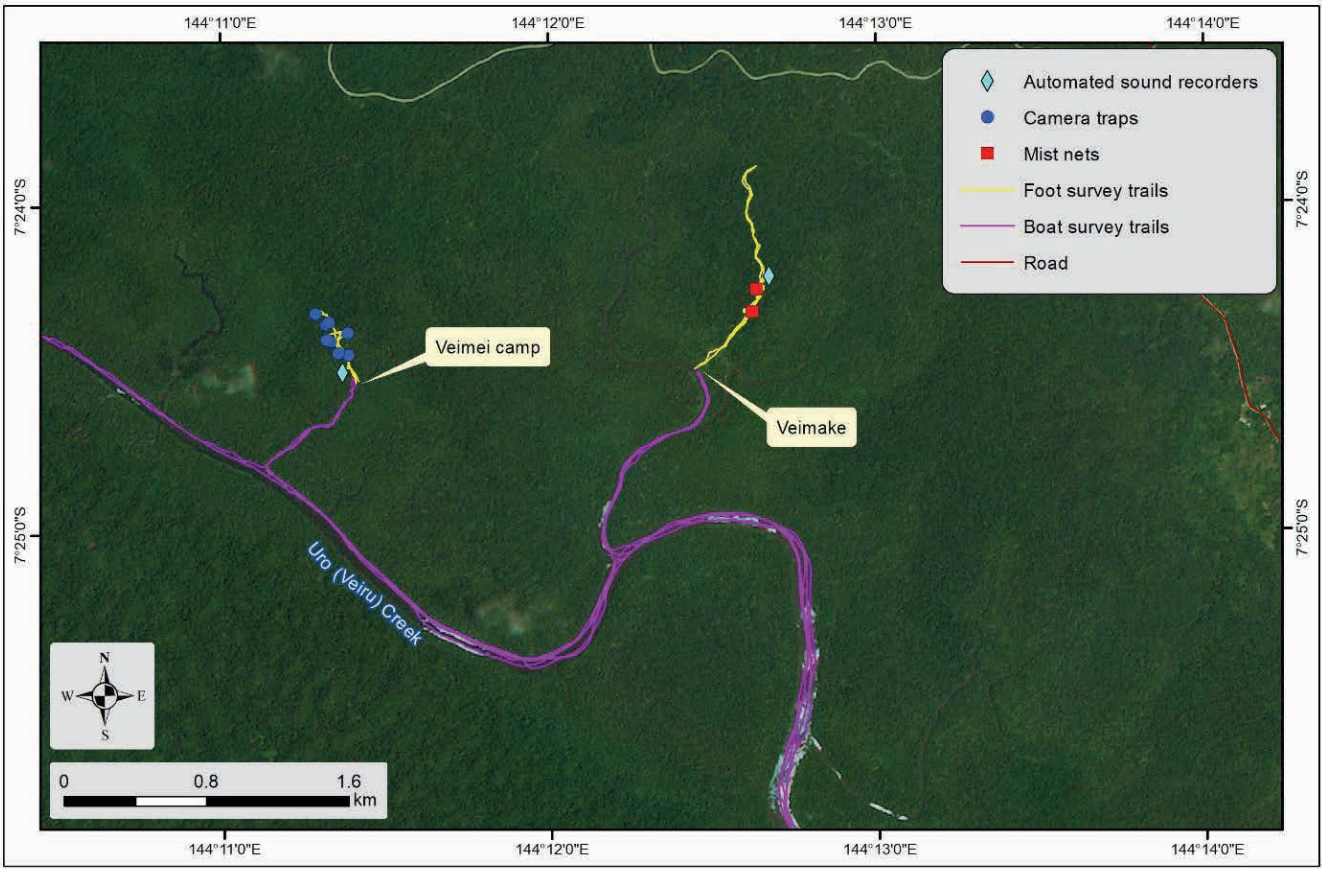

Figure 3. Detail of bird survey coverage, northwest Uro Creek catchment.

Survey methods included 'active' searches, camera trapping, mist netting and automated sound recording (Table 1). These techniques were combined to maximise completeness of the bird species inventory in the time available.

Table 1. Effort summaries.

Sampling method	Sampling effort
Active searches	
Boat survey hours	>14
Foot survey hours	19.50
Camera trapping	
No. camera traps	21.00
Camera trap hours	2,009.00
Mist netting	
No. mist nets	7
Diurnal net-hours	30.00
Automated sound recording	
No. recorders	6
Recording hours	372.00

Active searches

Active searches were conducted by boat (motorised tender) along all navigable sections of Uro Creek and the tributary A'oo Creek and parts of three other tributaries (Figure 1). Birds were surveyed on foot through forest, along watercourses and along pre-existing walking trails. Birds were surveyed at all times of day and identified visually and/or by their calls. Effort was weighted to early morning and late afternoon when access was possible at these times.

Camera trapping

Twenty-one white-flash digital camera traps (Reconyx HC550/PC850) were deployed unbaited along animal trails and at apparent feeding stations in an effort to photograph terrestrial birds and mammals. All camera traps were programmed to maximum detection sensitivity and to take three photographs on each 'trigger event' with the minimum amount of rest time between triggers (<2 seconds). Units were deployed for a total of more than 2,000 camera trap-hours (Table 1). Camera trap locations are shown in Figures 2–3.

Relative abundance indices (RAIs) were calculated from the rate of independent photographic capture 'events' (per hour x 100) summed across all cameras (Appendix 1). Events were considered independent where consecutive pictures of the same species were taken more than 30 minutes apart. Multiple events were scored within 30-minute periods where more than one individual was seen in a single photograph and/or where plumage differences permitted identification of separate individuals in successive photographs.

Mist netting

Seven mist nets (12 m, 31 mm mesh) were deployed by the bird and mammal survey teams in forest and clearings. All nets were erected close to the ground (<6 m high) on trimmed saplings, left in position for 1–2 days and checked regularly during daylight hours. Most mist netting was conducted at night to catch bats; diurnal effort was limited (30 net-hours) to allow time for other survey activities.

Captured birds were measured (bill, head, tarsus, wing), photographed and a small blood sample was collected (in 70% ethanol). All birds were released with the terminal end of three outer tail feathers clipped for identification on recapture.

Automated sound recorders

Three automated sound recorders (Wildlife Acoustics: Song Meter SM3) were deployed in six positions in forest environments by IW and herpetologist Stephen Richards (Figures 2–3). These recorded audible sounds, including bird calls, continuously throughout the sampling period (Table 1).

All Song Meter recordings were screened for the calls of notable species, including conservation listed species and birds not detected during active survey periods, using iZotope RX 5 Audio Editor software.

Conventions used

Taxonomy and nomenclature (common and scientific names) follow the International Ornithological Congress (IOC) World Bird List (version 8.1) (Gill and Donsker 2018). Where species are mentioned in the text the scientific name appears with the common name on first mention and only the common name is used thereafter.

Species appearing in square brackets (in text, tables and appendices) were only provisionally identified to species level. Though not definitively identified, encounters are considered most likely to have involved the species named.

Conservation listed species include those listed in the IUCN Red List of Threatened Species (IUCN 2017) as Threatened (Vulnerable—VU; no Endangered or Critically Endangered bird species were recorded), Near Threatened (NT) or Data Deficient (DD) and those listed as Protected (P) under the *PNG Fauna (Protection & Control) Act 1966*. The list of nationally protected species was obtained from Kula and George (1996). Restricted range (RR) species are those having a total global breeding range of less than 50,000 km^2 (Stattersfield et al. 1998).

A Garmin 60CSx GPS unit was used to record tracks and coordinates in the field.

Results

One hundred and twenty-six bird species from 41 families have been recorded within the Uro Creek catchment (Appendix 1), including 116 species during the 2017 surveys and 73 species in 1995 (Burrows 1995).

Twelve bird species were photographed by camera trap in 2017 (Appendix 1). Camera trap rates (RAIs) for photographed species are displayed in Figure 4. The Orange-footed Scrubfowl (*Megapodius reinwardt*) and Papuan Pitta (*Erythropitta macklotii*) were the most frequently camera trapped bird species; the number of photographic events for these taxa (20 and 14 respectively) was more than twice that of the next most frequently photographed bird – Southern Cassowary (*Casuarius casuarius*; six events).

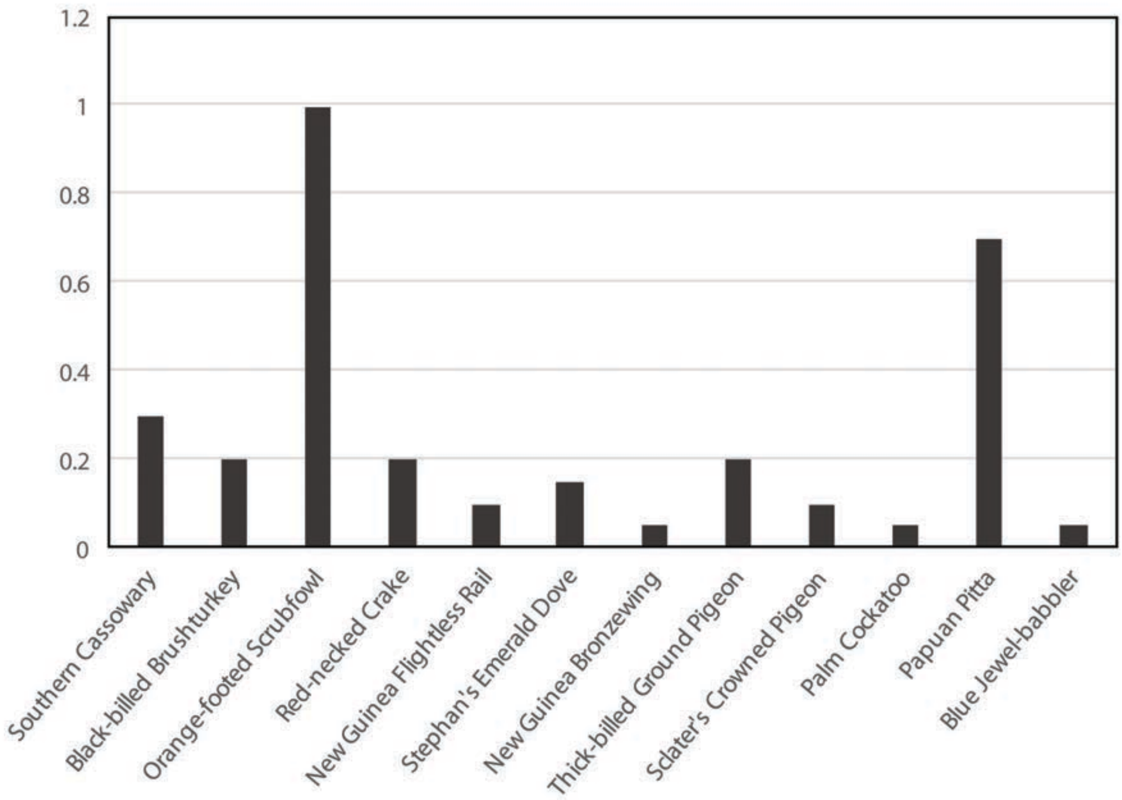

Figure 4. Camera trap rates (RAIs).

The Uro Creek avifauna includes 116 breeding resident species and 10 species that occur in the Kikori basin only or predominantly as non-breeding migrants (Appendix 1). Two breeding resident species – Pacific Koel (*Eudynamys orientalis*) and Oriental Dollarbird (*Eurystomus orientalis*) – have local populations seasonally augmented by non-breeding visitors from Australia.

Resident taxa include 113 species that occupy terrestrial environments and four potentially locally breeding wetland species—Spotted Whistling Duck (*Dendrocygna guttata*), Pacific Reef Heron (*Egretta sacra*; a coastal breeder), White-bellied Sea Eagle (*Haliaeetus leucogaster*) and Azure Kingfisher (*Ceyx azureus*). Recorded migrants include: six terrestrial species—Pacific Koel, Channel-billed Cuckoo (*Scythrops novaehollandiae*), Oriental Dollarbird, Forest Kingfisher (*Todirhamphus macleayii*), Sacred Kingfisher (*T. sanctus*) and [Satin Flycatcher (*Myiagra cyanoleuca*)]; and six wetland species—Great Egret (*Ardea alba*), Intermediate Egret (*A. intermedia*), Little Egret (*Egretta garzetta*), Australasian Darter (*Anhinga novaehollandiae*), Common Sandpiper (*Actitis hypoleucos*) and Little Tern (*Sternula albifrons*). Most migratory birds recorded at Uro Creek breed outside New Guinea in Australia (at least eight species) or in Asia (Common Sandpiper). Three of the migratory wetland species – Great Egret, Intermediate Egret and Australasian Darter – breed both in Australia and locally in New Guinea outside of the Kikori basin (predominantly Trans-Fly wetlands), so that the provenance of birds sighted at Uro Creek cannot be determined.

Twelve conservation listed species were recorded (Table 2). They include one bird listed by the IUCN as Vulnerable (Pesquet's Parrot (*Psittrichas fulgidus*)) and one as Near Threatened (Sclater's Crowned Pigeon (*Goura sclaterii*)) and 12 species that are Protected under Papua New Guinean law. No restricted-range bird species were recorded. Conservation listed species are discussed individually below (Species accounts).

Table 2. Conservation listed bird species recorded from Uro Creek.

Status indicates species listed as globally threatened (VU—Vulnerable) or Near Threatened (NT) by the IUCN and those listed as Protected (P) under the *PNG Fauna (Protection & Control) Act 1966*.

Scientific Name	English Name	Status	1995	2017
Ardea alba	Great Egret	P		X
Ardea intermedia	Intermediate Egret	P		X
Egretta garzetta	Little Egret	P		X
Goura sclaterii	Sclater's Crowned Pigeon	NT, P	[X]	X
Rhyticeros plicatus	Blyth's Hornbill	P	X	X
Probosciger aterrimus	Palm Cockatoo	P	X	X
Psittrichas fulgidus	Pesquet's Parrot	VU, P	X	X
Manucodia ater	Glossy-mantled Manucode	P	X	X
Phonygammus keraudrenii	Trumpet Manucode	P	X	X
Cicinnurus regius	King Bird-of-paradise	P	X	X
Seleucidis melanoleucus	Twelve-wired Bird-of-paradise	P	X	X
Paradisaea raggiana	Raggiana Bird-of-paradise	P		X

Species accounts

Species accounts follow for conservation listed taxa, rarely recorded species, species of significance to local communities, and wherever records extend a species' known geographical limits. Accounts for IUCN Threatened species include a summary of threats and susceptibilities. Unless otherwise stated, all dates refer to the 2017 surveys.

Southern Cassowary (*Casuarius casuarius*)

The Southern Cassowary (Plate 1A) occurs in southern New Guinea and Australia in lowland and foothill forest, normally below 300 m asl but occasionally higher (Coates 1985; Beehler and Pratt 2016). The world's largest avian frugivores, cassowaries play a critical role in forest ecosystem dynamics by dispersing the seeds of many rainforest plant species, including those with large fruits that lack alternative biological dispersal vectors (Mack 1995; Mack and Wright 2005; Westcott et al. 2008).

All cassowary species are hunted in New Guinea for their meat, plumes and other body parts, and captive chicks are reared by hand for food or trade (Coates 1985; Johnson et al. 2004; I. Woxvold, pers. obs.). Cassowaries are currently in high demand as bride price gifts in Papua New Guinean highland communities, providing opportunity for large financial rewards for some local hunters. Consequently, cassowaries are now rare or have been extirpated from the vicinity of many settled areas (e.g. Brodie and Pangau-Adam 2017). Until recently considered Vulnerable by the IUCN, the Southern Cassowary is now classified as Least Concern due largely to the presence in southern New Guinea of extensive areas of remote lowland forest where human population and hunting pressure are low.

In 2017 footprints and/or faeces were observed at Tipiowo and Veimei camp, and cassowaries were photographed on four camera traps (six events) at Tipiowo. Southern Cassowary was also recorded by Burrows in 1995. Camera trap records include pictures of adult and subadult birds, indicating local breeding activity.

Great Egret *(Ardea alba),* Intermediate Egret *(A. intermedia),* Little Egret *(Egretta garzetta)* (P)

Three nationally Protected egret species were recorded in small numbers along Uro Creek and its tributaries in 2017—the Great Egret (*Ardea alba*; three records), Intermediate Egret (*A. intermedia*; one record) and Little Egret (*Egretta garzetta*; six records). No egrets were recorded in 1995.

Each of these species occurs throughout New Guinea in a variety of wetland habitats, predominantly in the lowlands but occasionally up to montane elevations (Coates 1985). Their breeding status in New Guinea is poorly understood; some birds are present in all months, but each year there is a significant exchange of waterbirds between Australia and New Guinea with most birds occurring locally as non-breeding visitors (Coates 1985; Dingle 2004). Breeding at specific locations has been confirmed for the Great Egret (Aroa River, Trans-Fly) and Intermediate Egret (Trans-Fly) but not for the Little Egret (Bishop 2005; Beehler and Pratt 2016). There are no notable off-river waterbodies in the Uro Creek catchment, and these species are not expected to breed locally or to visit in large numbers.

New Guinea Flightless Rail (*Megacrex inepta*)

A large, flightless ground-bird endemic to the lowland swamp forests of central New Guinea. Shy and difficult to detect, its behavioural ecology, including breeding biology, is poorly known. They are often attracted to sago harvesting areas where they feed in the slurry (Gregory 1996). In many areas they are targeted by hunters as a source of food.

The New Guinea Flightless Rail is apparently widespread in suitable habitat within the Uro creek catchment. Recorded there previously in 1995 (Burrows 1995; Gregory 1996), in 2017 it was well known to local residents and said to be present in sago swamp woodland at Tipiowo, Eimu camp and Veimei camp. At Veimei camp single birds were camera trapped on two occasions near a sago tree recently felled for harvesting at the edge of sago swamp woodland (Plate 1E).

Sclater's Crowned Pigeon (*Goura sclaterii*) (NT, P)

The world's largest pigeons, Crowned Pigeons are terrestrial-foraging species endemic to the lowlands (below c. 500 m asl) of New Guinea. They occur in groups of up to 30 birds (usually less than seven) in closed-canopy evergreen forest, preferring areas of gentle alluvial terrain including seasonally flooded habitats (Coates 1985; Gibbs et al. 2001).

The distribution of *Goura* pigeons in the Gulf of Papua hinterland is poorly known. Sclater's Crowned Pigeon (*Goura sclaterii*) occurs from the Mimika River (Indonesia) east into Papua New Guinea at least as far as the Hegigio River catchment north of Mount Bosavi (I. Woxvold, unpublished data). To the east, there are prior confirmed records of Scheepmaker's Crowned Pigeon (*G. scheepmakeri*) west to at least as far as the Purari River (Beehler and Pratt 2016) and Era River catchments (I. Woxvold, unpublished data). Until the present surveys there was no available information on which species occupies the intervening expanse. Many direct encounters with crowned pigeons are fleeting and do not enable identification beyond genus level. All prior Kikori basin records, including Burrows' 1995 record from Uro Creek, refer to Southern Crowned Pigeon – within which both Sclater's Crowned Pigeon and Scheepmaker's Crowned Pigeon were formerly subsumed prior to a recent taxonomic split – with no information on which taxon (subspecies) was involved.

On 2 May 2017 a captive Sclater's Crowned Pigeon was presented to the survey team at Eimu camp (Plate 2A). The bird had apparently recently been snared in forest near Uro Creek a short distance upstream. On the same day two Sclater's Crowned Pigeons were camera trapped in alluvial forest at Veimei camp. Based on the 2017 results, the 1995 Uro Creek record is here provisionally referred to Sclater's Crowned Pigeon.

The 2017 results include the most easterly confirmed records of Sclater's Crowned Pigeon and the first from the Kikori basin. This may be close to the eastern limit of the species, given the occurrence of Scheepmaker's Crowned Pigeon along the Kikori River near Kikori Station and in the Sirebi River catchment at Wau Creek (see Chapter 1.5). More work is required to understand the precise geographic limits of these species and to determine whether any hybridisation and/or habitat segregation occurs in the potential zone of overlap.

Habitat loss, degradation and hunting present the major threats to crowned pigeons. All *Goura* species are susceptible to hunting, being easily captured and highly prized for their meat and plumes (Coates 1985; King and Nijboer 1994). Logging is cited as an additional threat to crowned pigeons (King and Nijboer 1994; BirdLife International 2017).

Long-billed Cuckoo (*Chrysococcyx megarhynchus*)

A rarely recorded cuckoo of lowland forest in New Guinea and a few satellite islands (Beehler and Pratt 2016). One was heard in hill forest at Veimake on 2 May 2017. Elsewhere locally, it has been recorded previously near Kopi camp, Gobe and Kantobo (Jaensch and Watkins, Undated; Diamond and Bishop, Undated B).

Papuan Hawk-Owl (*Uroglax dimorpha*)

The Papuan Hawk-Owl (*Uroglax dimorpha*) is endemic to New Guinea where it has been recorded throughout the mainland from the lowlands to 1,500 m asl, including in Gulf Province (Beehler and Pratt 2016). It occupies a wide range of habitats including rainforest, forest edge and gallery forest in savannah (Coates 1985; Pratt and Beehler 2015). Until recently considered Data Deficient by the IUCN, the Papuan Hawk-Owl is now classified as Least Concern due to a growing number of records from across New Guinea.

The song of the Papuan Hawk-Owl was recorded on a Song Meter unit deployed in forest on limestone near the A'oo cave, in hill forest at Tipiowo and in alluvial forest at Veimei camp.

Blyth's Hornbill (*Rhyticeros plicatus*) (P)

Occurs throughout New Guinea in a variety of forest types up to 1,500+ m asl, but is most common in the lowlands and hills (Coates 1985; Kemp 2001). As New Guinea's only hornbill species, and one of the region's largest and most mobile frugivores, Blyth's Hornbill (*Rhyticeros plicatus*) plays a critical role in forest ecosystem dynamics (Mack and Wright 2005; Kinnaird and O'Brien 2007).

Fairly common at Uro Creek, with up to three birds seen or heard on most days. Also recorded by Burrows in 1995. More widely, Blyth's Hornbill is fairly common in forest (excluding mangroves) throughout the lower Kikori basin up to at least 1,000 m asl (see Chapter 3.5). As a mobile and easily detected species, multiple records at the same site may involve repeat encounters with the same individuals; although widespread, at the local scale hornbills may be present in fairly low numbers.

Palm Cockatoo (*Probisciger aterrimus*) (P)

A large and conspicuous species occurring throughout the New Guinea lowlands and hills (to 1,300 m asl) in rainforest, secondary forest and tropical savannah where birds feed on a variety of seeds and fruit.

Fairly common at Uro Creek, with up to four birds seen or heard daily in 2017. Also recorded by Burrows in 1995. More widely, Palm Cockatoos are uncommon but widespread in forest (including mangroves) throughout the lower Kikori basin up to at least 1,400 m asl (I. Woxvold, unpublished data). As a mobile and easily detected species, multiple records at the same site may involve repeat encounters with the same individuals.

Pesquet's Parrot (*Psittrichas fulgidus*) (VU, P)

This unusual, large black-and-red parrot is a nomadic and specialist frugivore that feeds on a select variety of figs (Mack and Wright 1998). It is endemic to New Guinea where it inhabits hill and lower montane forest up to 1,200 m asl (occasionally to 2,000 m) (Coates 1985).

Pesquet's Parrot has been listed as one of Papua New Guinea's rarest birds (Beehler 1993), but recent surveys indicate that the species remains secure in large areas of suitable habitat in central and western mainland Papua New Guinea, much of which occurs in rugged terrain in areas with a low human population density (I. Woxvold, unpublished data).

At Uro Creek in 2017 one was recorded at Tipiowo on 28 April (Plate 2D), two were seen along A'oo Creek on 1 May, it was heard in hill forest at Veimake on 2 May and it was recorded on a Song Meter unit deployed at Veimei camp. It was also recorded by Burrows in 1995. It is a mobile and easily detected species and multiple records at the same site may involve repeat encounters with the same individuals. As a nomadic frugivore, numbers present in any one area are likely to change with seasonal patterns in food availability.

Hunting presents the major threat to Pesquet's Parrot. In some areas it is hunted for its plumes which are used for traditional ceremonial and trade purposes. As a result of hunting pressure it is now rare or extirpated from the vicinity of many settled areas (Coates 1985; Kocher Schmid 1993; Mack and Wright 1998; Igag 2002). Other threats include habitat loss and loss of food trees (*Ficus* spp.) and nest trees. It has been observed in logged forest (I. Woxvold, unpublished data; this study), though the birds may rely on more mature forest for nest sites.

Yellow-capped Pygmy Parrot (*Micropsitta keiensis*)
Two Yellow-capped Pygmy Parrots (*Micropsitta keiensis*) were seen along A'oo Creek on 28 April. Other encounters in 2017 were not identifiable beyond genus and are provisionally ascribed to this species.

The distribution of pygmy parrots (*Micropsitta*) in southern New Guinea is poorly known. Of two similar-looking lowland species, the Yellow-capped Pygmy Parrot (*M. keiensis*) occurs in the west and the Buff-faced Pygmy Parrot (*M. pusio*) in the east, with a potential zone of contact/overlap somewhere in the Gulf of Papua hinterland. Recent field guides and regional checklists report both species in the Kikori basin (Pratt and Beehler 2015; Beehler and Pratt 2016; Gregory 2017), though it is unclear on what records these assessments are based (Beehler and Pratt (2016) cite Schodde and Hitchcock (1968) as the source for a Lake Kutubu record of Buff-faced Pygmy Parrot, though no such record appears in that report).

The Kikori–Purari region may represent a zone of overlap within which these two species separate altitudinally. Both the Buff-faced Pygmy Parrot and Yellow-capped Pygmy Parrot are confidently reported from the Lake Kutubu WMA (Woxvold, Chapter 3.5), while all confirmable records from the lower Kikori basin (all below 200 m asl) involve Yellow-capped Pygmy Parrot—at Uro Creek, Iviri and Keboi Kerowa (Leary, Undated A) and within the Wau Creek proposed WMA (see Chapter 1.5). In the Purari basin, Buff-faced Pygmy Parrot was reported from uplands in the Crater Mountain WMA (above 850 m asl; Mack and Wright 1996), while Yellow-capped Pygmy Parrot is the only species confirmed present at lower elevations (all records below 250 m asl; Woxvold, unpublished data). Further observations are required to confirm this pattern.

Glossy-mantled Manucode (*Manucodia ater*) (P)
All birds-of-paradise (Paradisaeidae) are Protected under Papua New Guinean law.

The manucodes are a group of glossy black, rather crow-like birds-of-paradise. Unlike most birds-of-paradise, they form monogamous pairs and are sexually monomorphic. The Glossy-mantled Manucode (*Manucodia ater*) is endemic to New Guinea and nearby satellite islands where it inhabits a variety of forest habitats in the lowlands and foothills, locally up to c. 900 m asl (Coates 1990; Frith and Beehler 1998). It is the most common manucode in open and disturbed habitats.

At Uro Creek in 2017, singles were heard at A'oo Creek, Eimu camp, Veimake and Veimei camp. It was also recorded by Burrows in 1995.

Trumpet Manucode (*Phonygammus keraudrenii*) (P)
The Trumpet Manucode (*Phonygammus keraudrenii*) occurs in forest from the lowlands to 2,000 m asl where it feeds mainly on figs (Coates 1990; Frith and Beehler 1998). This species was uncommon at Uro Creek where it was heard only at Veimake. It was also recorded by Burrows in 1995.

King Bird-of-paradise (*Cicinnurus regius*) (P)
A common resident of lowland and foothill forests (to c. 300 m asl, less common higher), including swamp forest, of New Guinea and nearby islands.

This species was fairly common at Uro Creek with one or two birds heard on most days at A'oo Creek, Tipiowo and Veimei camp. It was also recorded by Burrows in 1995.

Twelve-wired Bird-of-paradise (*Seleucidis melanoleucus*) (P)
Endemic to New Guinea and Salawati Island where it inhabits lowland forest, especially swamp forest with sago (*Metroxylon sagu*), mostly near sea level but in places up to 180 m asl (Coates 1990; Frith and Beehler 1998).

Twelve-wired Bird-of-paradise was fairly common in suitable habitat at Uro Creek—hen-plumed birds were seen at A'oo Creek on 28 April and 2 May, and two birds were heard at Veimake during 1–2 May. It was also recorded by Burrows in 1995.

Raggiana Bird-of-paradise (*Paradisaea raggiana*) (P)
Endemic to southern and northeast Papua New Guinea where it inhabits primary and disturbed lowland, hill and lower montane forest to c.1,800 m asl. Males of the genus *Paradisaea* engage in elaborate and conspicuous group displays with up to 10 birds performing at a 'lek', usually in the upper portion or top branches of a canopy tree (Coates 1990; Frith and Beehler 1998).

Raggiana Bird-of-paradise was uncommon at Uro Creek, with one heard only at Veimake. It was not recorded by Burrows in 1995.

Biodiversity and conservation values

Survey completeness and possible additional species
The total of 126 species compares favourably with the results of surveys conducted at comparable elevations elsewhere in southern mainland Papua New Guinea, and available data are sufficient to conclude that the Uro Creek area supports a rich community of resident and migratory birds that includes multiple species of conservation significance.

After repeated surveys of lowland bird communities in the Lakekamu basin, Beehler and colleagues (Beehler et al. 1995; Beehler and Mack 1999) concluded that at least two months of cross-seasonal survey time is required to comprehensively census a lowland forest bird community in Papua New Guinea. While the total of 11 days (including partial days) spent by all surveyors in the Uro Creek catchment falls well short of this benchmark, coverage of the broader lower Kikori basin – a much closer analogue to the 1,700 km^2 Lakekamu study area than the Uro Creek site – is well in excess of that proposed by Beehler.

There is a strong similarity among the bird community at Uro Creek and those recorded at other sites in the lower Kikori basin (see Existing data). Of those species recorded to date at Uro Creek, all but three are known from other lower Kikori basin sites:

- Sclater's Crowned Pigeon—in most cases the identity of crowned pigeons previously reported from the Kikori basin is uncertain, and while Scheepmaker's Crowned Pigeon is certainly present near Kikori and at Wau Creek (see Chapter 1.5), available data are too few to draw conclusions about the broader distribution of either taxon within the basin.

- Meyer's Friarbird (*Philemon meyeri*)—an uncommon but vocal species of lowland and hill forest, previously unreported from below 250 m asl in the Kikori basin but recorded further north at Gobe, Kantobo and the Moro area (Burrows 1995; Diamond and Bishop, Undated B; Woxvold, Chapter3.5).

- Torresian Crow (*Corvus orru*)—a fairly common bird of coasts, settlements and open lowland areas; its absence from other lower Kikori inventories is unexpected.

Given the occurrence of most species more broadly across the lower Kikori basin, a list of most birds not yet recorded but that may occur at Uro Creek can be gleaned from the results of surveys conducted at other lower Kikori sites. Excluding predominantly coastal species expected to occur only at (or rarely away from) the delta shorefront and hill-zone species not likely below c. 400 m asl (data from Coates 1985, 1990; Bishop 2006; Beehler and Pratt 2016), some 88 potential additional species have been recorded elsewhere in the lower Kikori basin. They are listed in Appendix 2 along with their conservation status, residency/migratory status and broad habitat preference (terrestrial/freshwater environments). They include 60 species that occupy terrestrial habitats (forest and/or open environments and including aerial foraging species) and 30 wetland species, including birds of both freshwater and marine tidal environments (two species frequent both terrestrial and wetland habitats—Pacific Golden Plover (*Pluvialis fulva*) and [Swinhoe's] Snipe (*Gallinago [megala]*)).

Additional locally recorded terrestrial species include 50 breeding residents and ten non-breeding migrants (Appendix 2). Most migrants to terrestrial habitats breed in Australia—Black-faced Cuckooshrike (*Coracina novaehollandiae*), Australian Pratincole (*Stiltia isabella*), Rainbow Bee-eater (*Merops ornatus*), Nankeen Kestrel (*Falco cenchroides*), Australian Hobby (*F. longipennis*) and Tree Martin (*Petrochelidon nigricans*). The Pacific Golden Plover (*Pluvialis fulva*), [Swinhoe's] Snipe (*Gallinago [megala]*), Oriental Cuckoo (*Cuculus optatus*), and White-throated Needletail (*Hirundapus caudacutus*) breed in Asia.

Additional locally recorded wetland birds include seven breeding resident species – Wandering Whistling Duck (*Dendrocygna arcuata*), Forest Bittern (*Zonerodius heliosylus*), Black Bittern (*Dupetor flavicollis*), Striated Heron (*Butorides striata*), Great-billed Heron (*Ardea sumatrana*), Little Ringed Plover (*Charadrius dubius*) and Torrent Flyrobin (*Monachella muelleriana*) – and 23 non-breeding migrants (Appendix 2). The list of migratory wetland birds includes 13 shorebird species (Charadriidae, Scolopacidae) and two terns – Common Tern (*Sternaa hirundo*) and White-winged Tern (*Chlidonias leucopterus*) – that breed in the northern hemisphere, and eight species that breed in Australia, five of which also breed in New Guinea outside of the Kikori delta.

Appendix 2 includes ten conservation listed species recorded locally within the lower Kikori delta.

Forest Bittern (NT)—A rare heron endemic to New Guinea in forest swamps, streams and pools from the lowlands to 1,430 m asl. Recorded previously at Kopi (Diamond and Bishop, Undated B).

Papuan Eagle (*Harpyopsis novaeguineae*) (VU, P)—New Guinea's largest raptor; inhabits forested environments from sea level to over 3,000 m asl. Visually inconspicuous (it does not soar), it is most readily detected by its distinctive and far-carrying call. Recorded previously at Kopi and the Wau Creek area (Diamond and Bishop, Undated A, B).

Far Eastern Curlew (*Numenius madagascariensis*) (EN), Black-tailed Godwit (*Limosa limosa*) (NT), Grey-tailed Tattler (*Tringa brevipes*) (NT), Red-necked Stint (*Calidris ruficollis*) (NT), Curlew Sandpiper (*C. ferruginea*) (NT)—Five migratory shorebird species breeding in the northern hemisphere and seasonally present in New Guinea throughout the austral winter or *en route* to wintering grounds in Australia. They are most likely to be found in tidal flats, lagoons and estuaries in coastal areas, but also occur on the margins of tidal rivers and may occasionally occur in suitable habitat within the Uro Creek catchment. Recorded previously in the Kikori delta (Diamond and Bishop, Undated B; Jaensch and Watkins, Undated).

Blue-black Kingfisher (*Todiramphus nigrocyaneus*) (DD)—A rare and poorly known New Guinea endemic occupying lowland forest to c. 600 m asl, including mangroves, swamp and alluvial forest. The distinctive subspecies occupying southern mainland Papua New Guinea, *Todiramphus nigrocyaneus stictolaemus*, is known from a handful of records from the Trans-Fly (Western Province) east to near Port Moresby. Recorded previously in the Kikori delta (Diamond and Bishop, Undated B).

Magnificent Riflebird (*Ptiloris magnificus*) (P)—A bird-of-paradise (Paradisaeidae) of lowland and hill forests across most of New Guinea and on Cape York Peninsula (Australia). In southern New Guinea it occurs as far east as the Purari basin. Recorded previously at Kopi and the Wau Creek area (Burrows 1995; Diamond and Bishop, Undated A, B).

Yellow-eyed Starling (*Aplonis mystacea*) (NT)—A communally breeding species endemic to the south New Guinea lowlands from the Bird's Neck in Papua Province, Indonesia, east to Gulf Province in Papua New Guinea. Its preferred habitat is alluvial forest, including flood disturbed riparian zones. Recorded previously in the Kopi-Kikori area and at Pinini Creek (Burrows 1995; Diamond and Bishop, Undated B).

In addition to those species recorded previously nearby, the Uro Creek catchment includes habitat suitable for a number of additional uncommon species that are yet to be recorded in the lower Kikori basin. They include the following IUCN listed species:

- Gurney's Eagle (*Aquila gurneyi*) (IUCN Near Threatened)—A very large bird of prey (wingspan to 1.85 m) present throughout New Guinea where it is widespread though sparsely distributed in all forest habitats, mostly in the lowlands and hills. It is known from further upstream in the Kikori basin in the Lake Kutubu area (Woxvold, Chapter 3.5).

- Doria's Goshawk (*Megatriorchis doriae*) (IUCN Near Threatened)—A rarely encountered bird of prey endemic to lowland and hill forest throughout New Guinea, from sea level to at least 1,650 m asl. Not yet reported from the Kikori basin.

- Starry Owlet-Nightjar (*Aegotheles tatei*) (IUCN Data Deficient)—A poorly known night-bird endemic to the southern New Guinea lowlands from the Indonesia–Papua New Guinea border east to near Port Moresby. It was recently recorded for the first time in Gulf Province in the lower Purari River catchment (I. Woxvold, unpublished data).

- Three-toed Swiftlet (*Aerodramus papuensis*)—Very difficult to distinguish in the field from three other all-dark New Guinea swiftlets. Endemic to New Guinea where it has been recorded with certainty from only four localities between sea level and 2,400 m asl. Suitable roosting and breeding caves potentially occur locally in limestone areas, from which birds may forage more widely.

Conservation value of forest environments

Forest habitats support the majority of bird species residing or regularly occurring at Uro Creek—of the 126 bird species recorded, 116 (92.1%) occur in forest environments, and most of these are forest-dependent (cannot persist in converted habitats alone). All resident IUCN listed and nationally Protected species (except egrets) documented at Uro Creek are dependent on forest habitats.

The Uro Creek catchment supports a wide range of forest environments, including hill forest on limestone and non-calcareous sediments, alluvial forest, and a variety of swamp forest types including both freshwater (mixed swamp forest, sago/pandanus swamp woodland) and marine tidally influenced (mangrove) formations. While many forest birds are capable of utilising all of these environments, a number of species strongly prefer, or are specialist inhabitants of, just one or a few of these vegetation types. For example: Pesquet's Parrot, Rusty Mouse-warbler (*Crateroscelis murina*), Pale-billed Scrubwren (*Sericornis spiloderis*) and Fairy Gerygone (*Gerygone palpebrosa*) all prefer hill forest; New Guinea Flightless Rail, [Large-billed] Gerygone (*Gerygone [magnirostris]*), Black Thicket Fantail (*Rhipidura maculipectus*), Shining Flycatcher (*Myiagra alecto*) and Twelve-wired Bird-of-paradise are specialist inhabitants of flood-prone riparian and/or swamp forest environments; and Southern Cassowary and Sclater's Crowned Pigeon occur at highest densities in undisturbed alluvial forest. In addition, the forest-covered cave systems in the limestone foothills, such as the A'oo cave observed along A'oo Creek, provide roosting and nesting habitat for a variety of swiftlet species. The Uro Creek catchment thus contains a well-integrated complex of multiple forest ecosystems, each of which supports a somewhat distinctive bird community. Overall, the forest bird community of the Uro Creek catchment is therefore both more species rich and displays a higher level of beta diversity (a measure of the difference in species composition between sites) than communities present in comparably sized forest landscapes that include fewer terrain and substrate features.

Unfortunately, logging has impacted much of the non-swamp forest area within the Uro Creek catchment. The catchment is located at the eastern edge of the Turama Block 1 logging concession (Figure 5). Covering approximately 3,358 km^2, approximately one quarter (889 km^2; 26.5%) of Turama Block 1 had been logged by 2015, including nearly one third of the Uro Creek catchment (35.5/111.7 km^2; 31.8%) in the outer west, north and south (Figure 5). Among the sites visited in 2017, logged forest was surveyed in areas north of Veimake (logged in 2005–2006 according to local informants). The forest here was variable in structure, with some sites heavily impacted and others still supporting many large trees with a multi-layered understorey characteristic of mature forest.

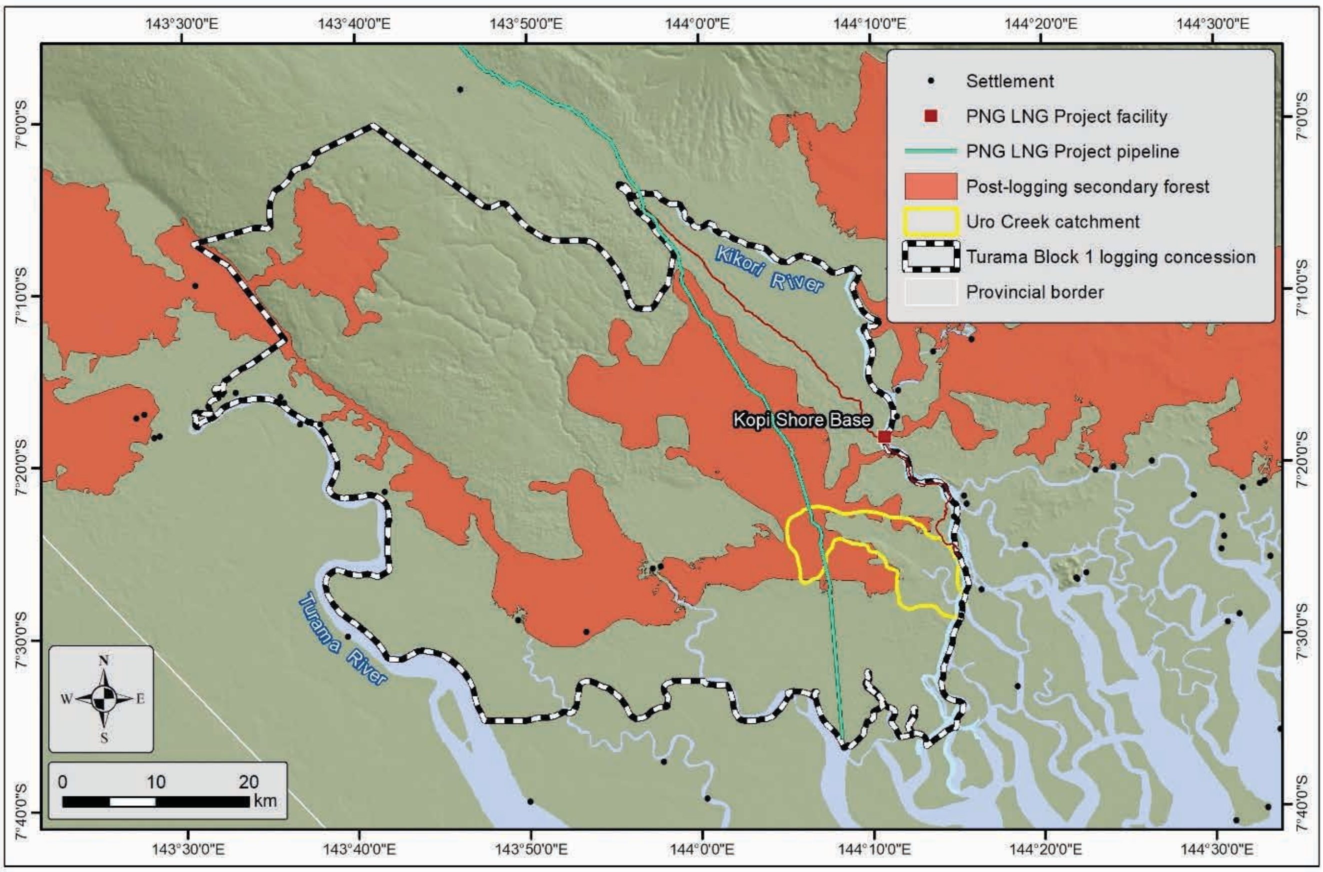

Figure 5. Post-logging secondary forest in western Gulf Province and the Turama Block 1 logging concession. (Reproduced from the PNG Forest Observatory, http://forest.pngsdf.com/).

The influence of logging on forest bird communities in New Guinea has been little studied (reviewed in Munks and Watling 2013). In general, results indicate that bird species richness and abundance is lower in logged secondary forest than in unlogged forest (Driscoll 1984, summarised in Lamb 1990; Marsden and Symes 2008; Tvardikova 2010; Dawson et al. 2011). However, studies have also variously found that: (1) species assemblages change with time as the forest regenerates; (2) species richness is highest in sites with intermediate disturbance; (3) species richness is higher in disturbed sites that are near primary forest habitats, and; (4) at the patch-scale, interior forest specialists (including a variety of understorey insectivores sensitive to change forest structure) often persist within the logged forest matrix in remnant areas of primary (or little disturbed) forest (Marsden and Symes 2008; Munks and Watling 2013; Woxvold, Chapter 1.5).

Though less widespread than logging, the conversion of forest by local landowners into settlements and gardens has a much higher impact on resident forest birds, effectively removing their required habitat at the local scale. Secondary forest in regenerating former garden sites and in natural forest degraded by local resource extraction supports altered forest bird communities, the structure of which depends on the age of regeneration and degree of disturbance.

Extensive areas of undisturbed forest, representing all mapped Papua New Guinea Forest Inventory Mapping System (FIMS) vegetation types, persist both within the Uro Creek catchment and in surrounding areas.

In relation to avifauna the Uro Creek forests present a number of conservation opportunities:

- They support a diverse bird community that includes a variety of conservation listed, rare and poorly known species. Notably, they support populations of one IUCN Vulnerable and one Near Threatened forest bird species.

- The Uro Creek catchment supports an ecologically diverse and well-integrated forest ecosystem-complex that is well connected with additional adjacent forest ecosystems (e.g. mangroves). It thus provides habitat supporting a variety of wide-ranging landscape-level nomadic bird species, including various large frugivores and birds of prey.

- Undisturbed forests within the Uro Creek catchment support numerous bird species that are sensitive to forest disturbance and that have been impacted by logging activities widespread in other sectors of the Kikori-Purari biogeographic region. In particular, remnant areas of mature alluvial forest on well drained gentle terrain, such as that observed near Veimei camp, are a favoured source of timber for the logging industry and support the highest densities of multiple terrestrial forest bird species (Woxvold, unpublished data), including Southern Cassowary and crowned pigeons.

- If the Uro Creek catchment forests are protected from further logging through establishment of a protected area, areas of regenerating logged forest will provide future opportunity for population growth of, or recolonization by, a variety of primary forest specialist bird species.

- Future logging is expected to impact some remaining areas of primary forest in Gulf Province. Since 2002, Gulf Province has endured the highest rate of logging-related forest loss of any mainland Papua New Guinean province (10.9% of commercially accessible forest: Bryan and Shearman 2015). The logging is ongoing and continues apace in multiple concessions within the Kikori-Purari biogeographic district. With protection of the Uro Creek forest, the expansion of logging activities elsewhere in Gulf Province will enhance the future conservation value of the Uro Creek environment.

- Formal protection of forests within the catchment would provide an excellent opportunity for research into the behavioural ecology of a suite of rare and poorly known New Guinean endemic bird species, and on the effects of logging and forest regeneration on individual bird species and avian community structure.

Conservation value of watercourses and riparian habitats

Watercourses and adjacent riparian vegetation within the Uro Creek catchment provide habitat for a number of wetland/riparian specialist bird species. Resident breeding taxa confirmed present include Spotted Whistling Duck, Pacific Reef Heron, White-bellied Sea Eagle, Azure Kingfisher, Little Kingfisher (*Ceyx pusillus*) and Shining Flycatcher. Six migratory waterbird species have also been recorded—Great Egret, Intermediate Egret, Little Egret, Australasian Darter, Common Sandpiper and Little Tern.

Given the position of Uro Creek at the interface of the foothill and deltaic zones amid a much more expansive system of riverine wetlands and estuaries, numerous additional waterbirds may be expected to occur there. Thirty wetland species are among the possible additional birds recorded elsewhere in the lower Kikori basin (Appendix 2), including 13 migratory shorebirds that breed in the northern hemisphere (another eight migratory shorebirds have been recorded in the Kikori delta but are not included in Appendix 2 due to their stronger preference for coastal environments). The conservation of migratory shorebirds is of increasing international concern due to ongoing population declines along the East Asian–Australasian Flyway (Gosbell and Clemens 2006; Wilson et al. 2011; Aharon-Rotman 2015; Szabo et al. 2016), and five of those species listed in Appendix 2 are listed by the IUCN as Threatened or Near Threatened with extinction. Migratory shorebirds congregate in greatest numbers in the extensive coastal environments (tidal flats, lagoons and estuaries) of the Kikori delta. Based on the number of Greater Sand Plover (*Charadrius leschenaultia*), Terek Sandpiper (*Xenus cinereus*) and Far Eastern Curlew (*Numenius madagascariensis*) recorded on prior surveys of the delta shorefront (Jaensch and Watkins, Undated), the Kikori delta is recognised as an internationally important wetland site under Criterion 6 of the RAMSAR Convention (Bamford et al. 2008).

While numerous wetland species are expected to visit the Uro Creek catchment, its river systems do not contain extensive areas of tidal mudflats that are required to support large numbers of migratory shorebirds, or significant off-river waterbodies that elsewhere support notable congregations of other non-breeding migrants or nesting colonies of resident species. As such, wetland birds occurring along Uro Creek and its tributaries are expected mostly to comprise small numbers of non-breeding migrants with scattered local breeding occurrences of solitary nesting species such as Forest Bittern, Black Bittern and Striated Heron. Given the extensive network of watercourses and estuaries nearby, watercourses within the proposed WMA are considered to be of local importance to resident and migratory waterbirds.

Recommendations

In terms of avifauna, the Uro Creek catchment is set in one of the world's most biologically diverse and endemically rich terrestrial regions (Olson and Dinerstein 1998; Brooks et al. 2006) and nearly one third of all bird species residing or regularly occurring in the New Guinea region (including satellite islands: 214/677; 31.6%) have to date been recorded there or may occur based on data from surveys conducted in comparable habitats elsewhere in the lower Kikori basin. It supports resident populations of a suite of conservation listed species, including two globally Threatened or Near Threatened bird species (Sclater's Crowned Pigeon and Pesquet's Parrot) and numerous additional nationally Protected and New Guinean endemic species.

Importantly, the demonstrated intent of local landowners to conserve the Uro Creek environment underpins all of the above-listed conservation opportunities (see Conservation value of forest environments). The following actions are recommended to enhance the scientific and conservation value of the Uro Creek catchment bird community:

- Formal protection of forests within as much of the Uro Creek catchment as possible, and parts of adjacent catchments where feasible. An effort should be made to incorporate (1) all remaining areas of unlogged forest present within the catchment and (2) significant/representative tracts of all forest ecosystem types present within the catchment, including all FIMS types and the major substrate variants on which they occur (e.g. hill forest on limestone and non-calcareous sediments).

- Protect forest within the proposed protected area from future logging.

- Support research into bird species and communities within any proposed proected area and surrounding areas.

- Establish hunting free zones in a variety of forest types and wetland areas within the potential proected area. As far as possible, keep dogs out of hunting free zones.

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Plate 1

A. Juvenile Southern Cassowary (*Casuarius casuarius*) at Tipiowo

B. Black-billed Brushturkey (*Talegalla fuscirostris*) at Veimei camp

C. Orange-footed Scrubfowl (*Megapodius reinwardt*) at Tipiowo

D. Red-necked Crake (*Rallina tricolor*) at Veimei camp

E. New Guinea Flightless Rail (*Megacrex inepta*) at Veimei camp

F. Stephan's Emerald Dove (*Chalcophaps stephani*) at Tipiowo

Plate 2

A. New Guinea Bronzewing (*Henicophaps albifrons*) at Tipiowo

B. Thick-billed Ground Pigeon (*Trugon terrestris*) at Tipiowo

C. Sclater's Crowned Pigeon (*Goura sclaterii*) at Eimu camp

D. Pesquet's Parrot (*Psittrichas fulgidus*) at Tipiowo

E. Papuan Pitta (*Erythropitta macklotii*) at Eimu camp

F. Yellow-bellied Longbill (*Toxorhamphus novaeguineae*)

Appendix 1Birds recorded in the Uro Creek catchment by Burrows in 1995 and IW in 2017.

Conservation status is shown for those species listed by the IUCN as Vulnerable (VU) or Near Threatened (NT) and species Protected (P) by law under the *PNG Fauna (Protection & Control) Act 1966*. Camera trap results are shown as Relative Abundance Index for all photographed species (ctRAI). Residency/migratory (Res/Mig) status indicates: BR—breeding resident species; M—species that occur in New Guinea only as non-breeding migrants; BR/M—breeding residents with populations seasonally augmented by non-breeding visitors, and with widespread local breeding range potentially overlapping the study area; M(BR)—breeding residents augmented by non-breeding visitors, but known breeding sites are localised and outside of the Kikori Basin; t—birds of terrestrial environments, including forest, open areas and aerial foraging species; w—birds of wetlands, including lakes, rivers and streams; data from Coates (1985, 1990) and Beehler and Pratt (2016). The number of individuals captured by mist net or hand is shown in brackets after the English Name.

Scientific Name	English Name	Status	1995	2017	ctRAI	Res/Mig
CASUARIIDAE						
Casuarius casuarius	Southern Cassowary		X	X	0.2987	BRt
ANATIDAE						
Dendrocygna guttata	Spotted Whistling Duck		X			BRw
MEGAPODIIDAE						
Talegalla fuscirostris	Black-billed Brushturkey		X	X	0.1991	BRt
Megapodius reinwardt	Orange-footed Scrubfowl		X	X	0.9955	BRt
ARDEIDAE						
Ardea alba	Great Egret	P		X		M(BR)w
Ardea intermedia	Intermediate Egret	P		X		M(BR)w
Egretta garzetta	Little Egret	P		X		Mw
Egretta sacra	Pacific Reef Heron		X			BRw
ANHINGIDAE						
Anhinga novaehollandiae	Australasian Darter		X			M(BR)w
ACCIPTRIDAE						
Henicopernis longicauda	Long-tailed Honey Buzzard			X		BRt
Accipiter hiogaster	Variable Goshawk			X		BRt
Haliastur sphenurus	Whistling Kite			X		BRt
Haliastur indus	Brahminy Kite		X	X		BRt
Haliaeetus leucogaster	White-bellied Sea Eagle			X		BRw
RALLIDAE						
Rallina tricolor	Red-necked Crake			X	0.1991	BRt
Megacrex inepta	New Guinea Flightless Rail		X	X	0.0996	BRt
SCOLOPACIDAE						
Actitis hypoleucos	Common Sandpiper		X			Mw
LARIDAE						
Sternula albifrons	Little Tern		X			Mw
COLUMBIDAE						
Macropygia amboinensis	Amboyna Cuckoo-Dove			X		BRt
Reinwardtoena reinwardti	Great Cuckoo-Dove		X	X		BRt
Chalcophaps stephani	Stephan's Emerald Dove			X	0.1493	BRt

Scientific Name	English Name	Status	1995	2017	ctRAI	Res/Mig
Henicophaps albifrons	New Guinea Bronzewing			X	0.0498	BRt
Trugon terrestris	Thick-billed Ground Pigeon			X	0.1991	BRt
Gallicolumba rufigula	Cinnamon Ground Dove			X		BRt
Goura sclaterii	Sclater's Crowned Pigeon (1)	NT, P	[X]	X	0.0996	BRt
Ptilinopus magnificus	Wompoo Fruit Dove		X	X		BRt
Ptilinopus perlatus	Pink-spotted Fruit Dove		X	X		BRt
Ptilinopus superbus	Superb Fruit Dove			X		BRt
Ptilinopus coronulatus	Coroneted Fruit Dove			X		BRt
Ptilinopus pulchellus	Beautiful Fruit Dove			X		BRt
Ptilinopus iozonus	Orange-bellied Fruit Dove		X	X		BRt
Ptilinopus nainus	Dwarf Fruit Dove			X		BRt
Ducula rufigaster	Purple-tailed Imperial Pigeon		X	X		BRt
Ducula pinon	Pinon's Imperial Pigeon		X	X		BRt
Ducula zoeae	Zoe's Imperial Pigeon		X	X		BRt
Ducula spilorrhoa	Torresian Imperial Pigeon			X		BRt
CUCULIDAE						
Centropus menbeki	Ivory-billed Coucal		X	X		BRt
Microdynamis parva	Dwarf Koel			X		BRt
Eudynamys orientalis	Pacific Koel		X	X		BR/Mt
Scythrops novaehollandiae	Channel-billed Cuckoo			X		Mt
Chrysococcyx megarhynchus	Long-billed Cuckoo			X		BRt
Chrysococcyx minutillus	Little Bronze Cuckoo			X		BRt
Cacomantis leucolophus	White-crowned Cuckoo			X		BRt
Cacomantis variolosus	Brush Cuckoo		X	X		BRt
STRIGIDAE						
Uroglaux dimorpha	Papuan Hawk-Owl			X		BRt
PODARGIDAE						
Podargus ocellatus	Marbled Frogmouth		X	X		BRt
Podargus papuensis	Papuan Frogmouth		X	X		BRt
HEMIPROCNIDAE						
Hemiprocne mystacea	Moustached Treeswift		X			BRt
APODIDAE						
Collocalia esculenta	Glossy Swiftlet		X	X		BRt
Aerodramus vanikorensis	Uniform Swiftlet		X	X		BRt
Mearnsia novaeguineae	Papuan Spine-tailed Swift		X	X		BRt
CORACIIDAE						
Eurystomus orientalis	Oriental Dollarbird			X		BR/Mt
ALCEDINIDAE						
Melidora macrorrhina	Hook-billed Kingfisher		X	X		BRt
Dacelo gaudichaud	Rufous-bellied Kookaburra		X	X		BRt
Todiramphus macleayii	Forest Kingfisher		X	X		Mt
Todiramphus sanctus	Sacred Kingfisher			X		Mt
Ceyx solitarius	Papuan Dwarf Kingfisher			X		BRt

Scientific Name	English Name	Status	1995	2017	ctRAI	Res/Mig
Ceyx azureus	Azure Kingfisher			X		BRw
Ceyx pusillus	Little Kingfisher			X		BRt
BUCEROTIDAE						
Rhyticeros plicatus	Blyth's Hornbill	P	X	X		BRt
CACATUIDAE						
Probosciger aterrimus	Palm Cockatoo	P	X	X	0.0498	BRt
Cacatua galerita	Sulphur-crested Cockatoo		X	X		BRt
PSITTACIDAE						
Psittrichas fulgidus	Pesquet's Parrot	VU, P	X	X		BRt
Micropsitta keiensis	Yellow-capped Pygmy Parrot			X		BRt
Eclectus roratus	Eclectus Parrot		X	X		BRt
Geoffroyus geoffroyi	Red-cheeked Parrot		X	X		BRt
Charmosyna placentis	Red-flanked Lorikeet		X	X		BRt
Lorius lory	Black-capped Lory		X	X		BRt
Chalcopsitta scintillata	Yellowish-streaked Lory		X	X		BRt
Trichoglossus haematodus	Coconut Lorikeet		X	X		BRt
Psittaculirostris desmarestii	Large Fig Parrot			[X]		BRt
Cyclopsitta gulielmitertii	Orange-breasted Fig Parrot		X	X		BRt
PITTIDAE						
Erythropitta macklotii	Papuan Pitta			X	0.6969	BRt
Pitta sordida	Hooded Pitta		X	X		BRt
MALURIDAE						
Malurus cyanocephalus	Emperor Fairywren			X		BRt
MELIPHAGIDAE						
Pycnopygius stictocephalus	Streak-headed Honeyeater			X		BRt
Xanthotis flaviventer	Tawny-breasted Honeyeater		X	X		BRt
Philemon meyeri	Meyer's Friarbird			X		BRt
Philemon novaeguineae	New Guinea Friarbird		X	X		BRt
Melilestes megarhynchus	Long-billed Honeyeater		X	X		BRt
Meliphaga sp.				X		BRt
ACANTHIZIDAE						
Crateroscelis murina	Rusty Mouse-warbler		X	X		BRt
Sericornis spilodera	Pale-billed Scrubwren			X		BRt
Gerygone [magnirostris]	[Large-billed] Gerygone			X		BRt
Gerygone chrysogaster	Yellow-bellied Gerygone		X	X		BRt
Gerygone chloronota	Green-backed Gerygone			X		BRt
Gerygone palpebrosa	Fairy Gerygone		X			BRt
POMATOSTOMIDAE						
Garritornis isidorei	Papuan Babbler			X		BRt
MELANOCHARITIDAE						
Melanocharis nigra	Black Berrypecker		X			BRt
Oedistoma iliolophus	Dwarf Longbill		X			BRt
Toxorhamphus novaeguineae	Yellow-bellied Longbill (1)		X	X		BRt

Scientific Name	English Name	Status	1995	2017	ctRAI	Res/Mig
PSOPHODIDAE						
Ptilorrhoa caerulescens	Blue Jewel-babbler		X	X	0.0498	BRt
ARTAMIDAE						
Peltops blainvillii	Lowland Peltops			X		BRt
Melloria quoyi	Black Butcherbird		X	X		BRt
Cracticus cassicus	Hooded Butcherbird		X	X		BRt
CAMPEPHAGIDAE						
Coracina boyeri	Boyer's Cuckooshrike			X		BRt
Coracina schisticeps	Grey-headed Cuckooshrike		X	X		BRt
Coracina melas	Black Cicadabird			X		BRt
Campochaera sloetii	Golden Cuckooshrike		X	X		BRt
Lalage leucomela	Varied Triller		X	X		BRt
PACHYCEPHALIDAE						
Pseudorectes ferrugineus	Rusty Pitohui		X	X		BRt
Colluricincla megarhyncha	Little Shrikethrush		X	X		BRt
ORIOLIDAE						
Pitohui uropygialis	Southern Variable Pitohui		X	X		BRt
Oriolus szalayi	Brown Oriole		X	X		BRt
DICRURIDAE						
Dicrurus bracteatus carbonarius	(Papuan) Spangled Drongo		X	X		BRt
RHIPIDURIDAE						
Rhipidura maculipectus	Black Thicket Fantail			X		BRt
Rhipidura leucothorax	White-bellied Thicket Fantail		X			BRt
MONARCHIDAE						
Symposiachrus guttula	Spot-winged Monarch		X	X		BRt
Arses telescophthalmus	Frilled Monarch		X	X		BRt
Myiagra cyanoleuca	Satin Flycatcher			[X]		Mt
Myiagra alecto	Shining Flycatcher		X	X		BRt
CORVIDAE						
Corvus tristis	Grey Crow			X		BRt
Corvus orru	Torresian Crow			X		BRt
PARADISAEIDAE						
Manucodia ater	Glossy-mantled Manucode	P	X	X		BRt
Phonygammus keraudrenii	Trumpet Manucode	P	X	X		BRt
Cicinnurus regius	King Bird-of-paradise	P	X	X		BRt
Seleucidis melanoleucus	Twelve-wired Bird-of-paradise	P	X	X		BRt
Paradisaea raggiana	Raggiana Bird-of-paradise	P		X		BRt
PETROICIDAE						
Poecilodryas hypoleuca	Black-sided Robin			X		BRt
HIRUNDINIDAE						
Hirundo tahitica	Pacific Swallow			X		BRt
STURNIDAE						
Aplonis metallica	Metallic Starling		X	X		BRt

Scientific Name	English Name	Status	1995	2017	ctRAI	Res/Mig
Mino dumontii	Yellow-faced Myna		X	X		BRt
Mino anais	Golden Myna			X		BRt
DICAEIDAE						
Dicaeum geelvinkianum	Red-capped Flowerpecker			X		BRt
NECTARINIIDAE						
Leptocoma aspasia	Black Sunbird		X	X		BRt
Cinnyris jugularis	Olive-backed Sunbird			X		BRt
Total			73	116		

Appendix 2. Possible additional species recorded in comparable habitats at nearby sites in the lower Kikori basin.

Conservation status is shown for those species listed by the IUCN as Endangered (EN), Vulnerable (VU), Near Threatened (NT) or Data Deficient (DD) and species Protected (P) by law under the *PNG Fauna (Protection & Control) Act 1966*. Residency/migratory (Res/Mig) status indicates: BR—breeding resident species; M—species that occur in New Guinea only as non-breeding migrants; BR/M—breeding residents with populations seasonally augmented by non-breeding visitors, and with widespread local breeding range potentially overlapping the study area; M(BR)—breeding residents augmented by non-breeding visitors, but known breeding sites are localised and outside of the Kikori Basin; t—birds of terrestrial environments, including forest, open areas and aerial foraging species; w—birds of wetlands, including lakes, rivers and streams; wt—species of both wetland and open terrestrial environments; data from Coates (1985, 1990) and Beehler and Pratt (2016).

Scientific Name	English Name	Status	Omo	Wau Ck	Utiti Ck	Pinini Ck	Kopi-Kikori	IW Kikori R.	Iviri	Kikori delta	Res/Mig
Dendrocygna arcuata	Wandering Whistling Duck						X				BR/Mw
Threskiornis molucca	Australian White Ibis							X			M(BR)w
Zonerodius heliosylus	Forest Bittern	NT					X				BRw
Dupetor flavicollis	Black Bittern		X								BRw
Nycticorax caledonicus	Nankeen Night Heron						X				M(BR)w
Butorides striata	Striated Heron						X	X		X	BRw
Ardea sumatrana	Great-billed Heron									X	BRw
Pelecanus conspicillatus	Australian Pelican									X	M(BR)w
Microcarbo melanoleucos	Little Pied Cormorant		X	X			X	X		X	M(BR)w
Phalacrocorax sulcirostris	Little Black Cormorant						X	X			M(BR)w
Aviceda subcristata	Pacific Baza			X		X	X				BRt
Harpyopsis novaeguineae	Papuan Eagle	VU,P		X			X				BRt
Hieraaetus weiskei	Pygmy Eagle						X				BRt
Accipiter poliocephalus	Grey-headed Goshawk			X			X				BRt
Accipiter cirrhocephalus	Collared Sparrowhawk						X				BRt
Gallirallus philippensis	Buff-banded Rail						X				BRt
Gymnocrex plumbeiventris	Bare-Eyed Rail			X							BRt
Amaurornis moluccana	Pale-vented Bush-hen						X				BRt
Pluvialis fulva	Pacific Golden Plover									X	Mwt
Pluvialis squatarola	Grey Plover							X		X	Mw
Charadrius dubius	Little Ringed Plover			X			X				BRw
Numenius phaeopus	Whimbrel							X		X	Mw
Numenius madagascariensis	Far Eastern Curlew	EN								X	Mw
Limosa limosa	Black-tailed Godwit	NT								X	Mw
Calidris acuminata	Sharp-tailed Sandpiper									X	Mw
Calidris ferruginea	Curlew Sandpiper	NT								X	Mw
Calidris ruficollis	Red-necked Stint	NT								X	Mw
Gallinago [megala]	[Swinhoe's] Snipe									X	Mwt
Xenus cinereus	Terek Sandpiper									X	Mw

Scientific Name	English Name	Status	Omo	Wau Ck	Utiti Ck	Pinini Ck	Kopi-Kikori	IW Kikori R.	Iviri	Kikori delta	Res/Mig
Tringa nebularia	Common Greenshank							X		X	Mw
Tringa brevipes	Grey-tailed Tattler	NT								X	Mw
Tringa stagnatilis	Marsh Sandpiper									X	Mw
Stiltia isabella	Australian Pratincole									X	Mt
Gelochelidon nilotica	Gull-billed Tern									X	Mw
Hydroprogne caspia	Caspian Tern									X	Mw
Sterna hirundo	Common Tern							X		X	Mw
Chlidonias hybrida	Whiskered Tern									X	Mw
Chlidonias leucopterus	White-winged Tern									X	Mw
Macropygia nigrirostris	Bar-tailed Cuckoo-Dove			X			X				BRt
Otidiphaps nobilis	Pheasant Pigeon			X		X	X				BRt
Ptilinopus aurantiifrons	Orange-fronted Fruit Dove						?			X	BRt
Ducula mullerii	Collared Imperial Pigeon		X							X	BRt
Gymnophaps albertisii	Papuan Mountain Pigeon			X			X				BRt
Centropus bernsteini	Black-billed Coucal			X			X			X	BRt
Cacomantis castaneiventris	Chestnut-breasted Cuckoo					X	X				BRt
Cuculus optatus	Oriental Cuckoo			X			X				Mt
Ninox theomacha	Papuan Boobook						X				BRt
Hirundapus caudacutus	White-throated Needletail			X			X				Mt
Todiramphus nigrocyaneus	Blue-black Kingfisher	DD								X	BRt
Syma torotoro	Yellow-billed Kingfisher			X		X	X				BRt
Merops ornatus	Rainbow Bee-eater			X			X			X	Mt
Falco cenchroides	Nankeen Kestrel						X			X	Mt
Falco longipennis	Australian Hobby						X				Mt
Falco peregrinus	Peregrine Falcon						X				BRt
Alisterus chloropterus	Papuan King Parrot		X								BRt
Pseudeos fuscata	Dusky Lory			X			X			X	BRt
Cyclopsitta diophthalma	Double-eyed Fig Parrot					X	X				BRt
Loriculus aurantiifrons	Orange-fronted Hanging Parrot			X		X	X				BRt
Ailuroedus stonii	Ochre-breasted Catbird			X	X		X				BRt
Myzomela eques	Ruby-throated Myzomela						X				BRt
Myzomela obscura	Dusky Myzomela						X		X	X	BRt
Myzomela nigrita	Papuan Black Myzomela						X				BRt
Glycichaera fallax	Green-backed Honeyeater						X			X	BRt
Pycnopygius ixoides	Plain Honeyeater						X				BRt
Ramsayornis modestus	Brown-backed Honeyeater									X	BRt
Caligavis obscura	Obscure Honeyeater			X							BRt
Meliphaga albonotata	Scrub Honeyeater						X			X	BRt
Meliphaga analoga	Mimic Honeyeater		X		X	X	X				BRt
Meliphaga gracilis	Graceful Honeyeater									X	BRt

Scientific Name	English Name	Status	Omo	Wau Ck	Utiti Ck	Pinini Ck	Kopi-Kikori	IW Kikori R.	Iviri	Kikori delta	Res/Mig
Meliphaga flavirictus	Yellow-gaped Honeyeater								X		BRt
Meliphaga aruensis	Puff-backed Honeyeater			X		X	X		X		BRt
Oedistoma pygmaeum	Pygmy Longbill						X				BRt
Artamus leucorynchus	White-breasted Woodswallow						X			X	BRt
Coracina novaehollandiae	Black-faced Cuckooshrike						X			X	M(BR)t
Coracina papuensis	White-bellied Cuckooshrike						X			X	BRt
Coracina incerta	Black-shouldered Cicadabird			X		?	X				BRt
Pachycephala simplex	Grey Whistler			X		X	X				BRt
Rhipidura leucophrys	Willie Wagtail		X	X			X			X	BRt
Rhipidura rufiventris	Northern Fantail			X			X			X	BRt
Rhipidura threnothorax	Sooty Thicket Fantail		X	X		X	X				BRt
Rhipidura rufidorsa	Rufous-backed Fantail			X			X				BRt
Symposiachrus manadensis	Hooded Monarch			X	X	X	X				BRt
Carterornis chrysomela	Golden Monarch			X		X	X				BRt
Ptiloris magnificus	Magnificent Riflebird	P		X			X				BRt
Monachella muelleriana	Torrent Flyrobin		X	X							BRw
Petrochelidon nigricans	Tree Martin									X	Mt
Aplonis mystacea	Yellow-eyed Starling	NT				X	X				BRt
Lonchura tristissima/leucosticta	Streak-headed/White-spotted Mannikin				X		X				BRt

Chapter 2.6. Mammals of of the Uro Creek catchment, Gulf Province, Papua New Guinea

Enock Kale, Kyle N. Armstrong, Pita Amick and Iain Woxvold

Camera trap image of a Ground Cuscus (*Phalanger gymnotis*) at Uro Creek

Summary

Uro Creek flows through the freshwater swamp forests of the lower Kikori basin in southern New Guinea, within the delta of the Kikori River near the town of Kikori in Gulf Province. The aims of this study were to: 1. assess mammal diversity and determine the presence and status of significant species in the Uro Creek area by conducting a rapid inventory survey; 2. encourage local landowners to conserve the forest, riparian habitats and their biodiversity within the catchment; and 3. summarise information on mammal diversity to support the establishment of a community-based protection area.

The survey was conducted between 28 April and 3 May 2017. While brief, the survey incorporated numerous techniques to maximise detection of species. Non-volant (non-flying) mammals were surveyed by live trapping with Elliott box traps (259 trap-nights), camera trapping with unattended movement-triggered cameras (20 sites), and by conducting spotlighting searches at night. Bats were surveyed by trapping with harp traps (four sites) and mist nets (five sites), and by recording their echolocation calls with electronic bat detectors (15 recording nights/sites).

The survey resulted in the detection of nine native non-volant mammal species in eight genera from three marsupial families (Peroryctidae—1 sp., Macropodidae—2 spp., Phalangeridae—1 spp.), and one rodent family (Muridae—5 spp.). In addition, one non-native species, the Pig (*Sus scrofa*), was detected. Most (seven) species were encountered using camera traps. Elliott trapping produced three individual rodents (trapping success rate of 1.2%), and further trapping in Babeio village produced the Black Rat (*Rattus rattus*), which is an introduced pest species. No terrestrial or arboreal mammal species were detected on opportunistic night searches. The most significant non-volant mammal species encountered were the Goodfellow's Tree Kangaroo *(Dendrolagus goodfellowi*; IUCN Endangered) and the Grey Dorcopsis (*Dorcopsis luctuosa*; IUCN Vulnerable).

A total of 25 bat species was also detected on the survey. Sixteen species of bat were captured (total 86 individuals). Nineteen species of bat were detected from their echolocation calls, with 10 of those also captured. Eight species detected during the survey were not expected to occur in the area based on their known distributions. None of the bat species are listed by the IUCN as Threatened or Near Threatened. One species of horseshoe bat that was detected, (*Rhinolophus mcintyrei*), is listed as Data Deficient.

The detection of 34 native mammal species over a five-night period is indicative of a diverse and intact mammal assemblage that is worthy of conservation. Numerous additional species are expected. It would be valuable to confirm the presence of Goodfellow's Tree Kangaroo *(Dendrolagus goodfellowi*), given that the record on the current survey was from a hunting trophy; the Lowlands Tree Kangaroo (*Dendrolagus spadix;* IUCN Vulnerable) is more likely to be present in this area. The conservation of biodiversity in the Uro Creek area will be facilitated by considering 'umbrella' species such as tree kangaroos and the Grey Dorcopsis, by engaging with local people to help control both domestic and wild dogs, and by encouraging a shift in the focus of their regular hunting towards feral pigs and away from larger mammal species and native mammals. Further efforts to detect species expected to occur should target arboreal non-volant species, searches for colonies of cave-roosting bats, and some identities from camera traps and bat detectors need to be confirmed by follow-up trapping and genetic work, especially of taxonomically-unresolved or morphologically-similar taxa.

Introduction

The Kikori basin covers an area of 2.3 million hectares and comprises multiple broad-scale habitats ranging from mangrove forest in the estuarine system, to freshwater swamp forest, lowland rainforest, and montane rainforest in the central range (Leary 2004). The mammal assemblage is diverse, and has been documented from on-ground surveys, examination of museum specimens and literature searches (Leary et al. 1995; Seri et al. 1995; Leary and Seri 1997; Namo 2004). Leary (2004) summarised the mammal diversity in two ecoregions that span a large extent of southern New Guinea (as described by Wikramanayake et al. 2002)—Southern New Guinea Freshwater Swamp Forest ecosystem ('freshwater swamp forest' hereafter) and Southern New Guinea Lowland Rainforest ecosystem ('lowland rainforest' hereafter). In the freshwater swamp forest, a total of 80 species across the ecoregion have been documented (1 monotreme, 20 marsupials, 20 rodents, 39 bats). Another compilation of mammal diversity from the Kikori basin, which extends from the lowlands up to montane habitats, documented 105 species (1 monotreme, 34 marsupials, 37 rodents, 33 bats; Namo 2004). The Kikori basin is suspected to be home to undiscovered and undescribed mammal species, especially in the relatively inaccessible limestone karst terrain where the lowland rainforest meets central range montane rainforests, so this species total is likely to be even higher.

Uro Creek forms part of a catchment within freshwater swamp forest that feeds into the Kikori River a few kilometres downstream from the Kikori station. There has been relatively little mammal survey work undertaken in this area (Leary et al. 1995; Seri et al. 1995; Leary and Seri 1997; Leary 2004), and there are currently three mammal species predicted to be within the area that are listed as species of conservation significance—Lowlands Tree Kangaroo (*Dendrolagus spadix*; IUCN Vulnerable), Grey Dorcopsis (*Dorcopsis luctuosa*; IUCN Vulnerable), and New Guinea Quoll (*Dasyurus albopunctatus*; IUCN Near Threatened).

The local community at Babeio has expressed an interest in conserving the significant habitats and species occurring in the Uro Creek catchment, possibly through establishment of a community-based protected area.

Aims

The aims of this study were to:

- assess mammal diversity and determine the presence and status of significant species at Uro Creek to promote their conservation by conducting a rapid inventory survey;

- encourage local landowners to conserve the forest, riparian habitats and their biodiversity within the catchment; and

- summarise information on mammal diversity to support any future attempts to establish a community-based protected area in the catchment.

Methods

Non-volant mammals

Several methods were employed to survey non-volant (non-flying) mammals: live trapping with Elliott box traps, camera trapping with unattended movement-triggered cameras, and by opportunistically detecting mammal species when conducting spotlighting searches at night.

Trapping was conducted between 28 April and 3 May 2017, and was spread across three transects, giving a total trapping effort of 259 trap-nights (Figure 1). Two sizes of Elliott box traps were used: small (37 x 10 x 10 cm) and large (15 x 15 x 46 cm). Small traps were baited with a mixture of sweet potatoes and fresh peanuts. Fresh sweet bananas and coconut sourced from the local market were added to the large traps in addition to the sweet potato and peanuts to attract larger-bodied rodents such as *Uromys* (Muridae) and bandicoots (Peroryctidae). Trapping was also undertaken on one night at Babeio village by local assistants who mentioned the presence of pest rodents in their houses.

Data from 20 Reconyx Hyperfire HC550/PC850 automatic 'camera traps' that were deployed around the Uro Creek site by IW are incorporated into this report. The location of each camera trap was recorded with a Garmin GPS unit. Details of camera trap deployment methods are described in Chapter 2.5 and their locations are illustrated in Figure 1.
An overall list of species identified in the camera trap images was compiled. Abundance cannot be estimated from the images, so instead a Relative Abundance measure was calculated to provide a rough indication of how common each species was. This is simply the proportion of camera trapping sites with one or more images of each species (e.g. a value of 0.6 indicates the species was detected at 6 out of 10 camera trapping sites).

Bat trapping

Bats were surveyed using mist nets (double-stranded nylon 'bird' mist nets), triple-bank harp traps (three rectangular frames 2 m high and 5 cm apart containing fishing line strung vertically, and positioned over a catch bag), and 'bat detectors' that record the ultrasonic echolocation calls of bats. Harp traps (two traps at a total of four sites) and mist nets (total of five sites) were set in the forest understorey across gullies, in the gaps amongst vegetation and on tracks to maximise the capture of bats flying through the understorey (Figure 2).

Identification of captures and sample collection

Identifications were based on information in Flannery (1995), Bonaccorso (1998), and the unpublished notes of the authors. Nomenclature follows the IUCN Red List accounts (http://www.iucnredlist.org/initiatives/mammals) except where these are out of date.

Most captured mammals were released after taking a small biopsy sample of skin for later genetic analysis. Biopsies were taken from the wing membrane of bats with a 4 mm dermal punch, and from the tail of rodents and small marsupials by cutting <5 mm from the tail tip. A small number of voucher specimens (5 bats) was retained to aid verification of identifications. Vouchers were fixed in 10% formalin and then transferred to 70% ethanol for long-term storage. Tissue biopsy samples were preserved in 95% ethanol.

Tissue samples were sequenced with the proprietary 'DArTseq' technique (Kilian et al. 2003), which is essentially identical to a relatively new class of genetic sequencing referred to commonly as 'RADseq' (Andrews et al. 2016) that generates DNA markers from across the genome and provides clarity for resolution of species boundaries and identifications. Sequence data was processed with a custom-written [R] language script, and identifications were made with the help of Principal Coordinates Analysis.

Bat echolocation recordings

Most small, insect-eating bat species can be distinguished from each other based on the frequency and pulse shape characteristics of their ultrasonic echolocation calls. Recordings of bat calls were made in high quality full spectrum WAV format between 28 April and 3 May 2017 with five Pettersson Elektronik D500X bat detectors for a total of 15 full recording nights (Figure 2). Bat detectors were waterproofed in plastic boxes, and microphones on a 3 m extension cable were attached to tree trunks c. 2.5 m high, with a funnel made from a plastic drink bottle placed over the microphone tip to protect it from moisture. The detectors were placed in a variety of habitats including adjacent to streams, within forest, along tracks, facing into clearings, and in open habitats. They were set in position before dusk and collected after dawn, and were moved to a new location each day. 'Reference' recordings were made from captured bats with a Titley Scientific Walkabout bat detector (sampling frequency 500 kHz), and also a Pettersson Elektronik D240X detector connected to a digital recorder, in order to establish a library against which to compare calls recorded by the bat detectors.

Acoustic processing of bat echolocation calls and summary of data

With high quality 'full spectrum' recordings, the datasets are typically many gigabytes, and not every sound file out of the many thousands recorded can be examined in a spectrogram. Thus, a customised, multi-step acoustic processing procedure that can filter large bat echolocation recording datasets from Papua New Guinea (Armstrong and Aplin 2014a; Armstrong et al. 2016) was applied to the recordings. This approach has been used on numerous published exploratory surveys in PNG, and details of this procedure are presented in Appendix 1.

An overall list of species identified in the recordings was compiled. Abundance cannot be estimated from recordings of echolocation, so instead a Relative Abundance measure was calculated to provide a rough indication of how common each species was. This is simply the proportion of recording sites with detections of each species (e.g. a value of 0.6 indicates the species was detected at 6 out of 10 recording sites).

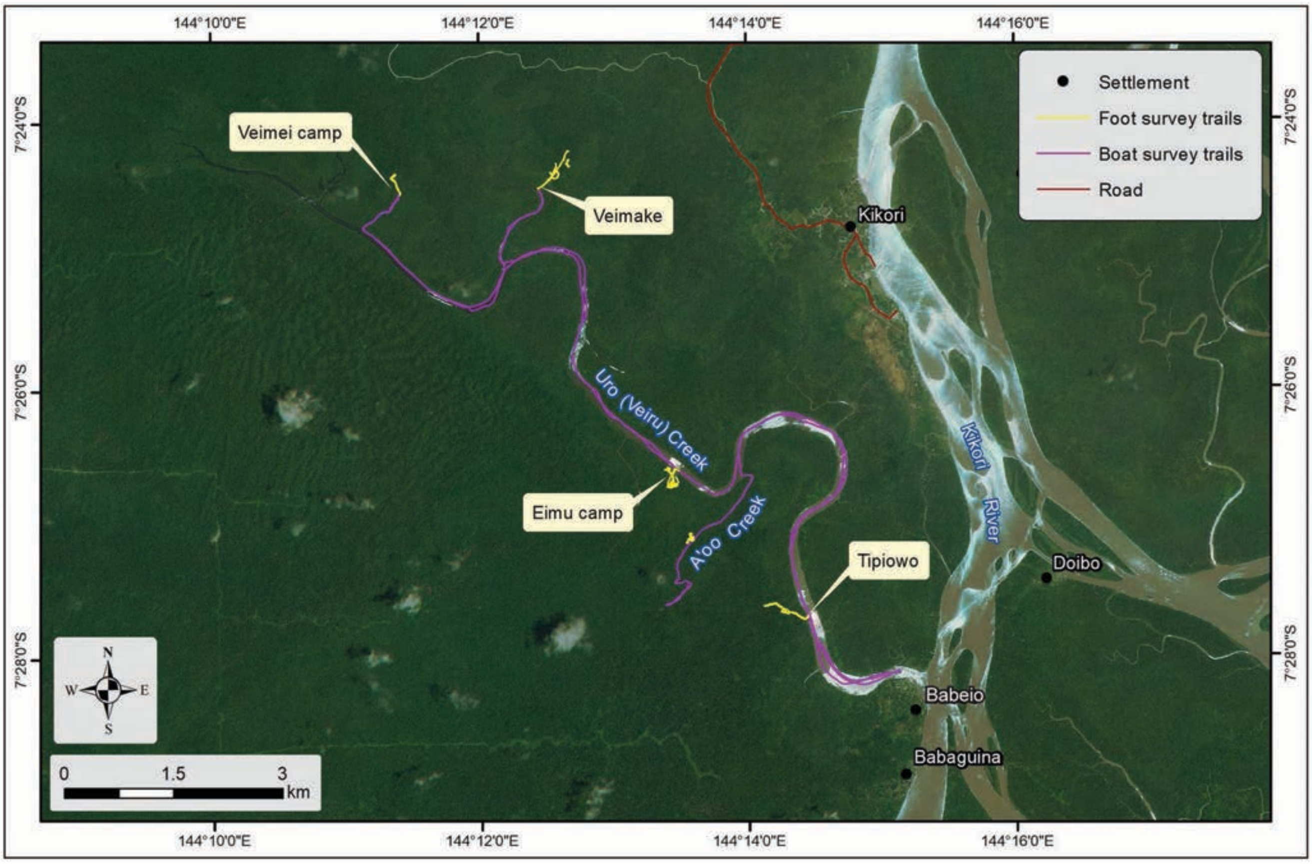

Figure 1. Survey coverage at Uro Creek

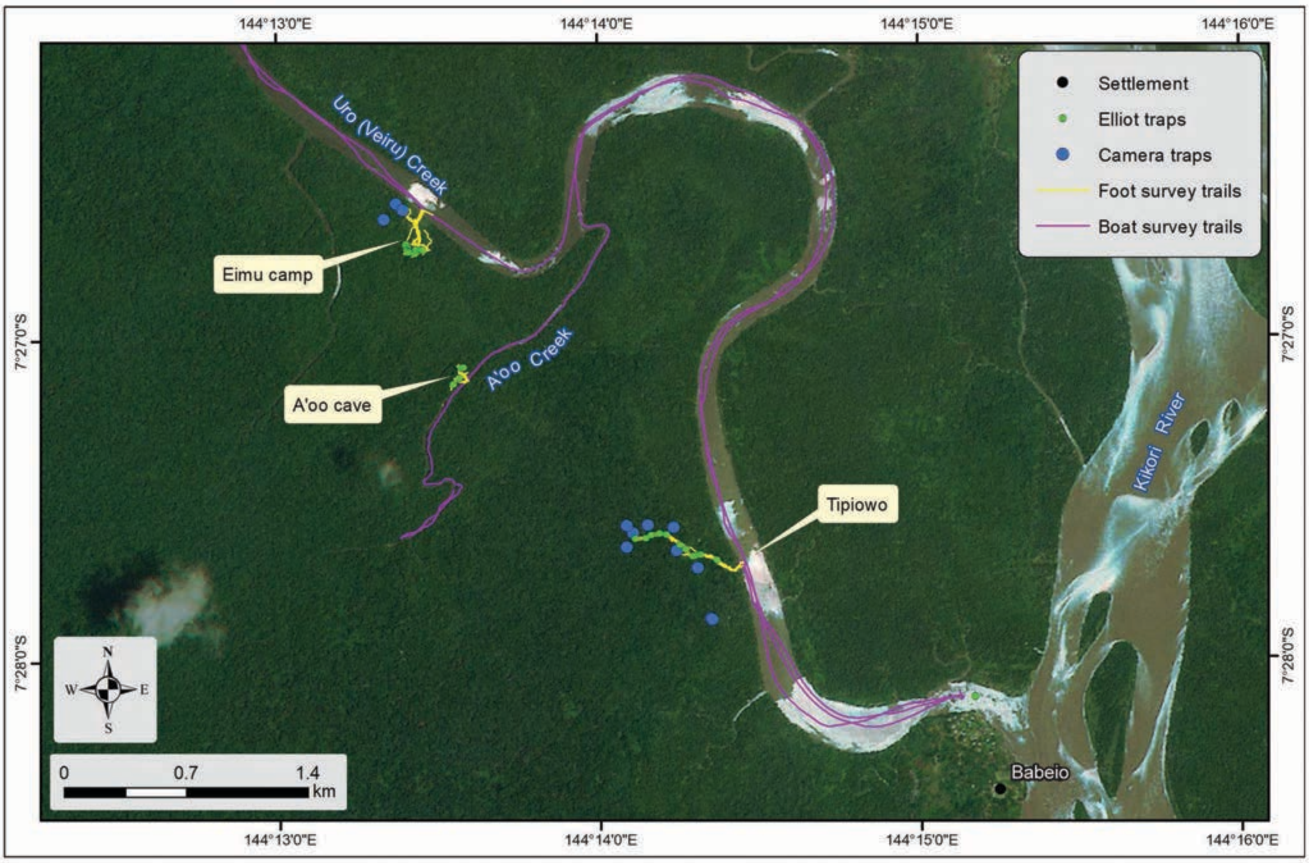

Figure 2. Placement of Elliott box traps and camera traps locations at Uro Creek, near Babeio village.

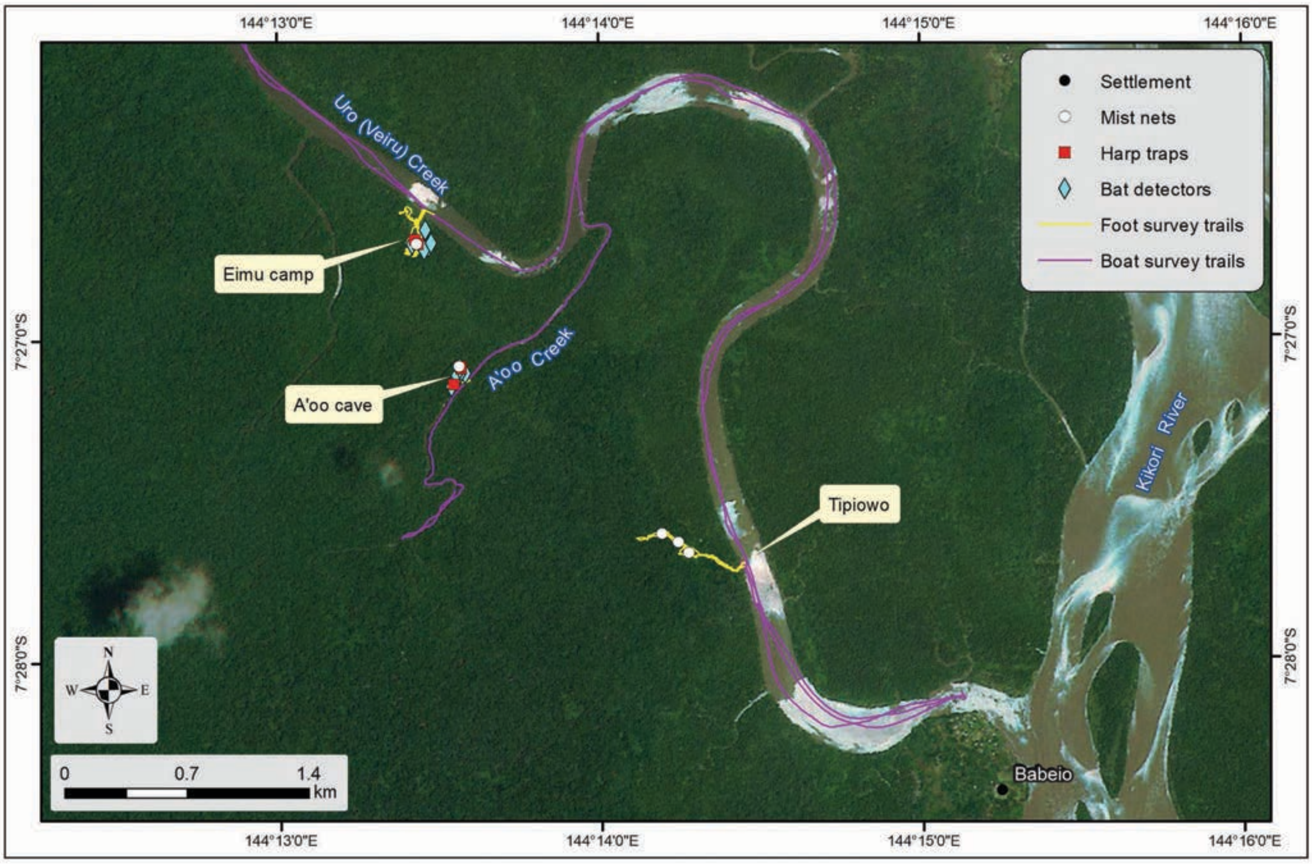

Figure 3. Deployment of bat trapping (harp traps and mist nets) and echolocation call recording equipment at Uro Creek.

Results

Non-volant mammals

At least nine native non-volant mammal species in eight genera from three marsupial families and one rodent family were detected (Table 1). In addition, one non-native species, the Pig (*Sus scrofa*), was detected relatively infrequently compared to some of the other native species (Plate 1F). The rodent family Muridae was the most species-rich with at least five species, and the marsupial families were represented by either one (Peroryctidae, Phalangeridae; Plate 1D) or two species (Macropodidae).

Most (seven) native species were detected through camera trapping (Table 1). The most commonly observed species were small bandicoots (either the Common Echymipera (*Echymipera kalubu*) or Long-nosed Echymipera (*E. rufescens*); Plate 1A) and the White-tailed Giant Rat (*Uromys caudimaculatus*) (Relative Abundance of 0.4). Some of the identifications from the camera trap images could not be determined unambiguously because capture was required to examine small features of external morphology. This is mainly a problem with small rodents, which we group under Rattus sp. while acknowledging that some individuals may represent other genera of small rats. Other species of rat were more obvious because of their colouration, such as the Large Leptomys(*Leptomys elegans*), which has a chestnut dorsal surface and white underparts, and a conspicuously black face (Plate 1E).

The most significant species encountered through camera trapping were two macropod species. The presence of Goodfellow's Tree Kangaroo (*Dendrolagus goodfellowi*) was recorded on the basis of two skin specimens shown to the survey team by a hunter at Babeio village (Plate 1B**)**. This species is listed as Endangered by the IUCN (Leary et al. 2016a). In addition, the Grey Dorcopsis (*Dorcopsis luctuosa*), was detected by camera trapping (Relative Abundance of 0.1). This species is listed as Vulnerable by the IUCN (Leary et al. 2016b; Plate 1C).

Elliott trapping produced three individual rodents, representing a trapping success rate of 1.2%. Two individuals of the Common Lowland Paramelomys (*Paramelomys platyops*) and one *Rattus* of indeterminate species were captured. Trapping within a house in Babeio village with four Elliott traps produced four individuals of the Black Rat (*Rattus rattus*), which is an introduced pest species. The identifications of both the *P. platyops* and *R. rattus* were confirmed with the DArTseq genetic sequencing method, with samples collected during the survey clustering with other samples of these species from various locations across Papua New Guinea.

Two nights of opportunistic searches resulted in nil observations of terrestrial or arboreal mammal species. This was despite numerous observations of signs of feeding and footprints of small mammals in the survey area.

Further details on selected species are discussed in Appendix 2.

Table 1. List of non-volant mammals encountered at Uro Creek (?: species identity to be confirmed; IUCN: conservation status on the IUCN Red List; CT: Relative Abundance values from camera trapping; LT: Elliott live trap capture; skin: hunting trophies from Babeio village).

Family	Common name	Genus species	IUCN	CT
MARSUPIALS				
Peroryctidae	Common Echymipera/ and/or Long-nosed Echymipera?	*Echymipera kalubu/* and/or *E. rufescens?*	LC	0.4
Macropodidae	Goodfellow's Tree Kangaroo	*Dendrolagus goodfellowi*	EN	skin
	Grey Dorcopsis	*Dorcopsis luctuosa*	VU	0.1
Phalangeridae	Ground Cuscus	*Phalanger gymnotis*	LC	0.1
RODENTS				
Muridae	Large Leptomys	*Leptomys elegans*	LC	0.1
	Common Lowland Paramelomys	*Paramelomys platyops*	LC	0.3
	Unidentified rat	*Rattus* sp.	—	0.3
	Black Rat	*Rattus rattus*	LC	LT
	White-tailed Giant Rat	*Uromys caudimaculatus*	LC	0.4
FERAL				
Suidae	Pig, Wild Boar	*Sus scrofa*	LC	0.1

Bats

A total of 25 bat species was detected on the survey, which included six species in the family Pteropodidae and 19 species of echolocating insectivorous bat in six families (Table 2; Figure 3). Eight of these species were not expected to occur in the area based on their known distributions. (Appendix 3). None of the species encountered are listed on the IUCN Red List as Threatened or Near Threatened. One taxon listed as Data Deficient was present—a horseshoe bat that was renamed after a recent taxonomic revision of the *Rhinolophus arcuatus* species complex (Patrick et al. 2013), *Rhinolophus mcintyrei* (Patrick and Ruedas 2017). This record represents a small range extension for the species, suggesting it is much more widely distributed in lowland elevations and habitats than previously supposed.

Six species of bat in the family Pteropodidae were captured in both mist nets and harp traps (total 34 individuals), mostly representatives of the Common Tube-nosed Fruit Bat *Nyctimene* sp. cf. *albiventer* species complex. There were at least two morphological types of the Common Tube-nosed Fruit Bat, referred to here as 'A' and 'B' (Plate 2A, B). Principal Coordinates Analysis undertaken on the DArTseq genetic sequencing data showed that the two morphological types were indeed distinct species (data not shown), but the unresolved taxonomy within the *albiventer* group prevented the allocation of names.

No large flying-foxes were observed, but cave-dwelling species of large fruit bat were captured (four individuals)—Lesser Bare-backed Fruit Bat (*Dobsonia minor*), and Moluccan Naked-backed Fruit Bat (*Dobsonia moluccensis*). Ten species of small insectivorous echolocating bats were also captured (Plates 2 and 3). The total number of captures was therefore 86 individuals (Table 2).

Most echolocation call types could be attributed with confidence to a single species. However, some calls could not be associated with a species reliably because either the calls of certain species are too similar to distinguish unambiguously, or there are taxonomic issues that prevent attributions to a particular species. The most obvious example are calls that are attributable to bent-winged bats (*Miniopterus* spp.)—because identification of the members in this genus from body characters is problematic, the identification of their calls is also unreliable. These call types are also very similar to calls produced by species of Pipistrelle (*Pipistrellus* spp.). Despite these difficulties, bat detectors produced records of nine more echolocating bat species than trapping alone. Further comments on identifications and taxonomic issues are presented in the individual species accounts that follow.

The most commonly recorded species were bent-winged bats ('large' and 'medium' sizes with a Relative Abundance of 0.7), small hipposiderids such as Temminck's Leaf-nosed Bat (*Aselliscus tricuspidatus*; Relative Abundance 0.7) and rhinolophids such as the horseshoe bat (*Rhinolophus mcintyrei*) and New Guinea Horseshoe Bat (*Rhinolophus euryotis*; Relative Abundance 0.6), and the Lesser Sheath-tailed Bat (*Mosia nigrescens*; Relative Abundance 0.6). The presence of so many species of Hipposideridae and Rhinolophidae indicates that caves suitable for diurnal roosting are somewhere nearby.

The most notable detection was an unidentified call thought to derive from one of the two species of free-tailed bat (*Otomops*). Low frequency calls such as those produced by Otomops are seldom detected in PNG.

Further details on selected species are discussed in Appendix 2.

Table 2. Species and echolocation call types of bats recorded at Uro Creek, with an estimate of Relative Abundance to indicate how common each was (asterisks indicate presence was expected based on information on the IUCN Red List, see Appendix 3).

Common name	Genus species	Call type	Rel Ab	Captures
PTEROPODIDAE—6				
*Lesser Bare-backed Fruit Bat	*Dobsonia minor*	—	—	2
*Moluccan Naked-backed Fruit Bat	*Dobsonia moluccensis*	—	—	2
*Common Tube-nosed Fruit Bat	*Nyctimene* sp. cf. *albiventer* 'A'	—	—	17
Common Tube-nosed Fruit Bat	*Nyctimene* sp. cf. *albiventer* 'B'	—	—	1
*Green Tube-nosed Fruit Bat	*Paranyctimene* sp. cf. *raptor*	—	—	4
*Common Blossom Bat	*Syconycteris australis*	—	—	8
EMBALLONURIDAE—2				
Raffray's Sheath-tailed Bat	*Emballonura raffrayana*	*45 i.fFM.d*	0.4	
*Lesser Sheath-tailed Bat	*Mosia nigrescens*	*65 i.fFM.d*	0.6	2
HIPPOSIDERIDAE—6				
*Temminck's Leaf-nosed Bat	*Aselliscus tricuspidatus*	*115 sCF*	0.7	26
*Spurred Leaf-nosed Bat	*Hipposideros calcaratus*	*135 sCF*	—	4
*Fawn-coloured Leaf-nosed Bat	*Hipposideros cervinus*	*140 sCF*	0.5	1
Diadem Leaf-nosed Bat	*Hipposideros diadema*	*58 mCF*	0.1	1
*Maggie Taylor's Leaf-nosed Bat	*Hipposideros maggietaylorae*	*125 mCF*	0.3	
Fly River Leaf-nosed Bat	*Hipposideros muscinus*	*96 mCF*	0.5	
RHINOLOPHIDAE—5				
a horseshoe bat	*Rhinolophus mcintyrei*	*70 lCF*	0.6	4
*New Guinea Horseshoe Bat	*Rhinolophus euryotis*	*52 lCF*	0.6	3
*Eastern Horseshoe Bat	*Rhinolophus megaphyllus*	*66 lCF*	0.1	2
Large-eared Horseshoe Bat	*Rhinolophus* sp. cf. *philippinensis*	*47 lCF*	0.2	
Greater Large-eared Horseshoe Bat	*Rhinolophus* sp. cf. *robertsi*	*33 lCF*	0.5	
MINIOPTERIDAE—3				
*Unidentified Bent-winged Bat 1	*Miniopterus* sp. 1 'large'	*38 st.cFM*	0.7	7
Unidentified Bent-winged Bat 2	*Miniopterus* sp. 2 'medium'	*45 st.cFM*	0.7	
*Unidentified Bent-winged Bat 3	*Miniopterus* sp. 3 'small'	*53 st.cFM*	0.4	
VESPERTILIONIDAE—2				
*Fly River Woolly Bat	*Kerivoula muscina*	*60 bFM*	0.3	2
*Short-winged Pipistrelle	*Philetor brachypterus*	*30 cFM*	0.4	
MOLOSSIDAE—1				
Unidentified Free-tailed Bat	*Otomops* sp.	*30 sFM*	0.1	
Total captures				**86**
Total Species Richness				**25**

Note: Some Miniopteridae are marked as expected species for the area, even though they are unidentified, given that there are candidates listed for their call types in Appendix 3.

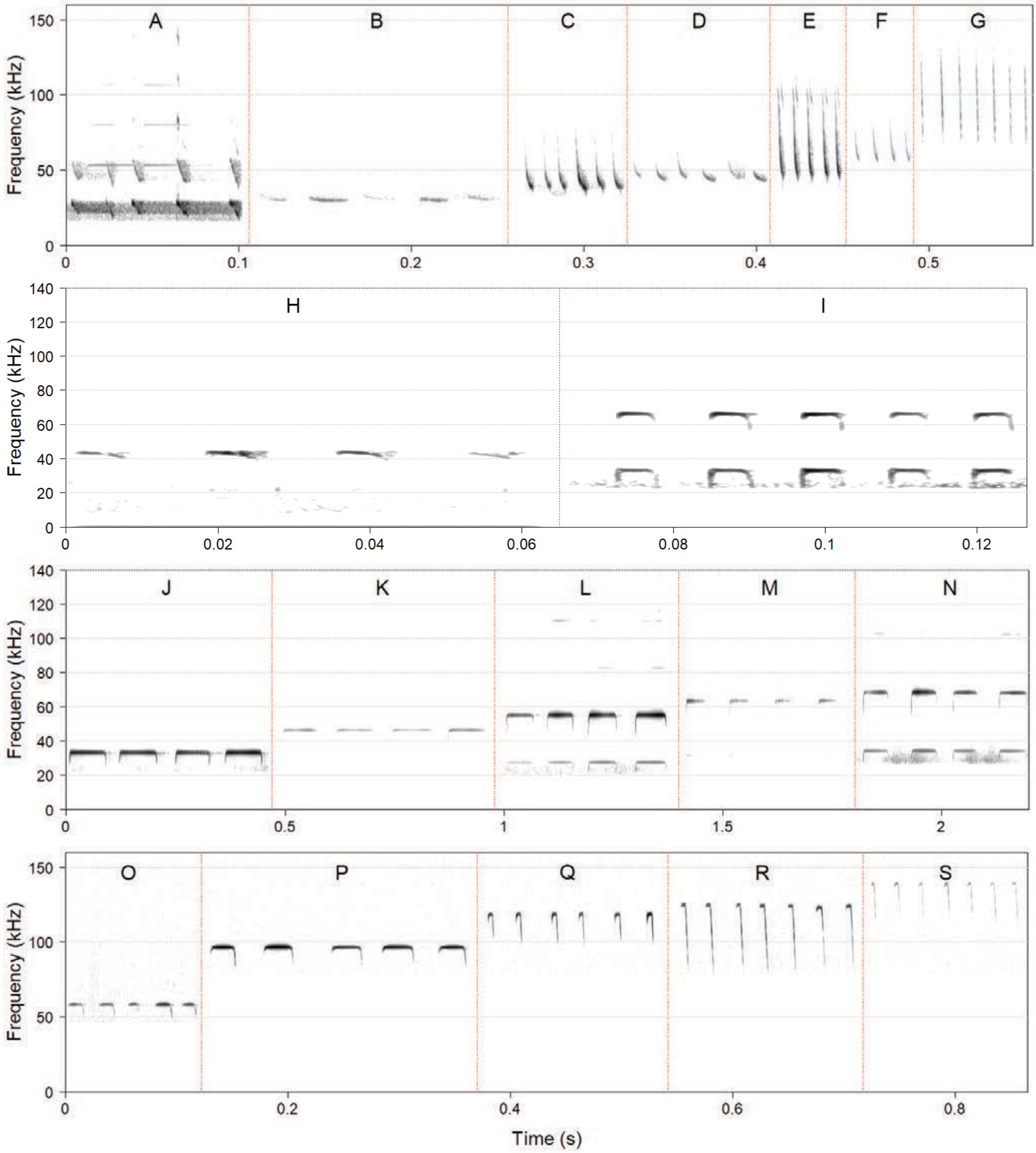

Figure 3. Examples of each echolocation call type (time is compressed between pulses; note the x-axes and y-axes are scaled differently in each plot).

A: *30 sFM Otomops* sp.; B: *30 cFM Philetor brachypterus;* C: *38 st.cFM Miniopterus* sp. 1 'large'; D, E: *45 st.cFM Miniopterus* sp. 2 'medium'; F: *53 st.cFM Miniopterus* sp. 3 'small'; G: *60 bFM Kerivoula muscina;* H: *45 i.fFM.d Emballonura raffrayana;* I: *65; i.fFM.d Mosia nigrescens;* J: *33 lCF Rhinolophus* sp. cf. *robertsi;* K: *47 lCF Rhinolophus* sp. cf. *philippinensis;* L: *53 lCF Rhinolophus euryotis;* M: *66 lCF Rhinolophus megaphyllus;* N: *70 lCF Rhinolophus mcintyrei;* O: *58 mCF Hipposideros diadema;* P: *96 mCF Hipposideros muscinus;* Q: *115 sCF Aselliscus tricuspidatus;* R: *125 sCF Hipposideros maggietaylorae;* S: *140 sCF Hipposideros cervinus.*

Discussion

The variety of approaches to surveying mammals at the Uro Creek study site (camera trapping, Elliott trapping, observational surveys, harp trapping, mist netting and recording echolocation calls) produced records of 34 species of native mammal (11% marsupials, 15% rodents, 74% bats). For a rapid assessment spanning only five nights, this is a significant level of detection, and without remote-detection equipment such as camera traps and bat detectors the total would have been only 18 species, and mostly bats.

In terms of return for effort, the number of mammal species detected compares well with past surveys of similar length in similar lowland habitat. A survey at Utiti Creek (35 m elevation in the 'Southern New Guinea Freshwater Swamp Forest ecoregion'; Leary and Seri 1995, 1997) produced 17 mammal species over four nights (30 July to 4 August 1995; 18% marsupial, 35% rodents, 47% bats). Short surveys at 'Veiru Creek' produced 14 species in similar habitat (20 m elevation), and eight species at Omo in the 'Southern New Guinea Lowland Rainforest ecoregion' (170 m elevation) (Leary and Seri 1997). Longer surveys in the Kikori Integrated Conservation and Development Program Area spanning a total of 40 days encountered a total of 30 non-volant species and 20 bat species (Leary et al. 1995; Seri et al. 1995).

There have been several compilations of the mammals in variously-defined parts of southern New Guinea. For the freshwater swamp and lowland rainforest ecoregions across the southern area of the island of New Guinea, Leary and Seri (1997) documented 80 and 68 mammal species, respectively (101 species in total; Namo 2004 reported a total of 105 species for the Kikori basin at all elevations). The Uro Creek study area is outside of the known distributions of some of these lowland species. However, while the use of newer electronics-based detection methods in the present survey allowed more of the assemblage to be sampled in a short amount of time, it is reasonable to expect that further survey effort at Uro Creek would detect additional mammal species. This includes undescribed species that are suspected to be present in the Kikori and Purari catchments that have been encountered on more recent environmental impact surveys (K.P. Aplin and K.N. Armstrong unpublished data).

A greater diversity of rodents is expected with further effort. Given that distinguishing different species of *Rattus*-sized rodent is challenging from camera trap photos, it was discouraging that Elliott trapping had such a low yield (three individuals; 1.2% success rate). Rodents make up around 32% of mammal species in Papua New Guinea (unpublished list compiled by K.P. Aplin and K.N. Armstrong) and there is likely to be additional undescribed species present that are only detectable by genetic sequencing, as has been found elsewhere (Aplin and Opiang 2017; Armstrong and Aplin 2017). On a rapid survey, there is very little time for 'trap shy' rodents to become accustomed to novel features in their environment, even if 'local' baits such as peanuts, sweet potato and banana are used. A more sustained trapping effort is likely to be more successful and provide specimens for robust determinations of identification. Likewise, longer term deployments of camera traps are likely to have a greater encounter rate of rare species, those that are seldom seen, and possibly those that are arboreal if they are targeted.

Bats

Of the 28 species of bat expected to be in the Uro Creek area based on the most current information available from the IUCN Red List website (see Appendix 3), 16 were encountered during this survey, and an additional nine species that were not expected were documented, bringing the total number of bat species detected to 25. Almost all of the species not recorded previously in this area were detected from their echolocation calls, and several have some level of taxonomic ambiguity (Appendix 2).

Newly-encountered species in the area include the two PNG 'phonic types' (=having different echolocation calls) of the Large-eared Bat (*Rhinolophus philippinensis*) species complex that are likely to be separate species (here referred to as Greater Large-eared Horseshoe Bat (*Rhinolophus* sp. cf. *robertsi*) and Large-eared Horseshoe Bat (*Rhinolophus* sp. cf. *philippinensis*). In addition, there was at least two morphological types of the Common Tube-nosed Fruit Bat

(*Nyctimene* sp. cf. *albiventer*), referred to as 'A' and 'B'. Tissues were taken for identification based on genetic analysis, with a comparative framework provided by a larger study of diversity within this genus currently underway (K.N. Armstrong unpublished data), and the preliminary results confirmed that these two morphological types are indeed very distinct at the species level even if names cannot be allocated at this time.

Bat diversity was enhanced by the presence of many cave-roosting species (*Aselliscus, Emballonura, Hipposideros, Miniopterus Rhinolophus*), and some bat species appeared locally abundant based on capture success (those in the genera *Aselliscus, Miniopterus, Nyctimene*). The presence nearby of suitable roost habitat can significantly elevate detection rates of bat species, and roosts could be part of active management strategy to conserve biodiversity, given that cave-roosting bats breed in underground structures and are generally vulnerable to disturbances within them.

Beyond those already expected for the area (Appendix 3), it is very likely that several other species will also be present in the area, which has received little previous survey effort for bat diversity. Bat species that fly high over the forest canopy are seldom encountered on biodiversity surveys because they are difficult to capture, and as a result there are very few records of species in the genera *Chaerephon, Otomops, Mormopterus* (=*Ozimops*), and *Saccolaimus* (Bonaccorso 1998). Only one poor quality call sequence attributed tentatively to a species of free-tailed bat (*Otomops* sp.) was recorded on the present survey. It is both remarkable and puzzling that there were not more low-frequency-emitting bats recognised in the recordings, since their calls are typically loud and easy to detect, and because they often forage in open spaces above and adjacent to river systems such as the main channel of Uro Creek. While the higher-flying species can be targeted with mist nets hoisted into the canopy, this is a lot of effort if bat detectors do not first indicate their presence.

Using electronic survey tools in rapid assessments—relevant considerations

Rapid biodiversity assessments such as the present study rely on techniques that can increase the rate of encounter of mammal species in a short time period with relatively little effort or specialised skill involved in their deployment. Camera trapping and the recording of diagnostic echolocation calls with bat detectors are not limited by the many factors that influence the success of a trapping program. They simply rely on the animals coming into close proximity of the equipment. Such devices allow deployment by non-specialists, low-cost field studies, and much longer deployment periods that further increase the chance of animal encounters. Given the diversity of mammals detected in the present study area in just a few nights with mostly remote-detection (non-trapping) methods, further efforts are likely to reveal the presence of additional species, especially those that are rare, seldom-seen or difficult to identify. Such efforts are certainly desirable so that future conservation and management actions in thearea consider the whole mammal assemblage. But there are two challenges that must first be resolved.

Firstly, while the camera traps and bat detectors allowed the compilation of a diverse list of taxa, there were still numerous examples where the identifications were problematic—because small diagnostic features (e.g. tail scalation patterns and nipple patterns in smaller rodents) were not visible in photographic images; or else the identification of echolocation call types was made difficult by the similarity of certain calls amongst some species (Appendix 2). Further trapping in the short-term would therefore be especially valuable. It would reduce considerably the number of unidentified species by providing the opportunity to examine captures of these problematic taxa. Mammal diversity could then be more reliably quantified with remote methods. In the case of species that are difficult to identify even after capture, and when there is a constraint on the collection of whole-animal vouchers for museum-based comparisons, the application of genetics-based identification will provide greater clarity from a small non-lethal biopsy sample.

Secondly, rapid assessments are not only limited by how possible it is to identify species from electronic images or acoustic recordings, they are also constrained by the state of taxonomic knowledge of some common PNG mammal groups. Mammal identification can be difficult because of the high prevalence of cryptic species—where a described species contains more than one morphologically-similar but genetically-distinct taxon. There is also a lack of published resources allowing the accurate identification of PNG mammals based on their morphology, which first requires their taxonomic resolution. There has been relatively little application of modern methods in mammal taxonomy to resolve species complexes in PNG, specifically the use of genetic markers. However, genetic markers can be used to make identifications before formal taxonomic description work. One recent ecological study on PNG vertebrates successfully used the DNA barcoding approach to ensure that taxa were identified reliably and consistently, and in some cases highlighted that some 'species' actually had taxonomically distinct forms at different elevations (on the Agogo Range and Hides Ridge; Aplin and Opiang 2017; Armstrong 2017; Armstrong and Aplin 2017; Richards and Armstrong 2017). The application of genetic markers to identification will provide greater clarity, and also allow future recognition of the same captured taxon even if it is undescribed or completely novel.

Thus, further trapping effort combined with genetic work could provide the basis for more accurate remote-detection surveys conducted by non-specialists. The strategic use of trapping, remote-detection methods, and genetics-based identification will each have an important role in a successful approach for long-term biodiversity management.

Biodiversity and conservation values

The detection of 34 native mammal species over a five-night period is indicative of a diverse and intact mammal assemblage of high biodiversity value. Particularly significant species include the Grey Dorcopsis (*Dorcopsis luctuosa*), a species listed as Vulnerable by the IUCN because of declining populations across its range. Numerous additional species are expected, including the IUCN-Vulnerable Lowlands Tree Kangaroo (*Dendrolagus spadix*).

The Babeio community should be encouraged to establish a community-based protected area within the Uro Creek catchment to ensure the long-term protection of this important mammal assemblage.

Balancing the needs of mammal conservation, cultural traditions and subsistence

Balancing the needs of biodiversity conservation with a recognition of the importance of bushmeat to rural or remote communities is challenging (e.g. Eisemberg et al. 2011). The take of bushmeat can be considerable, with one study recording 1.2 tons of wild meat sourced mainly from 37 large bodied mammal genera, including *Dendrolagus*, *Zaglossus* and *Phalanger* (Mack and West 2005). Such a reliance on bushmeat is likely to be common, since a large proportion of PNG people live in remote locations and at the fringe of the cash economy with few options for sourcing their protein from farm or domestic stocks (Mack and West 2005). In many IUCN Red List accounts for larger PNG mammals, hunting and take by wild dogs was identified as a threatening process that causes population decline (e.g. Leary et al. 2016a,b,c).

For communities that wish to manage their land for biodiversity conservation, they could make a commitment to stop hunting certain vulnerable species. Alternatively, recognising that a complete ban may not be desirable or achievable, they could develop a plan to manage their take sustainably, and monitor the persistence of these species.

An additional strategy for the sustainable management of species vulnerable to hunting pressure might be to encourage a greater-than-normal focus on feral pigs. The presence of pigs has several negative consequences for native biodiversity. They are destructive to the forest understorey and create significant soil disturbance, compete with native fauna for invertebrates and worms (Howarth 1985) and may also spread disease pathogens to native fauna (Hampton et al. 2004). By shifting a significant level of hunting pressure away from the native mammals and onto feral pigs, it could help to maintain mammal diversity and the quality of their habitat.

Even more helpful would be the reduction of wild dogs that are known to have a significant impact on macropod populations (e.g. Leary et al. 2016c). The combination of some level of cultural change, together with active management of pigs and dogs, could be sufficient to maintain viable populations of the more sensitive species. In this way, larger-bodied native mammals can serve as 'umbrella' species for the remainder of the mammal assemblage and their habitat. If the community was keen to promote the area or their management of it, then these species could also be used as 'flagship' species whose persistence demonstrates the effectiveness of their actions.

Recommendations

- Use more targeted trapping and genetic ID to resolve ambiguous identifications on a subsequent survey so that longer-term monitoring is based on verified knowledge of species presence and taxa with no ambiguity around their identification.

- Continue monitoring for mammals periodically to assess longer term patterns, using primarily camera traps and bat detectors and engaging with researchers for analysis and reporting.

- Promote the hunting of pigs over native mammal species, especially larger species such as the Grey Dorcopsis *Dorcopsis luctuosa* and the Lowlands Tree Kangaroo *Dendrolagus spadix*, and control wild and domestic dog numbers.

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Plate 1

A. Camera trap image of one of the small *Echymipera* bandicoots (Peroryctidae)

B. Trophy skins of Goodfellow's Tree Kangaroo (*Dendrolagus goodfellowi*)

C. Camera trap image of a female Grey Dorcopsis (*Dorcopsis luctuosa*) with a pouch young. A second individual is in the background

D. Ground Cuscus (*Phalanger gymnotis*)

E. The Large Leptomys (*Leptomys elegans*) , with its characteristically black face

F. Camera trap image of a pig (*Sus scrofa*)

Plate 2

Two species of tube-nosed fruit bat (designated as 'A' and 'B'), identified as being part of the Common Tube-nosed Fruit Bat *Nyctimene* sp. cf. *albiventer* species complex.

C. Lesser Sheath-tailed Bat (*Mosia nigrescens*)

D. Temminck's Leaf-nosed Bat (*Aselliscus tricuspidatus*)

Plate 3

A. Spurred Leaf-nosed Bat (*Hipposideros calcaratus*)

B. Fawn-coloured Leaf-nosed Bat (*Hipposideros cervinus*)

C. Diadem Leaf-nosed Bat (*Hipposideros diadema*)

D. New Guinea Horseshoe Bat (*Rhinolophus euryotis*)

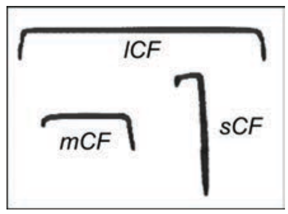
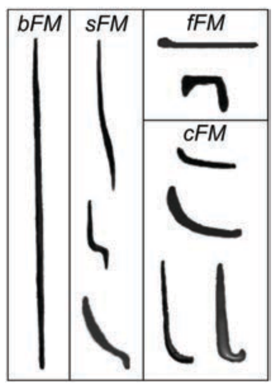
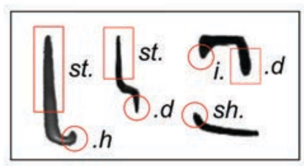
E. The horseshoe bat (*Rhinolophus mcintyrei*)

F. Fly River Woolly Bat (*Kerivoula muscina*)

Appendix 1. Processing of bat detector recordings.

Processing first involved the recognition of bat echolocation 'call types', followed by a separate step of allocating a species identification to each of these. The 'call types' are defined based on a standardised naming scheme that has been used in many published and unpublished surveys across Papua New Guinea and Wallacea in recent years (Armstrong and Aplin 2011, 2014b; Armstrong et al. 2014, 2015a,b; Armstrong 2017; K.N. Armstrong and K.P. Aplin unpublished reports; Supplementary Table 1). The provision of illustrated examples of identified call types provides the opportunity for future verification of call identifications and retrospective correction of species names on the basis of updated information.

Supplementary Table 1. Echolocation call categories based on the shape of search-phase calls (adapted from de Oliveira 1998a,b; Corben and O'Farrell 1999; Gannon et al. 2004; Armstrong and Aplin 2011, 2014a; Armstrong et al. 2014, 2015a,b; examples are not scaled equally). Echolocation calls generally consist of three main sections: an initial frequency sweep (IFS), followed by the main body (BST: Body Sub Type), and ending in a terminating frequency sweep (TFS). The overall call shape is represented by the codes in the form 'IFS.BST.TFS', prefixed by a value representing the mean characteristic frequency in kHz. Note that most CF pulses have a recognisable initial upward frequency sweep, and all have a terminating frequency sweep, so the IFS and TFS descriptors are not used for this Body Sub Type.

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

The WAV files were scanned for bat echolocation calls using SCAN'R version 1.7.7 (Binary Acoustic Technology) and a custom [R] statistical computing language script was then used to perform a Discriminant Function Analysis to compare bat calls from each nightly recording with data from reference calls and representative call types of Papua New Guinean bats (Armstrong and Aplin 2014b; Armstrong et al. 2014, 2015a; K.N. Armstrong and K.P. Aplin unpublished data). Verification of each call type was made from the original WAV files in a spectrogram within Adobe Audition CS6 version 5.0.2 software. Species were identified from the scored call types based on information in Armstrong and Aplin (2011, 2014b), Leary and Pennay (2011), Robson et al. (2012), Armstrong et al. (2014, 2015a), and K.N. Armstrong and K.P. Aplin (unpublished data).

Appendix 2. Species accounts—supporting information on selected species.

Brief species accounts are presented for selected species that have elevated conservation status on the IUCN's Red List, had an ambiguous identification, are part of a species complex with taxonomic issues that make identification difficult, or that are range extensions.

Order Peramelemorphia; Family Peroryctidae

Common Echymipera (*Echymipera kalubu*; IUCN Least Concern)

Long-nosed Echymipera (*Echymipera rufescens*; IUCN Least Concern)

The camera traps photographed at least one species of small peroryctid bandicoot, which could have been either the Common Echymipera (*Echymipera kalubu*) or the Long-nosed Echymipera (*E. rufescens*). The Common Echymipera is the most likely candidate given that it is indeed relatively common and has an elevational range that extends from sea level to 1,500 m asl (Flannery 1995; Menzies 1991). However, the Long-nosed Echymipera, while less common, is variable in coat colour and size and could be misidentified in photographs. Both species are known from the Kikori basin (Namo 2004), although Flannery (1995) indicated that this species has a preference for drier habitats. Small bandicoots are an important game animal for local hunters.

Order Diprotodontia; Family Macropodidae

Goodfellow's Tree Kangaroo (*Dendrolagus goodfellowi*; IUCN Endangered)

Lowlands Tree Kangaroo (*Dendrolagus spadix*; IUCN Vulnerable)

Goodfellow's Tree Kangaroo was recorded on the basis of two skin specimens shown to the survey team by a hunter at Babeio village. Local people are very familiar with tree kangaroos and target them during hunts, probably with the aid of dogs. However, this species does not occur in the delta area where the survey was conducted, rather the skins came from hunting expeditions in areas of higher elevation to the north where this species does occur. The skins may also be the result of trade—Babeio village is located just a few kilometres downstream from the main Kikori town and market, and Namo's (2004) annotated list also included a skin specimen at Kantobo village, illustrating that large native species are considered a delicacy. Thus, Goodfellow's Tree Kangaroo is not likely to be in the Uro Creek area, but the record highlights the importance of hunting and bushmeat to people. The lowland areas south of the central cordillera are inhabited by the Lowlands Tree Kangaroo *Dendrolagus spadix*, which is known from very few specimens (Flannery 1995). It is threatened by over-hunting, and removal of habitat—logging concessions cover almost 75% of the inferred range of the Lowlands Tree Kangaroo (Leary et al. 2016d). This species might be present in the proposed Uro Creek catchment.

Grey Dorcopsis *(Dorcopsis luctuosa*; IUCN Vulnerable)

Dorcopsis luctuosa is abundant in suitable habitat, but the IUCN lists this species as 'Vulnerable' because of a decreasing population trend, including in protected areas—it has apparently disappeared from Varirata National Park near Port Moresby. (Leary et al. 2016b). During the present survey images of the Grey Dorcopsis were captured on one camera traps. Hunting with dogs and forest degradation and clearing pose significant threats to populations of the Grey Dorcopsis so it is encouraging to record its presence within a proposed Wildlife Management Area.

Order Rodentia, Family Muridae

Black Rat (*Rattus rattus*; IUCN Least Concern)

The Black Rat is a globally invasive rodent species that has spread across the globe in ships and shipping containers, and has been transported inland on cargo vehicles. It is both invasive and an aggressive species. Local assistants on the present survey at Uro Creek are very familiar with this species, which is locally known as the 'container rat'. It is present in local houses and is considered an undesirable pest because it can devastate household food stocks and clothing. Four individuals were captured in just two live traps, with two rats entering the traps at the same time, which is probably a sign of both their local density and their bold behaviour. They also carry a range of disease pathogens that can be transferred to native mammal species as well as people (Banks and Hughes 2012).

Unidentified rats *Rattus* sp.

Identifying *Rattus* from photographs is challenging because small diagnostic characters on the body cannot be seen. Candidate species present in the Uro Creek study area may include not only species of *Rattus* (at least three according to the list compiled by Leary and Seri 1997 and Namo 2004; *R. leucopus*, *R. sordidus* and *R. verecundus*; though current distributions only place *R. leucopus* in this area; Aplin et al. 2016a,b, Wright et al. 2016a), but also *Paramelomys* (e.g. *P. platyops*; Wright et al. 2016b), *Melomys* (e.g. *M. leucogaster, M. rufescens;* Aplin 2016, Wright et al. 2016c) and *Pogonomys* (e.g. *P. loriae*; Leary 2016e). Capture, examination of external morphology, and ideally genetic work are required to make robust identifications in such groups where there are known taxonomic issues and cryptic taxa. The one individual of *Rattus* sp. that was trapped came from secondary regrowth forest on a transect at Tipiowo (Figure 1).

Order Chiroptera; Family Pteropodidae

Moluccan Naked-backed Fruit Bat (*Dobsonia moluccensis*; IUCN Least Concern)

This large fruit bat is identified easily in flight from the characteristic buzzing sound generated by the bare skin on its back and rump—which is how the species was detected on the present survey. The sound is similar to the flight of Blythe's hornbill and the vulturine parrot, though these are diurnal species. The Naked-backed Fruit Bat roosts mostly in recessed shady walls of sinkholes, in caves and under shallow rock overhangs, either from the ceiling or high up on walls (Bonaccorso 1998; Churchill 2008). In general, this species is common but roosting aggregations are vulnerable to disturbance. It is not known if roosts are present at Uro Creek, or whether animals visit from elsewhere to feed in the area.

Common Tube-nosed Fruit Bat (*Nyctimene* sp. cf. *albiventer*)

Green Tube-nosed Fruit Bat (*Paranyctimene* sp. cf. *raptor*)

Tube-nosed fruit bats are recognised by their large eyes, dark and yellow spots on the skin of the wing membranes (usually on the top of wing bones) and ears, the dark stripe down its back (*Nyctimene* only; *Paranyctimene* lacks this stripe) and the long, divergent tubular nostrils. The spotting on the skin helps with camouflage as they rest amongst tree foliage during the day. At night they feed mostly in undisturbed forest on fruits, and are an important pollinator and seed disperser in the forest.

There are unresolved taxonomic issues in the genera *Nyctimene* and *Paranyctimene*. There are several cryptic taxa within the *Nyctimene 'albiventer'* complex and others which are similar closely-related species that are easily misidentified (*N. certans, N. draconilla*) so we refer the Uro Creek species to *Nyctimene* sp. cf. *albiventer* types 'A' and 'B', pending further studies. The species of *Paranyctimene* present also needs genetic studies to confirm its identity.

Order Chiroptera; Family Emballonuridae

Most small species of sheath-tailed bat (*Emballonura* spp.) are relatively common and have an IUCN conservation status of Least Concern. However, they can be vulnerable to disturbance in their roosts, especially from hunting because they aggregate into colonies that range in size from a few individuals to hundreds in some cases (Bonaccorso 1998). This includes the two species detected on the survey: Raffray's Sheath-tailed Bat (*Emballonura raffrayana*) (call type *45 i.fFM.d*) and New Guinea Sheath-tailed Bat (*Emballonura furax*) (call type *55 i.fFM.d*).

Order Chiroptera; Family Hipposideridae

Most species of hipposiderids are relatively common and have an IUCN conservation status of Least Concern. However, they can be vulnerable to disturbance in their roosts, especially from hunting because they aggregate into colonies that range in size from a few individuals to hundreds in some cases (Bonaccorso 1998). Such species include: Temminck's Leaf-nosed Bat (*Aselliscus tricuspidatus*) (call type *115 sCF*), Fawn-coloured Leaf-nosed Bat (*Hipposideros cervinus*) (call type *140 sCF*), Diadem Leaf-nosed Bat (*Hipposideros diadema*) (call type *58 mCF*) and Maggie Taylor's Leaf-nosed Bat (*Hipposideros maggietaylorae*) (call type *125 mCF*).

Order Chiroptera; Family Rhinolophidae

Most species of rhinolophid bat are relatively common and have an IUCN conservation status of Least Concern. However, they can be vulnerable to disturbance in their roosts, especially from hunting because they aggregate into colonies that range in size from a few individuals to hundreds in some cases (Bonaccorso 1998). Such species include: the horseshoe bat (*Rhinolophus mcintyrei*), New Guinea Horseshoe Bat (*Rhinolophus euryotis*), Eastern Horseshoe Bat (*Rhinolophus megaphyllus*), and Large-eared Horseshoe Bat (*Rhinolophus philippinensis*) (see comments on taxonomy below).

A horseshoe bat (*Rhinolophus mcintyrei*; Call type *70 lCF)*

The Arcuate Horseshoe Bat (*Rhinolophus arcuatus*) is encountered commonly on acoustic surveys in PNG, and its presence has been reported under this name in numerous published and unpublished reports that the author KA has been involved in. When revising the conservation status of mammals in the South East Asian region, the IUCN chose to follow a taxonomic study that revised the taxonomy of this species, which split those occurring in New Guinea from the remainder in the Philippines and Indonesia and elevated them to species status (Patrick et al. 2013). The PNG representative of the *R. arcuatus* 'species complex' is now called *R. mcintyrei*, which does not have a common name. Despite its wide distribution in New Guinea, it was assessed as Data Deficient (Patrick and Ruedas 2017), but is unlikely to be facing significant threats.

Greater Large-eared Horseshoe Bat (*Rhinolophus* sp. cf. *robertsi*; Call type *33 lCF)*
Large-eared Horseshoe Bat (*Rhinolophus* sp. cf. *philippinensis*; Call type *47 lCF)*

These two forms are currently regarded as 'phonic types' (=having different echolocation calls) of the Large-eared Bat (*Rhinolophus philippinensis*), which is a species complex ranging from the Philippines to northern Australia that requires thorough taxonomic revision. In both New Guinea and northern Australia, two phonic types are present together in the same habitats (in sympatry), which probably suggests they are different species. The lower frequency call type *33 lCF* was only recorded recently in New Guinea (Richards 2005, 2008), and may never have been collected. All forms are clearly recognisable by their 'over-sized' ears and noseleaf. They roost in shallow caves but do not form larger colonies like some cave-roosting bat species.

Order Chiroptera; Family Miniopteridae

Unidentified bent-winged bat (*Miniopterus* sp. 1 'large'; Call type *38 st.cFM)*
Unidentified bent-winged bat (*Miniopterus* sp. 2 'medium'; Call type *45 st.cFM)*
Unidentified bent-winged bat (*Miniopterus* sp. 3 'small'; Call type *53 st.cFM)*

Three call types are allocated to species of bent-winged bat, with varying degrees of confidence. The *38 st.cFM* call type is similar to reference calls collected elsewhere in southern New Guinea from a large species of *Miniopterus*. The other two *st.cFM* call types with characteristic frequencies of around 45 kHz and 53kHz are likely to be from medium- and small-sized *Miniopterus*, though *Pipistrellus* is also a possibility for some examples. These two genera are very difficult to distinguish reliably, except where characteristic feeding buzzes are recorded. The reliable identification of bent-winged bats in PNG will not be possible until completion of a taxonomic study currently in progress (K.N. Armstrong and S. Wiantoro unpublished data).

All species of bent-winged bat aggregate in colonies that can number many thousands, typically females that congregate for the birth and development of young. Males also roost in caves but typically in smaller aggregations, and bats disperse to other caves outside the breeding season. Little is known about reproduction of bent-winged bats in Melanesia (Bonaccorso 1998). However, their aggregatory behaviour in caves make them vulnerable to disturbance and hunting.

Appendix 3. A list of bats expected and present (X) or not detected (—) from Uro Creek based on information in the IUCN Red List maps for each species.

An additional nine species of bat were encountered during the survey (Table 2).

Common name	Scientific name	IUCN	Presence
PTEROPODIDAE			
Lesser Bare-backed Fruit Bat	*Dobsonia minor*	LC	X
Moluccan Naked-backed Fruit Bat	*Dobsonia moluccensis*	LC	X
Dagger-toothed Long-nosed Fruit Bat	*Macroglossus minimus*	LC	—
Greater Tube-nosed Fruit Bat	*Nyctimene aello*	LC	—
Common Tube-nosed Fruit Bat	*Nyctimene albiventer*	LC	X
Green Tube-nosed Fruit Bat	*Paranyctimene raptor*	LC	X
Steadfast Tube-nosed Bat	*Paranyctimene tenax*	LC	—
Large-eared Flying-fox	*Pteropus macrotis*	LC	—
Great Flying-fox	*Pteropus neohibernicus*	LC	—
Common Rousette	*Rousettus amplexicaudatus*	LC	—
Common Blossom Bat	*Syconycteris australis*	LC	X
EMBALLONURIDAE			
Lesser Sheath-tailed Bat	*Mosia nigrescens*	LC	X
HIPPOSIDERIDAE			
Temminck's Leaf-nosed Bat	*Aselliscus tricuspidatus*	LC	X
Dusky Leaf-nosed Bat	*Hipposideros ater*	LC	—
Spurred Leaf-nosed Bat	*Hipposideros calcaratus*	LC	X
Fawn-coloured Leaf-nosed Bat	*Hipposideros cervinus*	LC	X
Maggie Taylor's Leaf-nosed Bat	*Hipposideros maggietaylorae*	LC	X
RHINOLOPHIDAE			
New Guinea Horseshoe Bat	*Rhinolophus euryotis*	LC	X
Eastern Horseshoe Bat	*Rhinolophus megaphyllus*	LC	X
VESPERTILIONIDAE			
Hoary Wattled Bat	*Chalinolobus nigrogriseus*	LC	—
Fly River Woolly Bat	*Kerivoula muscina*	LC	X
Maluku Myotis	*Myotis moluccarum*	LC	—
Short-winged Pipistrelle	*Philetor brachypterus*	LC	X
New Guinea Pipistrelle	*Pipistrellus angulatus*	LC	—
Papuan Pipistrelle	*Pipistrellus papuanus*	LC	—
Northern Broad-nosed Bat	*Scotorepens sanborni*	LC	—
MINIOPTERIDAE			
Little Bent-winged Bat	*Miniopterus australis*	LC	X
Large Bent-winged Bat	*Miniopterus magnater*	LC	X
Total Expected			**28**
Total Observed			**16**

View of Lake Kutubu looking to the west


Forest surveyed during 2017 at western edge of Lake Kutubu WMA. Right of Way is visible in centre.


Audio recorder (left) and harp trap (centre) used to sample frog calls and bats at Lake Kutubu.

Osia Gideon examining plant specimen in Lake Kutubu WMA.

Pagi Toko identifying a butterfly on the ROW


Forest interior, western edge of Lake Kutubu WMA.


Right of Way and surrounding forest, western edge of Lake Kutubu WMA.

Chapter 3.1. Flora of the Lake Kutubu Wildlife Management Area, Southern Highlands Province, Papua New Guinea

Osia Gideon

Riedelia sp. nov.

Summary

This report documents the broad vegetation types and floristics of the Lake Kutubu Wildlife Management Area (WMA) in Southern Highlands Province, Papua New Guinea (PNG). The survey was carried out at the north-western end of the lake at altitudes of approximately 800–850 m asl.

The plant communities surrounding Lake Kutubu are dominated by swamp forests at each end of the lake, medium crowned hill forest on the surrounding slopes below 1000 m asl, and lower montane forest on slopes above 1000 m asl. Although the forest interior gives the impression of a montane forest, with a prevalence of mosses and other epiphytes, the tree flora is dominated by common lowland rainforest species and few upper montane taxa are present.

The forests within the Lake Kutubu WMA are floristically rich, with approximately 70 species documented in two days including two new or undescribed species. A number of other noteworthy plants were detected including species with limited known distributions.

Introduction

Lake Kutubu is the second largest lake in PNG after Lake Murray in Western Province. It is located at an elevation of ~800 m asl, with a catchment area of 4,924 ha. The lake itself is 19 km long and 4 km at its widest point, and has a maximum depth of 70 m (Osborne and Totome 1992). It lies within karst terrain and was formed as a result of volcanic debris and ash blocking the valley and forming the lake.

Lake Kutubu is well known for its highly endemic fish fauna. Twelve of the 18 fish species that occur there are endemic to the lake, which is the highest level of endemicity known for any lake in the New Guinea–Australian region. Five of these endemic species constitute up to 40% of the artisanal fishery and subsistence fish catches in the lake (Enesar 2005). The lake is entirely contained within the Lake Kutubu WMA, which also includes most of the lake's catchment in approximately 1,000 ha of surrounding forest. The lake was listed as a Ramsar wetland in 1998 and the Ramsar boundaries match those of the WMA.

Since 1995 the World Wildlife Fund has carried out many biodiversity surveys in the Kikori River basin, including a number that overlapped with the Lake Kutubu WMA. Additional studies undertaken for the PNG LNG Project have also provided valuable data on the biodiversity of the Lake Kutubu region. Many of these data are available in the annexes of the PNG LNG EIS documents.

This report characterises the terrestrial vegetation communities (type and condition) of the WMA, following the PNG Forest Inventory Mapping System (FIMS), and presents the results of a short survey that aimed to document plants of significance including rare, threatened (i.e. nationally protected or IUCN-listed), endemic, undescribed or otherwise noteworthy species and to note the presence and location of invasive plant species, especially species known to be a major threat to natural ecosystems.

Methods

The survey was carried out at the north-western end of the lake (Figure 1) and consisted primarily of opportunistic collecting of vascular plants, and recording species observed using notebook and camera. Botanical specimens collected were dossed in ethanol (diluted to about 70%) and were transported to Port Moresby where they were dried at the UPNG Herbarium and later freighted to Lae for identification. Due to logistical constraints only a limited number of vouchers could be collected and processed; in most cases only 3–5 duplicates were collected for each vouchered species. Photographs and field descriptions were also made for all vouchered species. Most plants were identified at least to genus level in the field, and vouchers requiring additional study to permit identification were examined further using references and comparative collections at the National Herbarium (PNG Forest Research Institute).

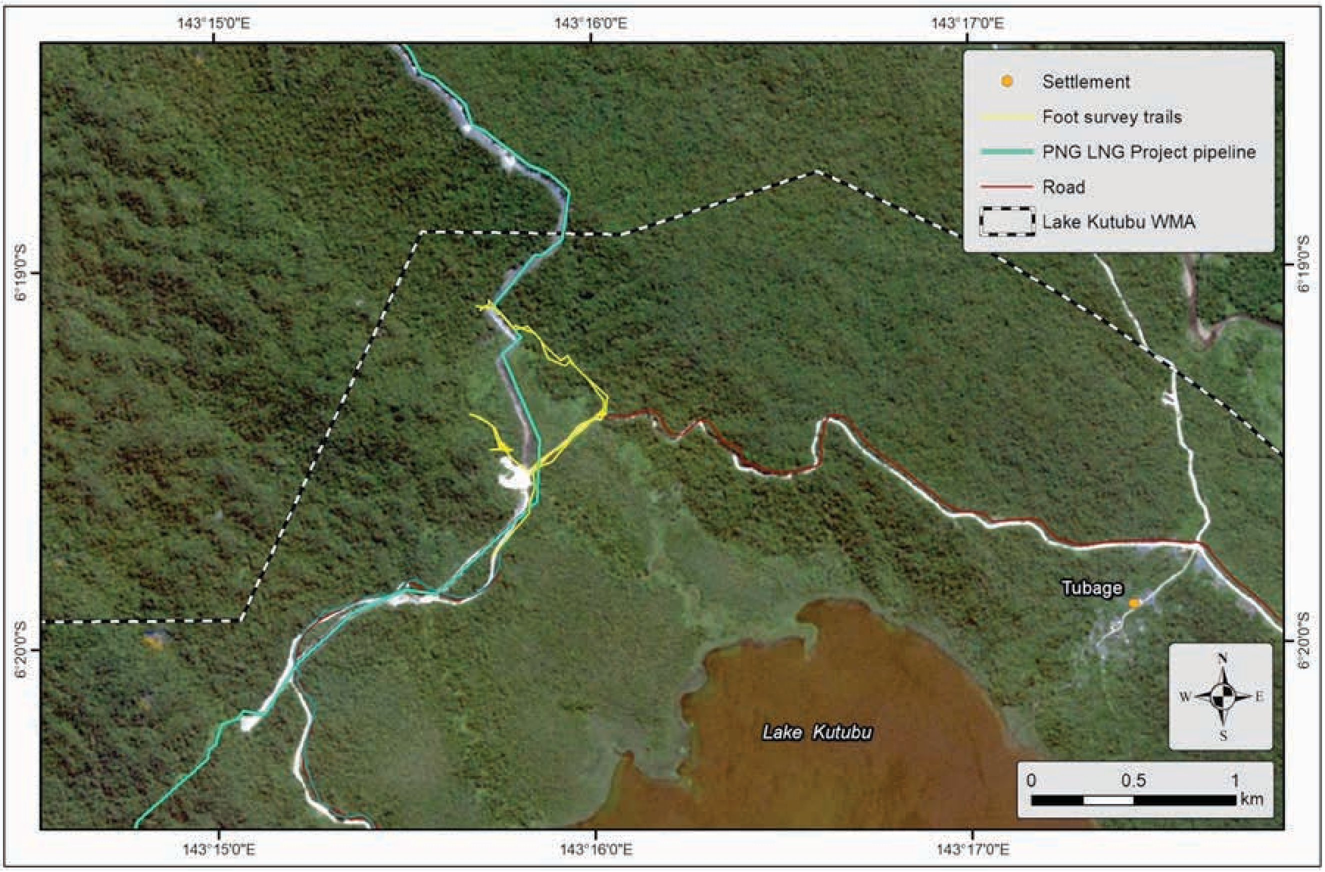


Figure 1. Sampling trails in the Lake Kutubu WMA

Only two days were spent at this survey site. Flowering or fruiting plants were collected or recorded while trekking through the forest along pre-established bush tracks. Noteworthy plants were identified and general observations were also made on the presence of weedy plants, especially well-known invasive species.

Vegetation Mapping

Vegetation mapping of the areas follow the PNG Forest Inventory Mapping System (FIMS), which recognises 63 major vegetation types for Papua New Guinea (Hammermaster and Saunders 1995). Most recent biodiversity surveys in PNG followed this system, which was based on the Saunder's (1993) map, mainly because it was easily applied in mapping. The system is based on aerial photography and remote sensing, and therefore gave detailed information on forest structure and species composition. Base maps used were the 1:100,000 series topographic maps provided by the PNG National Mapping Bureau. However, ground truthing often helped to provide a more reliable description of the unique forest types.

Dominant tree species for the different forest types in different areas were collated from Paijmans (1976) and Hammermaster and Saunders (1995). Unfortunately the scale of the FIMS maps, a system generally available only in 1:250,000 scale maps, does not allow the recognition of small but distinct vegetation communities. Plant communities at the survey site was ground-truthed against the FIMS classification and are described below. Hammermaster and Saunders (1995) recognized nine forest categories within the Bosavi-Strickland forest zone, and they considered Lake Kutubu areas to be part of this forest zone.

Results

Approximately 70 plant species were documented in two days of sampling including two new or undescribed species. The forest interior gives the impression of a montane forest, with a prevalence of mosses and other epiphytes, but the tree flora is dominated by common lowland rainforest species (Appendix 1). A number of other noteworthy plants were detected including species with limited known distributions. Forest types present in the Lake Kutubu WMA are noted, and noteworthy plants are described below.

Forest types in the Lake Kutubu WMA

Saunders (1993) recognized only three broad vegetation types surrounding Lake Kutubu: medium crowned forest (**Hm**), small crowned forest (**Hs**) and other non-vegetation and areas dominated by landuse (**O**). **Hm** is the dominant forest type surrounding the lake, with significant areas of swamp forest (**Wsw/Fsw**) at the south-eastern and north-western ends of the Lake. Hammermaster and Saunders (1995) considered the Lake Kutubu area to be part of the Bosavi-Strickland forest zone, rather than including it with the Highlands Provinces. They recognized nine forest categories within the Bosavi-Strickland forest zone, most of which are actually various combinations of these basic forest types.

The major vegetation types encountered at Lake Kutubu are described below.

Hm – Medium crowned forest (below 1,000 m)

Hm is the dominant forest type in the Lake Kutubu area. It includes various FIMS complexes of **Hm** (**Hm5/Hm8)**, and occurs widely in the Kikori basin. The canopy is 25–30 m high with 60–80% canopy closure, with emergents reaching up to 40 m high. Species composition varies widely according to altitude and substrate.

The forests traversed at the north-western end of the lake give the impression of a montane forest, with a prevalence of mosses and epiphytes, yet the tree flora is dominated by species common in lowland rainforests. Common tree taxa include *Pometia*, *Elmerillia*, *Cryptocarya*, *Litsea*, *Dryadodaphne*, *Elaeocarpus*, *Canarium*, *Buchanania*, *Syzygium*, *Terminalia*, *Calophyllum*, *Alphitonia*, *Gastonia*, *Rhus*, *Podocarpus*, and amongst them some lower montane taxa such as *Castanopsis*, *Lithocarpus*, *Galbulimima*, and *Spiraeopsis*. Understory tree species include *Saurauia*, *Ardisia*, *Euodia*, *Ficus*, *Myristica* and other small tree species. Herbaceous plants are common on the forest floor, dominated by gingers (*Alpinia*, *Riedelia*, *Etlingera*, and *Tapeinochilos*), aroids and various fleshy Urticaceae species (*Elatostema*, *Pilea*, *Procris*) and ferns.

L – Lower montane forest (above 1000 m asl), with or without *Nothofagus* (***Trisyngyne***) (Nothofagaceae).

This broad forest type occurs on the ridges surrounding the lake. It was not investigated during this survey but a description is provided by Paijmans (1976) and Hammermaster and Saunders (1995). Many of the **L** forests on the ridges around the lake may well be dominated by *Nothofagus* (*Trisyngyne*).

Wsw/Fsw – swamp woodland forests/mixed swamp forests

Swamp forests (**Wsw/Fsw**) occur at the south-eastern and north-western ends of Lake Kutubu. The forest is generally open, with a dense undergrowth of pandans (*Pandanus* spp.), palms (*Hydriastele* spp., *Calamus* spp., *Korthalsia zippeliana*, *Heterospathe* spp., *Metroxylon sagu*, and *Caryota rumphiana*), lianas, grasses and sedges. Large trees may reach over 100 cm diameter and up to 30 m tall. Epiphytes are abundant. Sago palms dominate in the small hollows or dolines where karst has produced local relief. Common tree taxa include *Myristica*, *Horsfieldia*, *Calophyllum*, *Campnosperma*, *Terminalia*, *Elaeocarpus*, *Fagraea*, *Neuburgia* and *Bischofia javanica*.

O – Other non-vegetation and areas dominated by land-use

This broad vegetation category includes a range of plant communities that have been affected by human activities. In the Kutubu area, food gardening is generally not pursued with the intensity seen in other parts of the Highlands. Gardening appears to be secondary for the Kutubu people as sago provides much of their traditional starch needs, and only a few small gardens were observed near settlements. Secondary or regrowth vegetation at various stages of succession predominate this broad category.

Species composition changes through the different periods of the succession. Abandoned gardens or forest clearings are immediately covered by herbaceous weeds, grasses and creepers provided by the soil seed bank. These are soon taken over by light demanding woody species, mostly Euphorbiaceae (*Macaranga*, *Omalanthus*, *Mallotus*, *Endospermum*), *Alphitonia*, *Neolarmarkia*, *Rhus taitensis*, *Saurauia*, etc. Ferns and large herbaceous plants like wild bananas (*Musa* spp.), gingers (*Hornstedtia*, *Alpinia*, *Amomum*) are common. Some of the long-lived pioneer species may persist to advanced regrowth (e.g. *Neolamarckia cadamba*, *Endospermum*, *Canarium*, *Pometia pinnata*, *Euodia*, and *Litsea*). Lianas are common through most stages of the succession, especially *Merremia*, *Pueraria*, *Mucuna*, *Trichosanthes*, *Faradaya*, *Entada*, *Ampelocissus* and *Cayratia*.

Noteworthy Plants

No species listed by the IUCN in a threat category above Least Concern was detected during this brief survey, but a number of IUCN-listed species may occur within the WMA. However a number of other noteworthy plant species and records were identified during this survey. These include new distributional records, poorly known species, and undescribed species. Each of these is described briefly below.

Actinidiaceae

***Saurauia* ?sp. nov. (Probable new species; Plate 1A, B)**

This plant is very distinct and most likely represents a new species. It is a soft-stemmed shrub to 2 m tall. Stem with dense long hairs. Leaves obovate, 30–40 X 15–20 cm, pubescent undersurface, petiole with dense reddish hairs. Inflorescence axillary, peduncle 10–15 cm, densely hairy with reddish hairs. Flowers: petals white, anthers yellow. Fruit not seen.

This species is distinct from all *Saurauia* previously encountered in the field and in the herbarium. Even though the genus *Saurauia* is poorly known in New Guinea, this is one of the more distinct and easily recognised species. *Saurauia* is a large genus of about 300 species, found in the tropical and sub-tropical regions of Asia and Central and South America. The island of New Guinea is one of the main centres of diversity for *Saurauia*, with more than 50 species. No comprehensive treatment of New Guinean *Saurauia* has been attempted since the work of Diels in 1922, and the family Actinidiaceae has yet to be treated for Flora Malesiana. This species is known to date only from the Lake Kutubu WMA.

Anacardiaceae

***Campnosperma brevipetiolata* Volkens and *C. coriaceum* (Jack) Hallier f. ex v. Steenis**

Three species of *Campnosperma* occur in New Guinea (*C. brevipetiolata*, *C. coriaceum* and *C. monatanum*). *Campnosperma* can be dominant in certain forests, especially lowland swamp forests, often associated with sago. It appears that *C. brevipetiolata* and *C. coriaceum* occur in the area, as reported in the PNG plants database (Conn et al. 2004). *Campnosperma brevipetiolata* was collected at Lake Kutubu (Anonymous NGF39) and *C. coriaceum* at Mubi Valley, between Ipigi and Hegiso (R. Pullen 2797), and it is highly likely that both species occur around the swamp forests of Lake Kutubu. It is not known whether *C. brevipetiolatum* and *C. coriaceum* can occur together in pure '*Campnosperma*' stands, but it is not impossible (Paijmans 1976).

Campnosperma species have a local significance in the Lake Kutubu area; the genus is well known as the source of 'tigaso-oil', sometimes called 'diumu-oil', which is used as body oil for singsings and traded throughout Southern Highlands and Hela Provinces. It is not known whether oil is extracted from both species, or only from one of them. The oil is also used to treat various skin diseases or sores.

The oil is extracted by cutting the base of the tree and collecting the sap or oil that is then stored in long bamboo containers. Wounding the tree and then continuously tapping the oil may eventually kill the tree, which is a conservation concern. Furthermore, *Campnosperma* species are targeted by loggers, and that poses a major threat. Neither of the species reported here has been assessed for their conservation status by IUCN.

Arecaceae (Palms)

***Calyptrocalyx merrillianus* (Burret) Dowe & M.D. Ferrero (Limited distribution)**

Calyptrocalyx merrillianus is a diminutive clustering palm with stems 1–2 m high and a crown with 3–4 leaves. Leaves regularly pinnate, pinnae 10–15 per side. Inflorescence 40–-60 cm long, 1–2 spiked, filiform. Fruits not seen. The species is only known from Upper Fly River (Western Province), Gulf and Southern Highlands (Kutubu Area), at elevations of 80–600 m. This species was named for the American botanist, Elmer Drew Merrill (1876-1956), who directed the study of the collections of the Archbold Expeditions to New Guinea in the 1930s to 1950s and described hundreds of new species. *Calyptrocalyx merrillianus* has a very limited distribution and therefore it is urgent that its conservation status is assessed as soon as possible.

Costaceae

***Tapeinochilos versteegii* Valeton (Poorly known, uncertain taxonomy; Plate 1C, D)**

Tapeinochilos versteegii is endemic to the southern part of New Guinea, from the Utakwa River in Indonesian Papua Province in the west to the Upper Fly River area in PNG. It has also been tentatively identified in the Lake Kutubu and Crater Mountain areas. It appears to be relatively common at Lake Kutubu. Leafy stems up to 3 m high, with branches radiating from below the inflorescence. Inflorescence up to 40 cm long and 10 cm diameter. Bracts recurved, coriaceous, red-brown to green towards the apex. Flowers slightly protruding beyond the bracts, corolla lobes yellow-brown, minutely pubescent. *Tapeinochilos* is a genus of about 16 species, with 14 in New Guinea one of which extends to tropical Australia and the Moluccas. One species is endemic to each of Solomon Islands and Vanuatu. The genus is not well represented in herbarium collections and most species are represented by less than 10 specimens so morphological variation cannot be easily assessed. The material collected from Lake Kutubu in 2017 is tentatively identified as *T. versteegii*, but the plants from there and also from Crater Mountain differ from the 'typical plants' known from around Kiunga and into Papua.

Zingiberaceae

***Riedelia* ?sp. nov. (Undescribed species; Plate 1E, F)**

This beautiful species was common in forest at Lake Kutubu during the 2017 survey. It is a terrestrial herb in a dense clump of 3–6 shoots, with pseudostems 1–2.5 m tall. Sheath green, lamina to 80 x 15 cm, base with 2 cm auricle, attenuate, clasping the pseudostem. Inflorescence axes reddish brown, branched once. Flowers: calyx tube orange to yellowish, with green apices; corolla white or cream, labellum cream; ovary red, style and stigma cream; anther brownish (post anthesis). The only other known collections of this species were by Axel Poulsen from Kiunga, Western Province (Poulsen et al. 2726 and Poulsen et al. 2730)

This plant probably represents an undescribed species. The genus *Riedelia* has about 70 species, mostly found in New Guinea but with outlying species in the Moluccas and possibly Solomon Islands. The last revisionary studies of the genus were undertaken a century ago, and since then many specimens have been collected and many of these represented new species. The genus desperately needs a modern revision. This species was previously known from Kiunga in Western Province and now from the Lake Kutubu WMA.

Other noteworthy species that are known to occur

Arecaceae (Palms)

***Orania disticha* Burret**

This interesting palm was collected by R. Schodde (Schodde 2188) at Tage, Lake Kutubu in 1961, and so far it has not been recollected there. It is also known from Central Province and three sites in Papua. It is possibly a rare species as it has not been reported by palm specialists visiting the area. I did not see it or any other *Orania* species during this visit.

Weedy and Invasive Species

Invasive species are considered one of the greatest threats to biodiversity, second only to habitat destruction. By definition, invasive plants are "those species that are not native to the ecosystem under consideration and whose introduction causes or is likely to cause economic or environmental harm." Increasing international trade and travel have greatly increased the chances of introducing invasive species.

Until recently, the Lake Kutubu area was an isolated region with little outside influence and with a relatively low local population. Subsistence gardening was also of low intensity because sago was the main staple in the area. Consequently, human impacts on the local vegetation were limited. However, the area is now connected by road to the rest of the Highlands and to the coast, which has allowed substantially increased movement of people and machinery.

As a result, we are likely to see an increase in the introduction of foreign flora and fauna into the area. The only invasive plant of ecological significance detected during the survey was *Piper aduncum*, which was observed along most of the roads around the lake. There may be other invasive species around Lake Kutubu, but it was not possible to comprehensively survey the area for weeds during the two days available.

Numerous additional garden and wayside weeds are present but these are not invasive and they do not pose major threats to the region's natural ecosystems. The common garden and wayside weeds encountered belong to many families, but especially Asteraceae (e.g. *Ageratum conyzoides, Crassocephalum crepidioides* and many other species), Cyperaceae (e.g. *Cyperus* spp., *Fimbristylus* spp., etc.), Poaceae (*Chrysopogon aciculatus, Paspalum conjugatum, Pennisetum purpureum, Ishaemum muticum* and many other spp.), Rubiaceae (e.g. *Hedyotis* spp, *Spermacoce* spp.), Commelinaceae (*Commelina* spp.), Convolvulaceae (*Merremia* spp., *Ipomoea* spp., etc), Lamiaceae (*Stachytarpheta* spp.), Fabaceae (*Mimosa* spp, *Pueraria*, *Crotolaria* and many other spp), Malvaceae (*Sida* spp.), Solanaceae (*Solanum* spp.), Euphorbiaeae (*Euphorbia* spp., *Phylanthus amarus*), and Verbenaceae.

Biodiversity and conservation values

The Lake Kutubu WMA is a protected area that retains substantial biodiversity values. In addition to the lakes' natural beauty, its surrounding forests protect the broader Lake Kutubu catchment, which provides resources for local communities through fisheries and clean water, as well as protecting a large number of endemic and conservation-significant wildlife species. The forests around the lake are representative of several forest types that are under pressure from extractive industries elsewhere; and the local flora contains a number of poorly-known and undescribed species.

The Lake Kutubu region represents an area of high floristic diversity, as indicated by various studies, and represents an important mixing zone of lowland and montane species. The Orchidaceae (orchids) is the largest family in New Guinea with almost 3,000 species, and a brief survey of the orchids of the Lake Kutubu area indicate as many as 342 species there (Clements and Harris, undated). Indirect impacts of fire, as shown by the burning of *Nothofagus* (*Trisyngyne*) forests, and the introduction of invasive plant species have the potential to cause system-wide impacts in the area.

Recommendations

The two day botanical survey reported here is inadequate to fully understand and appreciate the plant life of the area. However, the survey provides some guidance for future botanical studies and the following recommendations are provided:

- Even though a considerable effort has been made over the last two decades to improve the level of understanding of the region's flora, more work is still required to fully understand and appreciate it. Additional intensive botanical surveys are required to support management programs for the Lake Kutubu area.

- Extraction of timber from forests within the WMA for subsistence uses, including construction of canoes, should be carefully regulated.

- Tapping of 'tigaso' oil from *Campnosperma* species should be carefully studied so that a management plan for the species can be developed to regulate the harvest of this culturally significant resource.

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Plate 1

A. *Saurauia* sp. nov. from Lake Kutubu

B. *Saurauia* sp. nov. from Lake Kutubu

C. *Tapeinochilos versteegii* from Lake Kutubu

D. *Tapeinochilos versteegii* from Lake Kutubu

E. *Riedelia* sp. nov. from Lake Kutubu

F. *Riedelia* sp. nov. from Lake Kutubu

Appendix 1. List of plants collected or observed at Lake Kutubu (WMA).

Note: ? = the plant could not be identified any further.

Family	Species	OGG Field number	Photo or sighting	Comments
Actinidiaceae	*Saurauia* sp.		Photo	
Actinidiaceae	*Saurauia* sp. nov.	OGG 124, OGG 132, OGG 142	Photo	Very distinct, possibly new species.
Anacardiaceae	*Rhus taitensis*		Photo	
Anacardiaceae	*Semecarpus* sp.		Photo	
Annonaceae	*Miliusa* sp.	OGG 125	Photo	
Araceae	*Colocasia esculenta*		Photo	
Araliaceae	*Polyscias spectabilis*		Photo	syn. *Gastonia spectabilis*
Araliaceae	*Schefflera* sp.		Photo	
Arecaceae	*Calamus* sp.		Sighting	
Arecaceae	*Calyptrocalyx* cf. *merrillianus*	OGG 122		Small palm 50–150 cm tall
Arecaceae	*Korthalsia zippeliana*		Photo	
Arecaceae	*Licuala* sp.		Sighting	
Aristolochiaceae	*Aristolochia* sp.		Photo	
Asparagaceae	*Cordyline terminalis*		Sighting	
Begoniaceae	*Begonia* cf. *pseudobotryrs*	OGG 131, OGG 134		Widespread species
Blechnaceae	*Blechnum* sp.		Photo	
Blechnaceae	*Stenochlaena palustris*		Photo	
Ceratophyllaceae	*Ceratophyllum demersum*		Photo	Water plant
Convolvulaceae	*Merremia peltata*		Photo	
Costaceae	*Tapeinochilos versteegii*	OGG 121, OGG 137		Differs from the typical *T. versteegii*
Cyatheaceae	*Cyathea contaminans*		Photo	
Cyatheaceae	*Cyathea* sp.		Photo	
Cyperaceae	*Cyperus* sp.		Photo	
Euphorbiaceae	*Omalanthus novoguineensis*		Photo	
Fabaceae	*Mucuna* sp.		Photo	
Fabaceae	*Paraserianthes falcataria*		Photo	syn. *Albizia falcataria*
Flagellariaceae	*Flagellaria indica*		Photo	
Magnoliaceae	*Magnolia tsiampacca*		Photo	syn. *Elmerrillia tsiampacca*
Malvaceae	*Thespesia* sp.	OGG 148		
Marantaceae	*Comminsia* sp.		Photo	
Melastomataceae	*Melastoma malabathricum*		Photo	
Meliaceae	*Aglaia* sp.		Photo	
Moraceae	*Ficus damaropsis*		Photo	
Moraceae	*Ficus* sp.		Photo	Common regrowth species
Moraceae	*Ficus variegata*		Photo	
Onagraceae	*Ludwigia* sp.		Photo	Weedy species
Orchidaceae	*Calanthe* sp.	OGG 130		
Orchidaceae	*Dendrobium* sp.		Photo	

Family	Species	OGG Field number	Photo or sighting	Comments
Orchidaceae	*Dendrobium* cf. *obtusisepalum*		Photo	Lake Kutubu endemic?
Orchidaceae	*Goodyera* sp.	OGG 141		
Orchidaceae	*Grammatophyllum* sp.		Photo	
Orchidaceae	*Spathoglottis* sp.		Photo	
Pandanaceae	*Pandanus* sp. 1		Photo	
Pandanaceae	*Pandanus* sp. 2		Photo	
Pandanaceae	*Pandanus* sp. 3		Photo	
Piperaceae	*Piper aduncum*		Photo	Invasive species
Piperaceae	*Piper* sp. 1	OGG 139		
Piperaceae	*Piper* sp. 2		Photo	
Piperaceae	*Piper* sp. 3 (big leaf)		Photo	
Poaceae	*Imperata cylindrica*		Photo	
Poaceae	*Mischanthus* sp.		Photo	
Rubiaceae	*Argostemma bryophila*		Photo	
Rubiaceae	*Dolicholobium* sp.		Photo	
Rubiaceae	*Ixora* sp. 1	OGG 140		
Rubiaceae	*Ixora* sp. 2 (sp. nov.)	OGG 128		
Rubiaceae	*Lasianthus* sp.	OGG 129		
Rubiaceae	*Mussaenda ferruginea*	OGG 143		Widespread species
Rubiaceae	*Neolamarkia cadamba*		Photo	
Rubiaceae	*Psychotria aquatilis*	OGG 127		
Smilacaceae	*Smilax* sp.		Photo	
Thelypteridaceae	*Cyclosorus interruptus*		Photo	
Urticaceae	*Elatostema* sp.	OGG 135		
Urticaceae	*Nothocnide* sp.	OGG 136		
Urticaceae	*Pipturus argenteus*		Photo	
Urticaceae	*Procris* sp.	OGG 133		
Vitaceae	*Leea indica*		Photo	
Zingiberaceae	*Etlingera* sp. 1	OGG 126		
Zingiberaceae	*Etlingera* sp. 2	OGG 144		
Zingiberaceae	*Hornstedtia scottiana*		Photo	
Zingiberaceae	*Pleuranthodium* sp.		Photo	
Zingiberaceae	*Riedelia* sp. nov.	OGG 123, OGG 138, OGG 147		
?	?	OGG 145		
?	?	OGG 146		

Chapter 3.2. Butterflies of the Lake Kutubu Wildlife Management Area, Southern Highlands Province, Papua New Guinea

Chris Müller and Pagi Toko

The iconic Ulysses Butterfly (*Papilio ulysses*; Papilionidae), male at rest

Summary
We conducted a field survey to document the butterfly fauna of the Lake Kutubu Wildlife Management Area (WMA) in Southern Highlands Province, Papua New Guinea. Fifty butterfly species were recorded at Lake Kutubu during five days of sampling. Three additional, conservation significant birdwing butterflies, the PNG-Protected Butterfly of Paradise (*Ornithoptera paradisea)*, the PNG-Protected Goliath Birdwing (*Ornithoptera goliath*) and the IUCN Endangered, PNG-Protected Southern Tailed Birdwing (*Ornithoptera meridionalis*) (Papilionidae), have been recorded previously at Lake Kutubu, as well as two other Birdwing species (the Common Green Birdwing (*Ornithoptera priamus*) and the Oblong-spotted Birdwing, *Troides oblongomaculatus*). Six species were recorded from Southern Highlands Province for the first time. One of those (*Mycalesis biformis* (Nymphalidae), was only very recently recorded from PNG for the first time.

The conservation values of the Lake Kutubu butterfly fauna are discussed, potential threats are summarised and recommendations for approaches to retaining and utilising the Lake Kutubu butterfly diversity are provided.

Introduction
New Guinea is home to nearly 1000 described butterfly species, with approximately 840 recorded from Papua New Guinea (PNG) (Tennent 2006) and many of these (~40%) are endemic to the New Guinea region. New Guinea is also the centre of diversity for the world's largest butterflies, the Birdwings (*Ornithoptera*). The Lake Kutubu WMA is particularly important for butterflies, since five Birdwing species are known to occur there (Parsons 1983), and the area was considered as one of five potential reserves in PNG for the PNG-Protected Butterfly of Paradise (New and Collins 1991) and for the Endangered Southern Tailed Birdwing (Collins and Morris 1985; New and Collins 1991).

The results of a survey of butterflies in the Lake Kutubu WMA are presented in this report. The main aims of the survey were to record butterfly diversity, distribution and life histories with particular attention to new, rare and/or threatened species, migratory species and exotic pest species. The survey also aimed to identify significant butterfly communities and habitats, species of community/cultural significance and potential threats to butterfly biodiversity.

Methods
Surveying
Butterflies were sampled by 2–3 searchers (PT and 1–2 assistants) along existing walking tracks, the pipeline right of way (ROW), and new trails established in the forest to survey as many microhabitats as possible. Survey coverage is illustrated in Figure 1. Butterflies were sampled from approximately 0800 to 1630 hrs between 6–9 May, 2017. A small number of voucher specimens were collected using long handled nets and stored in glassine envelopes containing paradichlorobenzene and chloro-m-chresol.

Paper lures
Adult males of many hesperiids (skippers), and some lycaenids and nymphalids, imbibe moisture and presumably nutrients from bird droppings. These species are often attracted to small pieces of white paper, which they mistake for bird droppings when they are placed on the upper sides of leaves. We constructed 'paper lure baits' by placing approximately 10 pieces of paper within a ~0.5 m radius on the upper surfaces of leaves in the forest understorey. Once attracted, the male butterflies generally 'feed' for long periods, and can be surveyed at regular intervals. Figure 1 shows the location of paper lure baits set up at Lake Kutubu.

Identification
To aid identification of taxonomically difficult species, comparisons were made with type specimens of related butterfly species in the Australian National Insect Collection, Canberra, Australian Museum, Sydney and the Natural History Museum, London.

Conservation status

Species of conservation significance are those classified as Threatened, Near Threatened or Data Deficient by the IUCN (IUCN 2017), those Protected under PNG law and species that are new to science (discovered for the first time during this survey) or undescribed (previously known from one or more sites but remaining without a name).

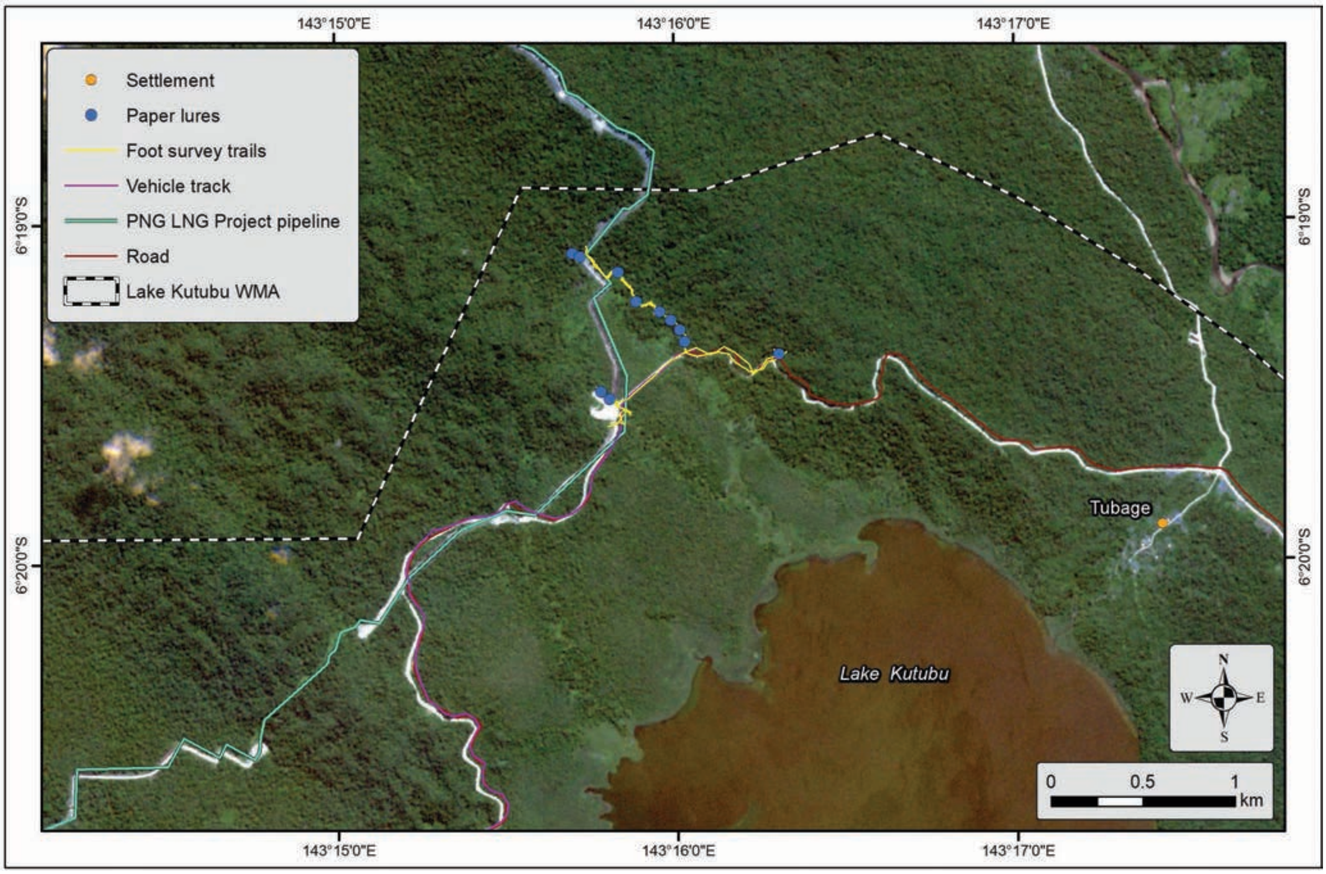

Figure 1. Map of the western edge of the Lake Kutubu WMA, showing the location of survey trails and paper lures used to sample butterflies.

Taxonomy and nomenclature

Nomenclature in this report follows that of Parsons (1998). Only a few butterflies in New Guinea have common names, so this report generally uses standard scientific names and draws only occasionally on Australian references to common names (Braby 2000).

Results

A total of 50 butterfly species was recorded during the survey of Lake Kutubu over a period of five days. These are listed in Appendix 1, conservation significant species are listed in Table 1, and selected species are illustrated in Plates 1 and 2.

Table 1. Significant butterfly species recorded at Lake Kutubu.

Common Name	Scientific Name	IUCN[1]	PNG Fauna Act[2]	Cultural importance
Butterfly of Paradise	*Ornithoptera paradisea*		P	
Southern Tailed Birdwing	*Ornithoptera meridionalis*	EN	P	x

[1]IUCN status EN = Endangered

[2]Status under the PNG Fauna (Protection and Control) Act. P = Protected

Conservation significant species

Ornithoptera paradisea (Papilionidae)

This is a large, stunning birdwing; the males have wingspans up to 125 mm and the females 170 mm. The males are black, green and gold with smaller tailed hindwings. The larvae feed on *Pararistolochia* species (Parsons 1998). Males are relatively inconspicuous, tending to remain inactive for long periods whilst settled on elevated perches. Males often establish territories on the tops of tall ridges especially in narrow clearings. They normally perch more than 20 m above the ground and defend their territories vigorously. Females are usually encountered feeding at flowers some metres above the ground, or flying in search of oviposition sites. In flight they are readily distinguished from other *Ornithoptera* females by the elongated shape of the hind wing.

The Butterfly of Paradise is distributed throughout much of mainland New Guinea, on Salawati Island (Indonesia), and may also occur on Yapen Island. Although most records are from north of the central cordillera and from low elevations, it has been taken at moderate elevations, including Lake Kutubu (800 m asl) and Aseki (1,200 m asl) in PNG (Parsons 1998) as well as at medium elevations in the Arfak Mountains, West Papua Province, Indonesia. The species is essentially confined to primary forest, including swampy areas.

This species is protected under the PNG Fauna (Protection And Control) Act 1966. It was not reported during the 2017 survey but was recorded from Lake Kutubu by Parsons (1998) and Lake Kutubu populations were described as a separate subspecies by So and Sato (1998).

Ornithoptera meridionalis (Papilionidae)

Although this is the smallest *Ornithoptera* it is still a large butterfly, the male's wingspan reaching up to 99 mm and the female's up to 124 mm. Males are green and black with a thin spatulate tail to the narrow hindwing, while females are predominantly brown and cream. According to Parsons (1998), the larvae feed exclusively on the vine *Pararistolochia meridionaliana*. Males are rarely observed and are very localised in their flight. Females are more wide-ranging, which is typical of other Birdwings.

This butterfly is endemic to mainland New Guinea, where it is primarily a lowland species, although there are records as high as 800 m in the Lake Kutubu district (Parsons 1998). It is an inhabitant of the margins of advanced secondary and primary forest. Suitable forest habitat is widespread at Lake Kutubu. No individuals were recorded during the survey but Parsons (1998) noted that A. Hutton found a dead, damaged female of *O. meridionalis* at 770 m nearby at Pimaga.

The species is considered Endangered by the IUCN (Gimenez Dixon 1996) and is protected by the PNG Fauna (Protection And Control) Act 1966. It is listed on CITES Appendix II within the PNG International Trade (Fauna and Flora) Act 1979.

Other significant records

Ocybadistes ardea (Hesperiidae)

In PNG, this species has been recorded from East Sepik, Madang and Morobe Provinces, as well as some outlying islands. The species also occurs in Indonesian Papua and surrounding islands and in coastal Queensland. Three specimens were collected at Lake Kutubu, representing the first record from Southern Highlands Province.

Telicota vinta (Hesperiidae)

Telicota vinta is one of a group of morphologically similar species, but examination of comparative material in the Australian National Insect Collection verified its identity. This species was previously known from Indonesian New Guinea, and from Central, Morobe, Western and East Sepik Provinces in PNG (Parsons 1998) so the new record fills a major gap in its known distribution. Two specimens were recorded during this study and the species was also identified at Wau Creek, lower in the Kikori basin.

***Hypochrysops dinawa* (Lycaenidae)**
Two individuals of *H. dinawa* were recorded at Lake Kutubu. It was previously known only from Western, Central and Northern Provinces (Sands 1986; Parsons 1998) so the new record fills a major gap in the known distribution of the species.

***Jamides reverdini* (Lycaenidae)**
This species was previously known from Western, East Sepik, Madang, Morobe, Central, Northern and Milne Bay Provinces. The Lake Kutubu record appears to be the first record of this species from Southern Highlands Province.

***Mycalesis biformis* (Nymphalidae)**
This species (Plate 2B) has a predominantly western distribution in New Guinea and had only recently been recorded in PNG from near Tabubil in Western Province (Müller 2015). The record from Lake Kutubu represents a major easterly range extension and the first record for Southern Highlands Province.

***Mycalesis fulvianetta* (Nymphalidae)**
In PNG, *M. fulvianetta* was previously recorded only from West Sepik and Central Provinces (Parsons 1998). A single male (Plate 2E) was taken at Lake Kutubu, representing a significant range extension for this species.

Discussion

Although only a modest number of butterfly species was recorded at Lake Kutubu, the fauna documented is certainly a substantial underestimate of the true diversity there. Results were likely impacted by seasonality, which has pronounced effects on upland butterflies (e.g., Saikia et al. 2010), and the butterfly inventory at Lake Kutubu differed from those at Wau Creek and Uro Creek in that it was based purely on collected voucher specimens without considering the numerous taxa that were observed but not collected. There is no doubt that additional survey effort will increase the Lake Kutubu butterfly inventory substantially.

Biodiversity and conservation values

Although the documented butterfly diversity in the WMA was relatively low, Lake Kutubu supports more species of Birdwing Butterfly (five out of eight species in PNG) than any other locality (D'Cruz 2008). Three conservation-significant species, namely the PNG-Protected Butterfly of Paradise, the PNG-Protected, Endangered Southern Tailed Birdwing, and the PNG-Protected Goliath Birdwing, are known (Collins and Morris 1985), in addition to the Common Birdwing and the Oblong-spotted Birdwing (D'Cruz 2008).

Given this diversity, the Lake Kutubu WMA was considered an important reserve for Birdwing butterflies by Collins and Morris (1985). The high number of new Gulf Province records for butterflies documented during the Lake Kutubu survey reflects the incomplete knowledge of the local butterfly fauna, and suggests that additional surveys will reveal other species not previously known from the area. No butterfly pest species (of which there are only very few in PNG) were recorded.

Recommendations

- As with most butterfly species occurring in PNG, Birdwing butterflies are generally specific to primary and mature secondary forest. Habitat loss and degradation are the most significant threat to the butterfly fauna at Lake Kutubu, so minimising habitat degradation through gardening or removal of trees for canoes and timber will be important for maintaining this significant assemblage of butterfly species.

- The Insect Farming and Trading Agency (IFTA) and the Wau Ecology Institute, which both closed in 2009, formerly supplied Birdwing butterfly specimens to an international market. Butterfly species were 'ranched' (reared under controlled conditions), and there is potentially an opportunity for local communities to obtain export permits to trade in insects. Three *Ornithoptera* birdwing species present at Lake Kutubu, *O. paradisea*, *O. meridionalis*and *O.*

goliath have been reared elsewhere in PNG for commercial purposes. Indeed, Parsons (1983) remarked "Ironically it is now becoming an accepted fact that the very demand for *Ornithoptera* is one of the main assets which will ensure their future survival if they can be exploited in the correct way."

- Lake Kutubu is the second-largest lake in Papua New Guinea after Lake Murray, and the largest upland lake. It has a lot of tourism potential given the natural beauty of the lake and that it abounds with spectacular wildlife (including the variety of Birdwing butterflies). The development of sustainable ecotourism activities should be encouraged to promote the long-term conservation of this important protected area.

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Plate1

A. *Notocrypta waiguensis*

B. *Papilio euchenor*

C. *Dicallaneura decorata*

D. *Tellervo nedusia*

E. *Hypolimnas deois*

F. *Cethosia cydippe*

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Plate 2 *Mycalesis* butterflies known or expected to occur at Lake Kutubu

A. *Mycalesis asophis* (from Wau Creek)

B. *Mycalesis biformis*

C. *Mycalesis cacodaemon* (from Wau Creek)

D. *Mycalesis duponchelii* (from Uro Creek)

E. *Mycalesis fulvianetta*

F. *Mycalesis mucia*

G. *Mycalesis pernotata* (from Wau Creek)

H. *Mycalesis phidon*

I. *Mycalesis shiva* (from Uro Creek)

J. *Mycalesis terminus*

Scale bar = 10mm

Appendix 1. Butterfly species recorded at Lake Kutubu.

Family	**Subfamily**	**Species**	**English Name**
Hesperiiidae	Pyrginae	*Tagiades nestus*	
Hesperiiidae	Coeliadinae	*Choaspes hemixanthus*	
Hesperiiidae	Hesperiinae	*Arrhenes dschilus*	
Hesperiiidae	Hesperiinae	*Arrhenes marnas*	
Hesperiiidae	Hesperiinae	*Notocrypta renardi*	
Hesperiiidae	Hesperiinae	*Notocrypta waiguensis*	Banded Demon
Hesperiiidae	Hesperiinae	*Ocybadistes ardea*	
Hesperiiidae	Hesperiinae	*Pelopidas agna*	Dingy Swift
Hesperiiidae	Hesperiinae	*Suniana sunias*	Wide-Brand Grass Dart
Hesperiiidae	Hesperiinae	*Telicota colon*	
Hesperiiidae	Hesperiinae	*Telicota vinta*	
Papilionidae	Papilioninae	*Graphium euryplus*	Pale-Green Triangle
Papilionidae	Papilioninae	*Ornithoptera meridionalis**	Southern Tailed Birdwing
Papilionidae	Papilioninae	*Ornithoptera paradisea**	Butterfly of Paradise
Papilionidae	Papilioninae	*Ornithoptera priamus**	Common Green Birdwing
Papilionidae	Papilioninae	*Ornithoptera goliath**	Goliath Birdwing
Papilionidae	Papilioninae	*Papilio aegeus*	Orchard Swallowtail
Papilionidae	Papilioninae	*Papilio euchenor*	
Papilionidae	Papilioninae	*Papilio ulysses*	Ulysses
Papilionidae	Papilioninae	*Troides oblongomaculatus**	Oblong-spotted Birdwing
Pieridae	Coliadinae	*Eurema hecabe*	Large Grass Yellow
Pieridae	Coliadinae	*Eurema puella*	Broad-Margined Yellow
Pieridae	Pierinae	*Delias gabia*	
Pieridae	Pierinae	*Delias ladas*	
Lycaenidae	Riodininae	*Dicallaneura decorata*	
Lycaenidae	Lycaeninae	*Hypochrysops dinawa*	
Lycaenidae	Lycaeninae	*Hypochrysops polycletus*	
Lycaenidae	Lycaeninae	*Jamides reverdini*	
Lycaenidae	Lycaeninae	*Paraduba metriodes*	
Lycaenidae	Lycaeninae	*Philiris* sp. 1 (unidentified)	
Lycaenidae	Lycaeninae	*Pithecops dionisius*	
Lycaenidae	Lycaeninae	*Psychonotis caelius*	Small Green-Banded Blue
Lycaenidae	Lycaeninae	*Theclinesthes miskini*	
Lycaenidae	Lycaeninae	*Udara dilecta*	
Lycaenidae	Lycaeninae	*Upolampes evena*	
Nymphalidae	Ithomiinae	*Tellervo nedusia*	
Nymphalidae	Danainae	*Euploea alcathoe*	No-brand Crow
Nymphalidae	Morphinae	*Taenaris artemis*	
Nymphalidae	Morphinae	*Taenaris catops*	Catops Owl
Nymphalidae	Morphinae	*Taenaris cyclops*	
Nymphalidae	Satyrinae	*Melanitis amabilis*	

Family	Subfamily	Species	English Name
Nymphalidae	Satyrinae	*Mycalesis biformis*	
Nymphalidae	Satyrinae	*Mycalesis fulvianetta*	
Nymphalidae	Satyrinae	*Mycalesis mucia*	
Nymphalidae	Satyrinae	*Mycalesis phidon*	
Nymphalidae	Satyrinae	*Mycalesis terminus*	Orange Bush Brown
Nymphalidae	Nymphalinae	*Cethosia cydippe*	Red Lacewing
Nymphalidae	Nymphalinae	*Cupha prosope*	Rustic
Nymphalidae	Nymphalinae	*Hypolimnas alimena*	Blue-Banded Eggfly
Nymphalidae	Nymphalinae	*Hypolimnas deois*	
Nymphalidae	Nymphalinae	*Mynes geoffroyi*	White Nymph
Nymphalidae	Nymphalinae	*Neptis brebissonii*	
Nymphalidae	Nymphalinae	*Neptis praslini*	Yellow-eyed Aeroplane
Nymphalidae	Nymphalinae	*Vagrans egista*	Vagrans
Nymphalidae	Nymphalinae	*Vindula arsinoe*	Cruiser
*Literature record			

Chapter 3.3. Dragonflies and damselflies (Odonata) of the Lake Kutubu Wildlife Management Area, Southern Highlands Province, Papua New Guinea

Stephen Richards, Pagi Toko and Günther Theischinger

Huonia epinephele

Summary

We report the results of a survey of dragonflies and damselflies in the Lake Kutubu Wildlife Management Area (WMA) in Southern Highlands Province, Papua New Guinea (PNG). Twenty-nine species of odonates were encountered in five days, including 14 species of damselflies (Zygoptera) and 15 species of dragonflies (Anisoptera). Two species, one in the argiolestid genus *Wahnesia* and one in the platystictid genus *Drepanosticta*, are new to science. They were discovered for the first time during this survey and are currently known only from forest adjacent to Lake Kutubu. One additional species in the coenagrionid genus *Pseudagrion* is undescribed, but was previously known from other sites in south-central PNG and was also collected at Uro Creek during the 2017 surveys. All three of these species are associated with clear-flowing streams in forest.

One species, the platycnemidid damselfly *Nososticta finisterrae*, that was found along small streams near the lake is listed as Data Deficient by the IUCN. Another species of *Nososticta*, *N. conifera*, was previously known only from the type locality in the Lakekamu Basin ~390 km to the southeast. The Lake Kutubu record represents a significant range extension and only the second known locality for this poorly-known damselfly.

Introduction

The southern foothills of Papua New Guinea's central cordillera support a rich but poorly-known odonate fauna. For example recent surveys in the Crater Mountain WMA (Oppel 2005), and in the foothills of the Muller Range (Kalkman et al. 2011) and the Star Mountains (Richards and Theischinger 2015) documented both high species diversity and numerous species that were new to science (e.g. Michalski and Oppel 2010; Orr and Kalkman 2010; Orr et al. 2014; Theischinger and Richards 2011; 2014; 2015a,b; Gassmann et al. 2016).

Although comprehensive surveys of odonates have not been conducted in the Lake Kutubu area, Polhemus (1995) collected damselflies from a number of streams around Moro including several that drain into the lake. That study documented 18 species of damselflies at altitudes of ~800–1,000 m asl in the vicinity of Lake Kutubu and provides a useful baseline against which to compare future studies. Here we report the results of a comprehensive survey of damselflies and dragonflies conducted at the western edge of the Lake Kutubu WMA.

Methods

The survey at Lake Kutubu was conducted by three people (SR, PT and a local assistant) between 5 and 9 May 2017. Survey activities focused on forest habitats within the WMA at the western edge of Lake Kutubu, where searches were conducted along forest trails and along the pipeline Right of Way (ROW) (Figure 1). Adult odonates were observed with close-focus binoculars or collected with a long-handled net during daylight (normally 10 am to ~4.30 pm) from freshwater habitats including small streams in closed forest (Plate 1A) and more open habitats, forest pools and seepages, and flooded sections of the pipeline ROW (Plate 1B). Voucher specimens of species requiring further examination were treated with acetone for about 12 hours, sun-dried, and subsequently stored in labelled envelopes. Larvae were not sampled because larval stages of most New Guinea odonates cannot be assigned confidently to species.

Identifications are based largely on Michalski (2012), which summarises the papers on New Guinean odonates published by M. A. Lieftinck between 1933 and 1978 (e.g. Lieftinck 1949), with reference also to Kalkman and Orr (2013) and Orr and Kalkman (2015). Comparative odonate material in existing public collections was also examined where necessary.

The conservation status of each species was taken from the IUCN Red List (IUCN 2017): LC = Least Concern; DD = Data Deficient; NE = Not Evaluated. Species are referred to as 'new to science' if they were discovered for the first time during this survey, and as 'undescribed' if they are unnamed but were previously known from other sites.

The general vegetation structure of the area is described in Chapter 3.1, and only those habitat features relevant to odonates are mentioned further here.

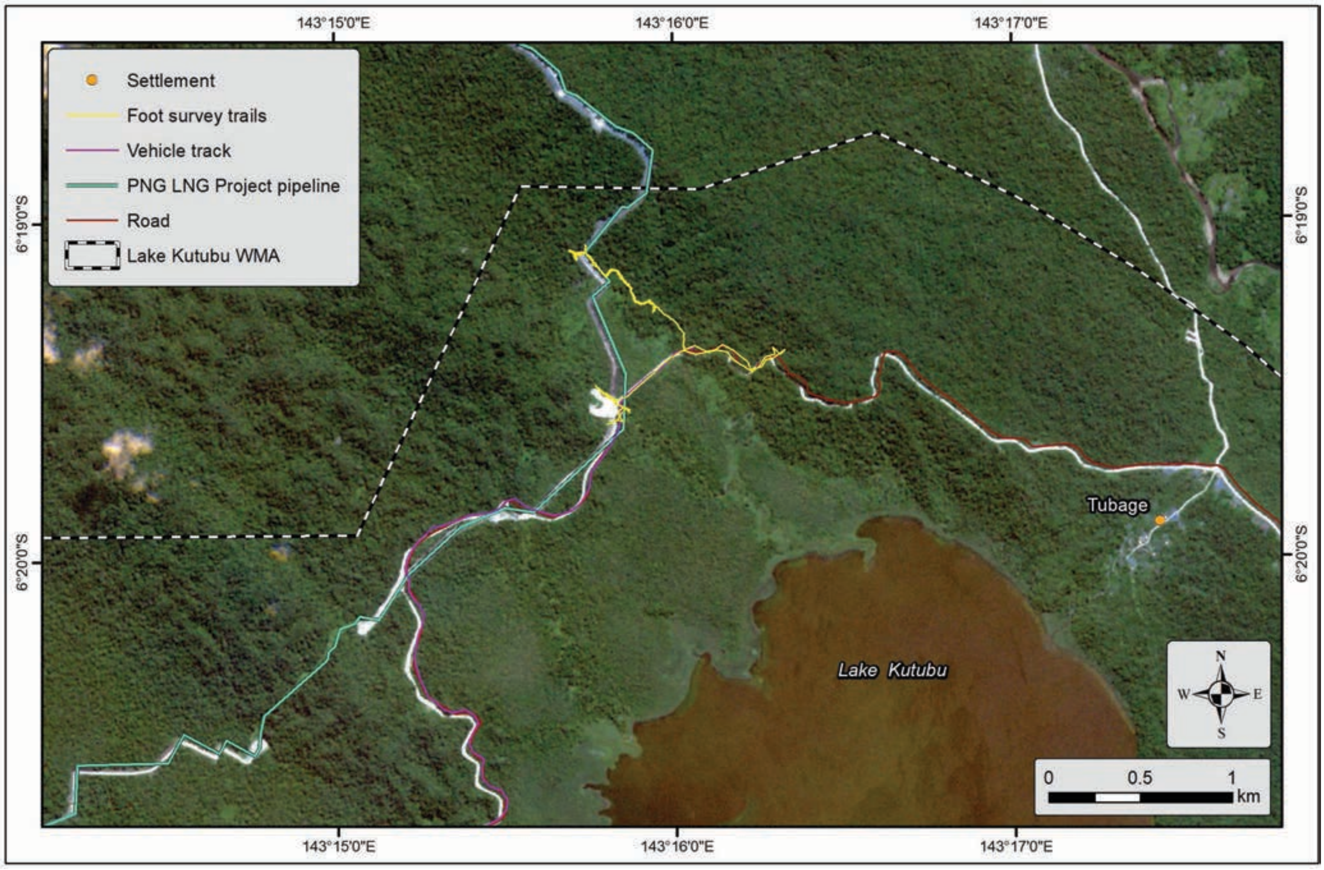

Figure 1. Odonate survey trails in the Lake Kutubu WMA.

Results and discussion

Twenty-nine species of odonates were encountered, including 14 species of damselflies (Zygoptera) and 15 species of dragonflies (Anisoptera) (Appendix 1). Two species, one in the argiolestid genus *Wahnesia* and one in the platystictid genus *Drepanosticta*, are new to science. They were discovered for the first time during this survey and are currently known only from forest adjacent to Lake Kutubu. One additional species in the coenagrionid genus *Pseudagrion* is undescribed, but was previously known from other sites in south-central PNG. All three of these species are associated with clear-flowing streams in forest. They were all formally described during the preparation of this report.

Nososticta finisterrae, a platycnemidid damselfly that was found along small streams near Lake Kutubu is listed as Data Deficient by the IUCN. All other species are listed as Least Concern or have not been evaluated (IUCN 2017). Another species of *Nososticta*, *N. conifera*, was previously known only from the type locality at Lakekamu ~390 km to the SE of Lake Kutubu. The new Lake Kutubu record represents a significant range extension and is only the second known locality for this damselfly.

A list of species encountered during the survey is presented in Appendix 1, species accounts are presented below for species of conservation significance, and selected species are illustrated in Plates 1 and 2.

Significant species

IUCN listed species

One of the species documented during this survey has been evaluated by the IUCN as Data Deficient.

Family Platycnemididae: *Nososticta finisterrae*

This is a small blue and black damselfly with orange/red markings on the terminal segments (Plate 1C). It was not common during the survey; only two individuals were observed, perched on twigs overhanging a small stream in sunlight penetrating from a large treefall. Although it is listed as Data Deficient by the IUCN due to the fact that: 'The species is only known from the type series from Milne Bay, Papua New Guinea collected in the 19th century. Details on its distribution and habitat are lacking' (Kalkman 2009), this species is now known to occur more widely in southern Papua New Guinea (Kalkman et al. 2011).

Undescribed species and species new to science

One species collected at Lake Kutubu is undescribed (previously known but not yet named), and two are new to science (discovered for the first time during this survey). Brief accounts for each of these species are provided below.

Family Coenagrionidae: *Pseudagrion parafarinicolle*

A small, dark and moderately robust damselfly that was previously known from several other sites in Gulf Province was found along disturbed, sunny sections of small streams at both Lake Kutubu and Uro Creek. It was undescribed at the time of this survey. It has recently been described based on the material collected at Lake Kutubu (Theischinger et al. 2018). Although very similar to *P. farinicolle* it differs from that species by several features of the male appendages. Males of this species become distinctly pruinose (covered with a waxy film) on the thorax as they mature (Plate 1D).

Family Argiolestidae: *Wahnesia kutubuensis*

A moderately large and robust damselfly of the genus *Wahnesia* was encountered at Lake Kutubu. This species, which perches with the wings spread flat, is new to science. It has a dark thorax with two narrow dorsal, and broader lateral, pale markings, the dorsal surface of segment 8 of the abdomen is entirely pale, and the legs are entirely dark (Plate 1E). *Wahnesia kutubuensis* was found along two streams near the edge of Lake Kutubu. One of these was steep, rocky, and had been partially converted to a banana garden, while the other was lower gradient and had a substrate of both sand and rock. However both streams were clear-flowing with areas of dense, shady riparian vegetation where the adults perched on leaves in dappled sun. They were never observed in areas with strong sunlight. This species, which was recently described by Theischinger et al. (2018) is known only from the Lake Kutubu WMA.

Family Platystictidae: *Drepanosticta johncanni*

A moderately small, dark species of *Drepanosticta* with dark terminal abdominal segments that was found at Lake Kutubu is new to science (Plate 1G). Several specimens of this secretive genus were found perched in low vegetation along small streams in the Lake Kutubu WMA. It shares these streams with *Wahnesia kutubuensis*, another species discovered during the survey at Lake Kutubu, but occupies more deeply shaded microhabitats than that species. This small damselfly, which was recently described by Theischinger et al. (2018) is currently known only from the Lake Kutubu WMA.

Major range extensions

Family Platycnemididae: *Nososticta conifera*

Documentation of the small blue-and-black damselfly *Nososticta conifera* (Plate 2A) along a small stream draining into Lake Kutubu at KP86 (Plate 2B) represents a major range extension and only the second known location for this species. *Nososticta conifera* was described from the Lakekamu Basin, 390 km from Lake Kutubu, by Theischinger and Richards (2006). The type series was collected in 1996 and the species has not been encountered since. At 800 m asl Lake Kutubu is much higher than the Lakekamu Basin (~80–120 m asl at the type locality) so this new record also represents a substantial increase in the known elevational range for the species.

General comments

The odonate fauna at Lake Kutubu had a diversity intermediate between that found at Wau Creek and Uro Creek in the Kikori Delta (29 species vs 25 and 46 respectively; see Chapters 1.3 and 2.3). Furthermore, although Lake Kutubu is at a higher elevation than both of these sites (>800 m vs <100 m asl) nearly 2/3 (62%) of the species encountered there were also found at either Wau Creek or Uro Creek. In contrast just 39% of species encountered at Wau Creek were shared with nearby Uro Creek suggesting that habitat type and local habitat diversity play a more important role in determining the structure of species assemblages in the lowlands and foothills of the Kikori basin than altitude or distance between sites. This result was not surprising because the area surveyed at Lake Kutubu contained a number of open, disturbed habitats that are dominated by widespread libellulid dragonflies that occur across the lowlands and foothills of southern New Guinea and were also found at the delta sites. In contrast several small, shaded streams draining into Lake Kutubu provided habitat for two stream-dwelling damselflies (*Wahnesia kutubuensis* and *Drepanosticta johncanni*) that are new to science, and another more open stream supported a population of a previously undescribed damselfly of the genus *Pseudagrion* that was also found at Uro Creek.

The total species diversity encountered at Lake Kutubu is similar to that recorded from a 515 m asl site in the foothills of the Muller Range (31 species; Kalkman et al. 2011) over a similar sampling period (6 days). However it is likely that the odonate fauna at Lake Kutubu is substantially more diverse than we documented. For example Polhemus (1995) documented 18 (vs 14) species of damselflies from sites in and around the Lake Kutubu WMA, and at the Crater Mountain Biological Research Station (CMBRS; 800–1,300 m asl) Oppel (2005) found 61 species during 112 days of fieldwork. Furthermore Oppel reported a very slow rate of species detection. After five days of sampling he had encountered less than 15 species (vs 29 species during this study) and it took 45 days to find the first 75% of species that were eventually documented there (Oppel 2005). Although rates of species detection vary depending on a number of factors including difficulty of terrain and different levels of daily search effort, it is likely that the 2017 survey at Lake Kutubu has documented substantially fewer species than are actually present and that additional species that are new to science await discovery. However given the relatively limited availability of surface water habitats due to the extensive areas of karst in the Lake Kutubu area, the total odonate diversity is unlikely to rival that encountered in the Crater Mountain WMA.

We documented only one damselfly species listed as Data Deficient by the IUCN, but the discovery of two new species in such a small area was unexpected. Both of these species are known to occur only along small, shaded forested streams that are characterised by high humidity and relatively stable microclimates. These species may be impacted by increased exposure to direct sunlight as removal of forest cover for gardens, and harvesting of wood for fires and for construction of canoes continues in the forest around Lake Kutubu. Limiting damage to riparian vegetation along small, clear-flowing streams in forest within the Lake Kutubu WMA is the most practical way to ensure the long-term survival of these species.

Biodiversity and conservation values

Covering an area of 49.24 km^2, Lake Kutubu was recognised as a Wetland of International Importance (Ramsar Site) in 1998 based on a number of criteria including the high proportion of endemic fishes living in the lake. The Lake Kutubu WMA, which was established in 1992, also incorporates a substantial tract of forest and covers an area approximately five times the size of the lake in one of the world's most biologically diverse terrestrial regions (Olson and Dinerstein 1998; Brooks et al. 2006). Forest types represented in the WMA include upper hill forest, lower montane forest, and swamp forest/woodland.

In addition to providing protection for water catchments feeding the lake, which is also a source of food and income for dozens of villages, the forests surrounding Lake Kutubu support a rich biodiversity. Some components of the WMA's terrestrial and semi-aquatic biodiversity, such as birds (see Chapter 3.5), are relatively well known but other taxa in these forests remain poorly documented. For odonates, the study by Polhemus (1995) around Moro and Lake Kutubu recorded the highest diversity of damselflies of all regions he sampled in the Kikori basin. Although Polhemus sampled a number of sites near Lake Kutubu that are outside the WMA, habitat continuity between the WMA and the surrounding forest areas suggests that most species encountered at those sites are likely to occur in forests within the WMA.

Combining the results from this study with those obtained by Polhemus (1995), it is clear that the Lake Kutubu WMA supports a rich odonate fauna; furthermore two new species of damselflies (*Drepanosticta johncanni* and *Wahnesia kutubuensis*) that were discovered for the first time during the 2017 surveys are currently known only from this WMA. Forest around the lake also supports one of only two known populations of the poorly known damselfly *Nososticta conifera* and a population of the recently described damselfly *Pseudagrion parafarinicolle*, which has a limited known distribution in south-central PNG. All four of these species are restricted to small, clear-flowing streams. Although *N. conifera* and *Pseudagrion parafarinicolle* were found along exposed, moderately degraded stretches of stream where the canopy had been largely removed, the two newly discovered species appear to be mainly confined to cool, clear, well vegetated streams with extensive canopy cover.

Recommendations

Maintaining the current diversity of odonates within the Lake Kutubu WMA, and ensuring the long-term survival of stream-dwelling forest interior species in particular, will require actions to minimise the impacts of logging and forest degradation. The following activities are recommended with respect to odonates in order to maintain or enhance the conservation values of the Lake Kutubu WMA catchment:

- The odonate fauna of the Lake Kutubu WMA remains incompletely documented. Because odonates are useful indicators of both habitat quality and potential impacts of climate change (Clark and Samways 1996; Ott 2010), further research into the local odonate fauna should be conducted with a focus on documenting odonate diversity and community structure across habitat types and comparing areas with different forest disturbance histories.

- Activities that damage or degrade riparian vegetation along small forest interior streams (such as collection of firewood and felling of trees for canoes), particularly in less degraded forest, should be prevented or minimised.

- Maintaining the ecological integrity of these small, shaded clear-flowing watercourses and their adjacent riparian vegetation and canopy cover will be important to ensure the long-term survival of forest-interior stream specialists.

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Plate 1

A. Small stream in forest at Lake Kutubu

B. Exposed pool along ROW near Lake Kutubu

C. *Nososticta finisterrae* (IUCN Data Deficient)

D. *Pseudagrion parafarinicolle*

E. *Wahnesia kutubuensis*

F. *Drepanosticta johncanni*

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Plate 2

A. *Nososticta conifera*

B. *Nososticta conifera* habitat near Lake Kutubu

C. *Agrionoptera longitudinalis*

D. *Neurothemis ramburii*

E. *Agriocnemis femina*

F. *Xiphiagrion truncatum*

Appendix 1. List of odonate species encountered in the Lake Kutubu WMA

Species	**IUCN**
Argiolestidae	
Wahnesia sp. 1.	NE
Calopterygidae	
Neurobasis australis	LC
Chlorocyphidae	
Rhinocypha tincta	LC
Coenagrionidae	
Agriocnemis femina	LC
Pseudagrion parafarinicolle	NE
Teinobasis pulverulenta	NE
Teinobasis scintillans	NE
Teinobasis sp. 2 (pale yellow)	NE
Xiphiagrion truncatum	NE
Isostictidae	
Selysioneura cervicornu	NE
Platycnemididae	
Idiocnemis australis	NE
Nososticta finisterrae	DD
Nososticta conifera	NE
Platystictidae	
Drepanosticta sp. 1.	NE
Aeshnidae	
Anax maclachlani	NE
Libellulidae	
Agrionoptera longitudinalis	LC
Brachydiplax duivenbodei	LC
Diplacina smaragdina	NE
Huonia epinephele	NE
Neurothemis decora	NE
Neurothemis ramburii	LC
Neurothemis stigmatizans	LC
Orthetrum sabina	LC
Orthetrum serapia	LC
Orthetrum villosovittatum	LC
Pantala flavescens	LC
Protorthemis coronata	NE
Tramea eurybia	LC
Macromiidae	
Macromia celaeno	NE
Total number of species = 29	

Chapter 3.4. Herpetofauna of the Lake Kutubu Wildlife Management Area, Southern Highlands Province, Papua New Guinea

Stephen Richards and Chris Dahl

Oreophryne oviprotector

Summary

We report the results of a survey of frogs and reptiles in the Lake Kutubu Wildlife Management Area (WMA), in Southern Highlands Province, Papua New Guinea (PNG). Twenty-six species were encountered including 19 frogs and 7 reptiles. Ten species of frogs (52.6%) are undescribed and one of these represents a new genus that is currently known only from the Lake Kutubu-Agogo Range area.

The extremely high proportion of undescribed frogs encountered during the survey reflects the incomplete state of knowledge about frogs in the central mountains of PNG. The forests of the Lake Kutubu WMA support important populations of a number of frog species with small known distributions.

Introduction

The herpetofauna of Papua New Guinea is exceptionally diverse, with nearly 700 species of frogs and reptiles currently known from the country (Allison and Tallowin 2015). This number is expected to increase substantially because recent taxonomic revisions of the fauna and exploration of remote regions have revealed numerous new species, particularly in the frog families Pelodryadidae (previously Hylidae) and Microhylidae (e.g. Kraus and Allison 2009a,b; Richards et al. 2009; Günther et al. 2012; Günther and Richards 2011, 2016), the gecko genus *Cyrtodactylus* (e.g. Rösler et al. 2007; Oliver et al. 2008; Oliver et al. 2012, 2016) and the snake genus *Stegonotus* (Ruane et al. 2017).

Existing knowledge about the frogs and reptiles of the Kikori basin is derived largely from a series of surveys sponsored by the World Wildlife Fund (WWF) between 1995 and 2003. These included a number of sites in hill and lower montane forest around Lake Kutubu, and resulted in a number of unpublished flora and fauna inventories (e.g. Hartshorn 1995; Richards 2000, 2002b,c; Richards and Allison 2003) and a guide to the frogs of the Kikori Basin (Richards 2002a). Surveys in the Lake Kutubu area including the nearby Agogo Range also resulted in the discovery and description of a number of new species including *Litoria spartacus* by Richards and Oliver (2006), *Nyctimystes kuduki* by Richards (2007), *Cyrtodactylus capreoloides* by Rösler et al. (2007), and *Cophixalus wempi* by Richards and Oliver (2010). Despite these publications a number of species discovered in the mountains around Lake Kutubu during the WWF surveys remain undescribed. They are illustrated in Richards (2002a).

Here we report the results of a herpetofauna survey conducted within the Lake Kutubu WMA in Southern Highlands Province, PNG, during May 2017.

Methods

Field methods

The survey at Lake Kutubu was conducted by three people (SR, CD and a local assistant) during 5–9 May, 2017. Survey activities focused on forest habitats within the WMA at the western edge of Lake Kutubu, where searches were conducted along forest trails and along the pipeline Right of Way (ROW) (Figure 1). Field methodology closely followed the protocols proposed by Catennazzi et al. (2016) for rapid herpetofauna assessments in tropical environments. We conducted intensive searches for frogs and reptiles along a network of existing trails. During the day we searched for heliothermic (basking) reptiles along trails through forest, in clearings, and on stream banks. Small lizards were collected by hand or were stunned with a large rubber band. Large lizards and snakes were collected by hand. Non-basking reptiles were sampled by searching in deeply shaded forest, during rain, or at dusk. We searched for nocturnal reptiles, including geckos, by walking along forest trails at night with a headlamp. We searched for frogs at night by conducting visual-encounter and aural surveys along streams, and in and around small ponds. Because a large proportion of New Guinea's frogs have life cycles that are independent of freestanding water, we also conducted extensive visual and aural searches along trails in forest away from water. Frog calls are an important diagnostic character that assists greatly with species identification so whenever possible we recorded the advertisement calls of frogs with a Marantz PMD-661 Solid-state Recorder and a Sennheiser ME66 microphone.

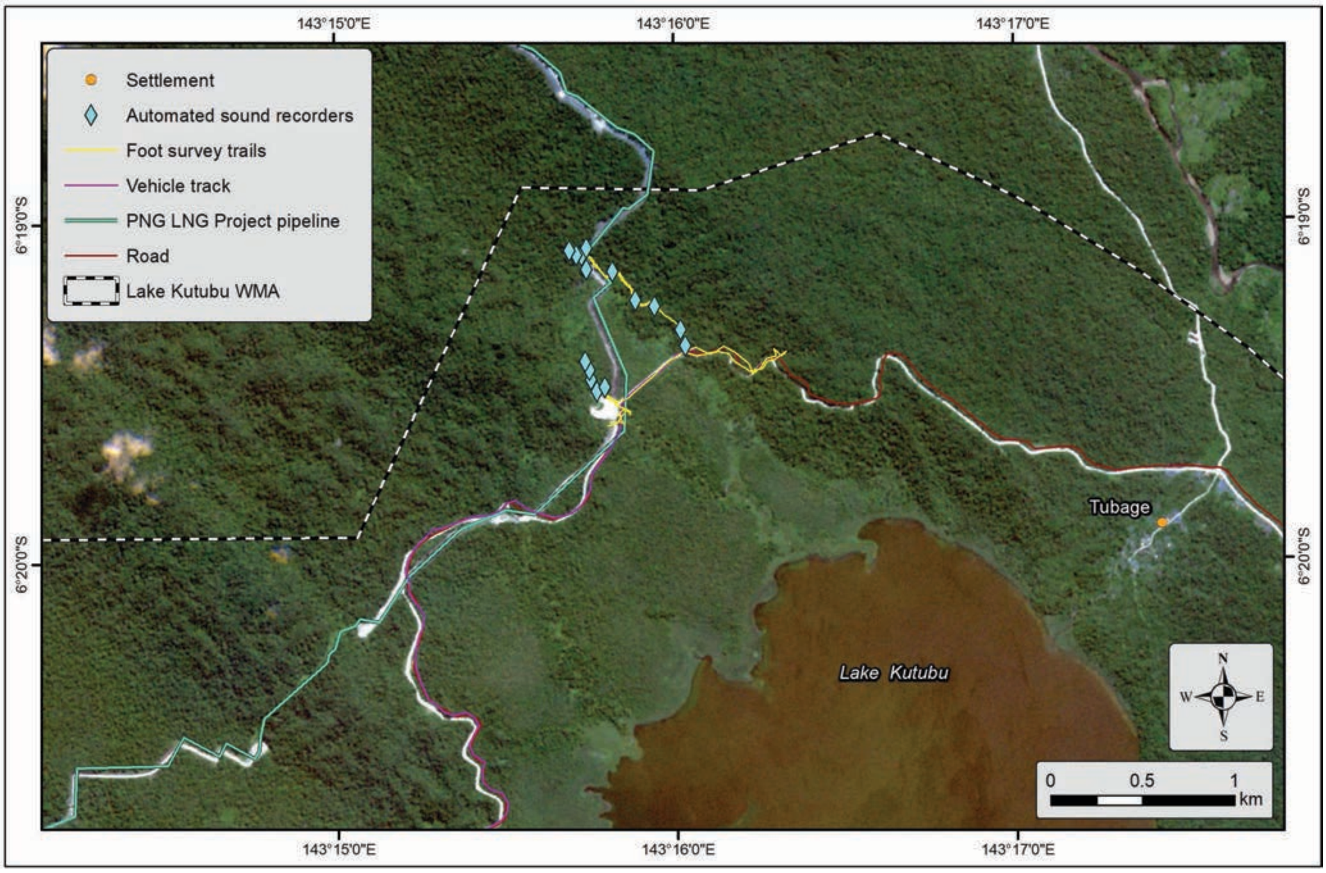

Figure 1 Herpetofauna survey coverage at Lake Kutubu

We deployed three automated sound recorders (SongMeter SM3) for four days at locations intended to sample the acoustic environment in different habitats occupied by frogs (Figure 1). SongMeter recordings were screened for the calls of notable species, including frogs not detected during active survey periods, using Adobe Audition software. Screening followed the protocols described by Richards and Armstrong (2017), and species detected by automated recorders were incorporated into the species list.

Images of reptiles captured by the camera trap arrays established during this survey (see Chapters 3.5, 3.6) were also examined and species identified from these images are incorporated into the lists presented here.

Representatives of most species were photographed alive and a small number of voucher specimens were retained for more detailed examination and identification. Voucher specimens were euthanized by submersion in chlorotone (for amphibians and small reptiles), or with lethal injection of chlorotone for larger reptiles. Specimens were fixed in 10% formalin solution, and then stored in 70% ethanol. Samples of liver tissue for DNA analyses were extracted from representative specimens and stored in 95% ethanol. Voucher specimens will be deposited in the Papua New Guinea National Museum and Art Gallery, Port Moresby, and the South Australian Museum, Australia.

The conservation status of each species was taken from the IUCN Red List (IUCN 2017): LC = Least Concern; DD = Data Deficient; NE = Not Evaluated. Species are referred to as 'new to science' if they were discovered for the first time during this survey, and as 'undescribed' if they are unnamed but were previously know from other sites.

The general vegetation structure of the area is described in Chapter 3.1, and only those habitat features relevant to herpetofauna are mentioned further here. A map illustrating the trails used during this survey is presented in Figure 1.

Results and discussion

Twenty-six species were encountered during the three surveys including 19 frogs and 7 reptiles (Appendix 1). Ten species of frogs (52.6%) were undescribed and one of these represents a new genus that is currently known only from the Lake Kutubu-Agogo Range area. One species of *Choerophryne*, *C. alainduboisi*, that was undescribed when it was documented during the 2017 survey was formally described during preparation of this report.

The forest in the Lake Kutubu WMA supports a high diversity of frogs and a remarkably high proportion of undescribed species. Each of these is discussed below, and representative species and their habitats are illustrated in Plates 1–2. Ongoing protection of these forests will help to ensure the long-term future of this important frog assemblage.

Undescribed and other significant species

Undescribed species

Ten species collected during this survey were undescribed (unnamed but previously known from other sites. These include six microhylid frogs in the genera *Austrochaperina*, *Choerophryne* (described during preparation of this report), *Cophixalus*, *Copiula* and *Hylophorbus*, three treefrogs in the genus *Litoria* and a large stream-dwelling frog in the genus *Papurana*. Brief accounts for each of these species are presented here.

***Austrochaperina* sp. 1. (Plate 1A)**

A small (~35 mm), moderately robust pale brown frog with short limbs, a pale tip of the snout, and distinctly expanded toe discs but only slightly expanded finger discs. It is a forest-dwelling species that, in the Lake Kutubu WMA was found in moist litter on the forest floor where males called with a very long series of ~100–120 harsh yapping notes lasting around 20 s during and after rain. *Austrochaperina* sp. 1. Appears to represent an undescribed species previously known from several localities in the southern foothills of Papua New Guinea in Southern Highlands and Gulf provinces (S.J. Richards, unpublished data).

***Choerophryne alainduboisi* (Plate 1B)**

A very small (males < 20 mm) frog with a variable pattern of darker and lighter brown markings dorsally, long arms, and distinctly expanded finger and toe discs. The call is a short nasal 'buzz' lasting ~0.3–0.4 s uttered from hidden positions among leaves in dense low foliage. It was listed as *Choerophryne* (then *Albericus*) *tuberculus* by Richards (2002a) but it is not that species. This species was undescribed at the time of this survey, and was commonly encountered in hill forest within the WMA; it was recently described from forest on nearby Iagifu Ridge (Günther and Richards 2018).

***Cophixalus* sp. 1**

A small (< 20 mm), rather short-legged frog with expanded finger and toe discs and an angular snout. Several individuals of this species were heard calling from litter on the forest floor during overcast conditions. *Cophixalus* sp. 1 is similar to *C. wempi*, a species described by Richards and Oliver (2010) from the nearby summit of Iagifu Ridge but appears to have fewer tubercles on the legs and eyelids, and its calls are shorter and have a higher frequency. It is tentatively considered to be undescribed because similar frogs have been documented elsewhere in the region (S. J. Richards, unpublished data). Genetic studies are currently underway to determine its taxonomic status.

***Copiula* sp. 2 (Plate 1C)**

A moderately large (males 30–35 mm), short-legged microhylid frog with a plump body and an angular snout that called from within or on top of litter on the forest floor during and after rain. The call is a series of 1–3 (most commonly two) harsh, slowly produced 'yapping' notes lasting about 0.2–0.3 s. This species was previously known from several other sites in Southern Highlands Province including Arakubi Quarry on the Agogo Range (Richards and Armstrong 2017).

***Hylophorbus* sp. 1.**

A moderately large (~33 mm), terrestrial frog with long legs, a rounded snout and a small spot above the groin. It lives in moist leaf litter on the forest floor where males call from within or on the surface of the litter with a long sequence of slowly repeated honking notes. *Hylophorbus* sp. 1. is undescribed but it is known from several localities in the southern foothills of Papua New Guinea spanning both the Kikori and Purari River catchments in Gulf Province (S. J. Richards, unpublished data).

New genus and new species (Plate 1D)

This is a tiny species (<13 mm) that was previously known from forest adjacent to Arakubi Quarry on the Agogo Range (Richards and Armstrong 2017). In the Lake Kutubu WMA it was commonly heard but rarely seen. It lives in moist litter on the forest floor where males call with a series of 30–60 high-pitched chirping notes lasting ~10–13 s. Unlike most frogs this species calls almost exclusively during the day, with highest vocal activity occurring early in the morning and late in the afternoon. DNA barcoding revealed that this species does not belong in any existing genus of microhylid frogs in New Guinea.

***Litoria* sp. 3 (Plate 1E)**

A medium sized (males to ~ 40 mm) slender treefrog with large eyes, limited webbing between the fingers and a small spine on each heel. This species is closely associated with slow-flowing but clear streams (Plate 1F) where males call from low riparian vegetation with a series of quiet ticking notes occasionally followed by a short trill. It belongs to a taxonomically difficult group of frogs related to *Litoria genimaculata* and is listed as *Litoria* sp. nov. 4 in Richards (2002a).

***Litoria* sp. 4 (Plate 2A)**

A moderately small (< 40 mm), slender, predominantly green frog with a distinct white bar behind the eye and bright red colouration on the underside of the lower belly and legs. It was common along small seepage streams at Lake Kutubu where males called with a short, harsh note 'rrak'. *Litoria* sp. 4 was previously known from Iagufu Ridge, Gobe Ridge and Arakubi and it was listed as *Litoria* sp. nov. 7 in Richards (2002a).

***Litoria* sp. 5 (Plate 2B)**

A small (< 35 mm) very slender, predominantly brown frog with scatterd green flecks on the back and pale yellow on the undersides of the legs. It was common along small seepage streams at Lake Kutubu where males called from leaves up to 2 m high with a series of 3–6 rapidly repeated bleating notes. This species is illustrated as *Litoria nigropunctata* in Richards (2002a) but that species is now known to be restricted to northern New Guinea. The undescribed species at Lake Kutubu has a broad distribution along the southern flanks of New Guinea's central cordillera from at least Timika in Papua Province, Indonesia in the west (Richards et al. 2015) to the Kikori basin in the east.

***Papurana* sp. 1 (Plate 2C).**

This very large frog (to >100 mm) was previously considered to be Papurana arfaki, a species widespread across the lowlands and foothills of New Guinea. However recent genetic studies have shown it to be distinct from that species and it is currently being described as a new species (L. Oliver et al. in prep). Several individuals were observed along small streams draining into the western edge of Lake Kutubu.

General comments

The total of 19 species of frogs documented at Lake Kutubu is slightly less than the diversity reported from Wau Creek (23 species) but more than that documented at Uro Creek (14 species. However the number of reptile species encountered (7 species) is substantially lower than both of these sites. Although reptile diversity on the island of New Guinea is strongly constrained by altitude (Tallowin et al. 2017), with much greater species diversity encountered in lowland habitats (e.g. 44 species in the lowlands of the Lakekamu basin; Allison et al. 1998) the low diversity documented at Lake Kutubu probably also reflects the fact that survey effort was focused heavily towards frogs during this survey.

Biodiversity and conservation values

The forests at Lake Kutubu support a moderately high diversity of frog species, and nearly half of the frog species encountered there are undescribed. Most of these have limited known ranges in the mountains of south-central PNG, and the Lake Kutubu WMA represents a significant refuge for this assemblage of poorly known species. In particular an undescribed genus and species of microhylid frog with a very small known distribution that is focused on the Lake Kutubu-Agogo Range area appears to be abundant in forests at the western edge of the WMA and probably occurs in suitable terrestrial habitats throughout the protected area. The protection afforded to this species by the Lake Kutubu WMA may be vital for its long-term survival.

Habitats that are significant for frogs within the WMA include small, shaded clear-flowing watercourses and their adjacent riparian vegetation that are used for breeding by an undescribed treefrog related to *Litoria genimaculata* and an undescribed ranid frog related to *Papurana arfaki*; and two additional undescribed treefrogs breed in smaller, clear seepage streams within the WMA. The moist litter on the forest floor around the lake shelters six species of undescribed microhylid frogs that all have small known distributions in the lowlands and foothills of southern PNG. Like other terrestrial Australopapuan microhylid frogs (Anstis et al. 2011) these species are predicted to lay direct-developing eggs in or under moist litter on the forest floor. Because reduction of the forest canopy through damage to or removal of trees in the primary forest increases insolation to, and reduces humidity and moisture content of, the litter layer this disturbance may lead to increased embryonic mortality of these species. Retention of unlogged forest with intact canopy cover within the WMA is important for their long-term survival.

The invasive Cane Toad (*Rhinella marina*) is abundant in Moro Camp but was not detected in forest within the WMA. This toad proliferates in open, disturbed habitats so maintaining high quality forest within the WMA, while also taking care not to inadvertently transport toads into the forest there in cargo, will significantly reduce the chances of this species becoming established within the forests of the WMA.

Recommendations

Maintaining frog diversity, and particularly the assemblage of undescribed species, within the Lake Kutubu WMA will require that forest within the boundaries be protected from future logging. In addition the following activities are recommended:

- Activities that damage or degrade the remaining patches of primary forest, particularly the small clear waterways, within the WMA should be prevented or minimised, including cutting of timber for construction of canoes or fuel.

- The invasive Cane Toad (*Rhinella marina*) which is abundant at Moro, was not detected at sites surveyed within the WMA. This species is commonly transported between sites in human cargo, and in PNG and Solomon Islands is sometimes moved to new sites on purpose in the belief that it controls snakes. Care should be taken to avoid accidentally (or purposefully) transporting this toad into the WMA.

- Lake Kutubu has tremendous tourism potential. In addition to the area's natural beauty and the conservation and cultural significance of the aquatic environment within the WMA, efforts should be made to promote the region's terrestrial biodiversity more generally.

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Plate 1

A. *Austrochaperina* sp. 1

B. *Choerophryne alainduboisi*

C. *Copiula* sp. 2

D. New genus and species of microhylid frog

E. *Litoria* sp. 3

F. Stream habitat of *Litoria* sp. 3 and *Papurana* sp. 1

Plate 2

A. *Litoria* sp. 4

B. *Litoria* sp. 5

C. *Papurana* sp. 1

D. *Varanus indicus*-group (camera trapped)

E. *Emoia caeruleocauda*

F. *Emoia longicauda*

Appendix 1. List of frogs and reptiles encountered at Lake Kutubu and their IUCN status

Frogs	**IUCN Status**
Microhylidae	
Austrochaperina sp. 1	NE
Choerophryne crucifer	NE
Choerophryne alainduboisi	NE
Cophixalus sp. 1	NE
Copiula sp. 2	NE
Hylophorbus rufescens	LC
Hylophorbus sp. 1	NE
Liophryne schlaginhaufeni	LC
Metamagnusia slateri	LC
Oreophryne oviprotector	NE
Oreophryne pseudunicolor	NE
Sphenophryne cornuta	LC
Genus nov. sp. nov.	NE
Pelodryadide	
Litoria infrafrenata	LC
Litoria sp. 3 cf. *genimaculata*	NE
Litoria sp. 4 (red-legs)	NE
Litoria sp. 5	NE
Ranidae	
Papurana sp. 1	NE
Papurana daemeli	LC
Total frogs = 19	
Reptiles	
Scincidae	
Emoia caruleocauda	LC
Emoia longicauda	NE
Emoia sp. (large)	NE
Emoia sp. (small)	NE
Varanidae	
Varanus indicus-group	LC
Colubridae	
Stegonotus cucullatus	NE
Stegonotus parvus	NE
Total reptiles = 7	

Chapter 3.5. Avifauna of the Lake Kutubu Wildlife Management Area, Southern Highlands Province, Papua New Guinea

Iain A. Woxvold and Leo Legra

Pesquet's Parrot, an IUCN Vulnerable species encountered at Lake Kutubu

Summary

Birds were surveyed at the Lake Kutubu Wildlife Management Area (WMA) in Southern Highlands Province, Papua New Guinea, during 6–18 May 2017. Survey methods included active searches, camera trapping, mist netting and automated sound recording. The results of prior bird surveys conducted in the area are combined with those of the present study. Two hundred and sixteen bird species have been recorded within and immediately adjacent to the WMA, including 127 species during the 2017 surveys. Eighteen conservation listed species have been recorded, including seven species listed by the IUCN as Vulnerable (Papuan Eagle (*Harpyopsis novaeguineae*), Pesquet's Parrot (*Psittrichas fulgidus*)) or Near Threatened (Gurney's Eagle (*Aquila gurneyi*), Grey-tailed Tattler (*Tringa brevipes*), Red-necked Stint (*Calidris ruficollis*), Striated Lorikeet (*Charmosyna multistriata*), Banded Yellow Robin (*Poecilodryas placens*)) and 13 species that are Protected under Papua New Guinean law. Three restricted-range bird species are confirmed present—Striated Lorikeet, Greater Melampitta (*Megalampitta gigantea*) and Banded Yellow Robin. The Lake Kutubu WMA supports an ecologically diverse ecosystem-complex that includes a variety of well-connected forest and wetland types. The forest bird community is species rich and includes species typically representative of lowland, hill and montane forest environments. Existing avian conservation values and the potential for ecotourism are discussed, and recommendations for their future enhancement proposed.

Introduction

Lake Kutubu is mainland Papua New Guinea's largest perched lake. Lying at approximately 820 m above sea level (asl) on the southern slopes of the central cordillera, it covers more than 4,900 hectares (ha) of the Kikori River basin in Southern Highlands Province. It is flanked by high-relief terrain with forested mountain slopes rising more than 400 m above lake level within one kilometre of its shore. The landforms, geology, climate and vegetation of the Lake Kutubu area are summarised in detail in the Report Summary.

The Lake Kutubu and adjacent Mubi River valleys are the traditional lands of the Foi people (Regis 2000). First contact with Europeans did not occur until the 1930s (Champion 1940). Half a century later, in the late 1980s commercial reserves of oil and gas were discovered in the uplands of the Kikori basin. Production is ongoing, and the Lake Kutubu area hosts a variety of support facilities and infrastructure.

In June 1992 the Lake Kutubu Wildlife Management Area (WMA) was established, covering more than 23,500 ha of the lake and immediate surrounds (excluding the Moro facilities area) (Figures 1 and 4 in Report Summary). In partnership with industry leaders (a joint venture led by Esso Highlands Limited, then operator of the PNG LNG Project), in 1994 the World Wildlife Fund (WWF) initiated the Kikori Integrated Conservation and Development Project (KICDP), currently termed the Kikori basin Conservation Program, aimed at preserving biodiversity within the Kikori drainage (Leary et al. 1996; McCall and Flemming 2000). Since then, WWF and its partner organisations have conducted numerous biodiversity surveys in the region, including within and around the Lake Kutubu WMA.

As part of a broader multi-disciplinary biodiversity study, this report outlines the results of bird surveys undertaken in the Lake Kutubu WMA in 2017, and provides a summary of prior bird records from the WMA and its immediate surrounds.

Existing data

The first ornithologist to visit Lake Kutubu was R. Schodde of the Commonwealth Scientific and Industrial Research Organization (CSIRO). In 1961 he spent four weeks (13 September to 10 October) surveying birds at the northwest end of the lake between the Soro River outlet and the Mubi River valley (Schodde and Hitchcock 1968). In addition to general field observations, Schodde collected 132 specimens from 79 species (held in the Australian National Wildlife Collection (ANWC), Canberra). The records are well annotated, with most encounters traceable to within the WMA. Exceptions include those species shot by local Papua New Guinean assistants whose movements were not documented but are presumed to have been restricted to the local vicinity.

More than 30 years later, as part of the first KICDP survey program, in 1994 (Hartshorn et al. 1994) and 1995 (Burrows 1995) Ian Burrows surveyed birds within and immediately adjacent to the Lake Kutubu WMA around Moro and the lake area, and outside (more than 4 km south and west of) the WMA on the Agogo Range (at c. 900–1,100 m asl along the Agogo-Kaipu and Kantobo roads). During ≤10 observation days (1994 and 1995 surveys combined; no trapping) most of the forest survey effort was expended in the Agogo Range. Unfortunately, only the 1994 reconnaissance report (Hartshorn et al. 1994) distinguishes records from the Agogo Range and the Moro–Kutubu areas, and the provenance of many species observed by Burrows only in 1995 cannot be determined. Nevertheless, all surveys were conducted at elevations within those covered by the WMA, and most species of uncertain provenance have been recorded locally by other workers.

Subsequently Roger Jaensch (Wetlands International), with a variety of accompanying workers, observed birds on and around Lake Kutubu during four visits in 1997–1999 (Jaensch, Undated A, B; Jaensch and Kulmoi, Undated). Jaensch made additional brief surveys outside the WMA on the nearby Agogo Range and annotated his results sufficiently to distinguish records from each site.

Jared Diamond and David Bishop conducted repeat-visit surveys of the Moro–Lake Kutubu–Agogo Range area in 1998, 1999, 2001, 2003, 2006 and 2007 (Diamond and Bishop, Undated; K. D. Bishop, *in litt.* 2018). Their observation-based surveys were conducted at 790–1,440 m asl while based at Moro near Lake Kutubu and at the Ridge Camp on the Agogo Range (Iagifu Ridge). Diamond and Bishop (Undated) reported combined results from the Agogo Range and Moro–Kutubu areas, but have recently provided a list of those species recorded within the WMA (K. D. Bishop, *in litt.* 2018).

Insofar as locality information can be determined with certainty, the results of the above surveys are combined with those of the present study to provide a comprehensive list of birds recorded to date within the Lake Kutubu WMA. While the WMA was delineated to exclude converted habitats of the Moro camp and airstrip, birds recorded at these sites are here included among the WMA records as this area-of-exclusion is immediately surrounded by the WMA.

Methods

Birds were surveyed by IW and LL within the Lake Kutubu WMA during 6–9 May and on 18 May 2017, and a camera trapping study was conducted there during 6–18 May. Surveys were conducted north of Lake Kutubu between Moro and Tubage village (Figure 1). The main survey effort was spent near the kilometre point (KP) 86–87 section of the pipeline right-of-way (ROW), providing access to wooded swamps, hill forest and lower montane forest. Hill forest along the KP 89–90 section of the pipeline ROW was surveyed on the morning of 9 May (4.25 hours). Additional opportunistic records were collected by IW while based at Moro during 4–18 May and 19–24 August 2017.

Survey methods included 'active' searches, automated sound recording, mist netting and camera trapping (Table 1). These techniques were combined to maximise completeness of the bird species inventory in the time available.

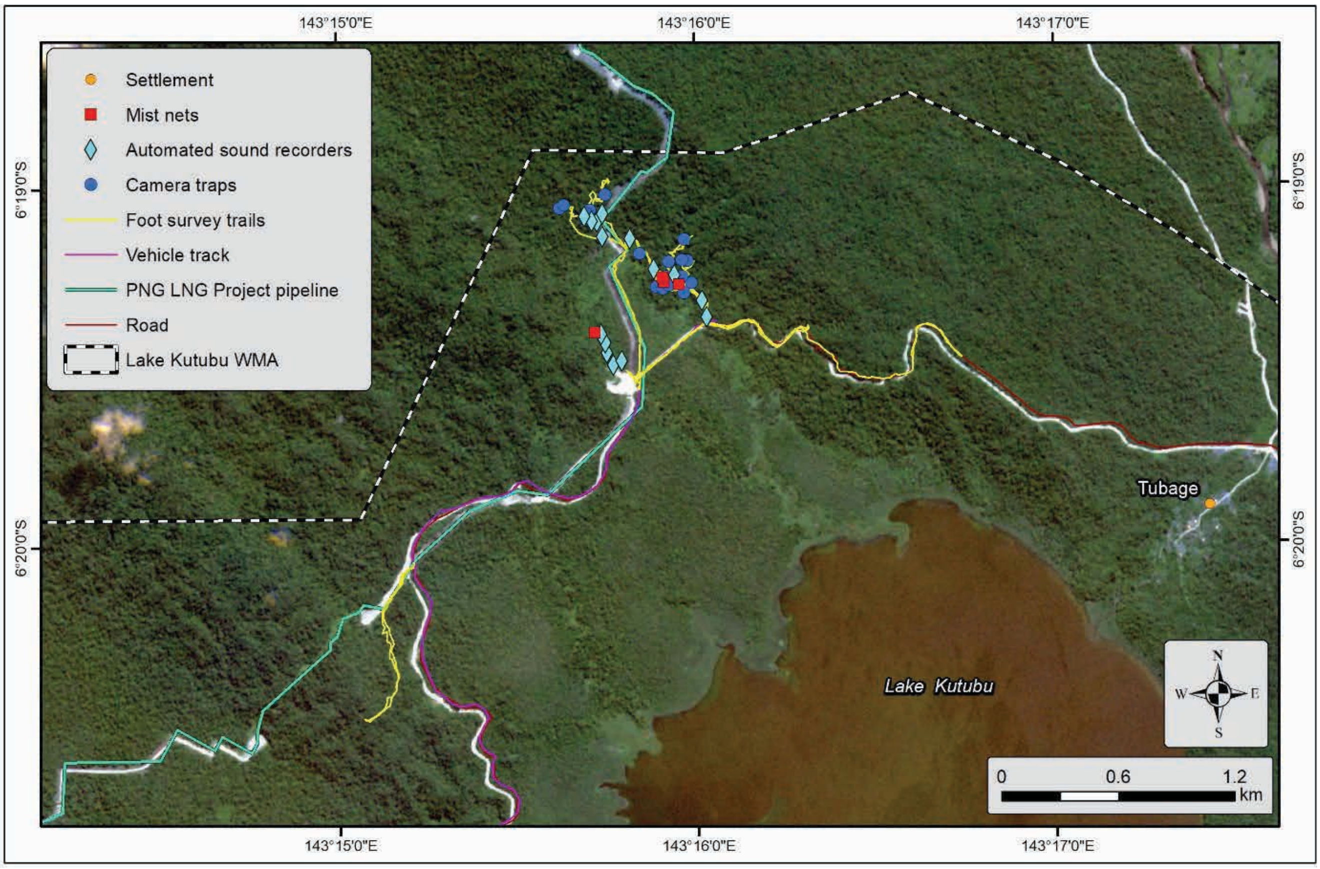

Figure 1. Bird survey coverage in the Lake Kutubu WMA during 2017.

Table 1. Effort summaries.

Sampling method	Sampling effort
Active searches	
Search hours	33.75
Camera trapping	
No. camera traps	19
Camera trap hours	5,198.75
Mist netting	
No. mist nets	4
Diurnal net-hours	21.00
Automated sound recording	
No. recorder positions	15
Recording hours	290.75

Active searches

Active searches were conducted by foot through forest, along roads and along the pipeline ROW. Birds were identified visually and/or by their calls. Logistic constraints restricted searches to periods between 07:40 and 16:15, precluding searches during the most active periods of bird activity.

Camera trapping

Nineteen unbaited white-flash digital camera traps (Reconyx PC850) were deployed along animal trails in an effort to photograph terrestrial birds and mammals. All camera traps were programmed to maximum detection sensitivity and to take three photographs on each 'trigger event' with the minimum amount of rest time between triggers (<2 seconds). Units were deployed for a total of nearly 5,200 camera trap-hours (Table 1). Camera trap locations are shown in Figure 1.

Relative abundance indices (RAIs) were calculated from the rate of independent photographic capture 'events' (per hour x 100) summed across all cameras (Appendix 1). Events were considered independent where consecutive pictures of the same species were taken more than 30 minutes apart. Multiple independent events were scored within 30-minute periods only when more than one individual was seen in a single photograph and/or where plumage differences permitted identification of separate individuals in successive photographs.

Mist netting

Four mist nets (12 m, 31 mm mesh) were deployed in forest near KP 87 by the mammal survey team in an effort to catch bats at night (Figure 1). Three of these nets, located near hill forest–wooded swamp edge between the road and pipeline ROW, were left open during the day for a total of 21 daylight net-hours. All nets were erected close to the ground (<6 m high) on trimmed saplings and checked regularly during daylight hours. Captured birds were measured (bill, head, tarsus, wing), photographed and a small (<1 millilitre) blood sample was collected and preserved in 70% ethanol. All birds were released after the terminal end of three outer rectrices (tail feathers) were clipped to permit identification on recapture.

Automated sound recorders

Automated sound recorders (Wildlife Acoustics: Song Meter SM3) were deployed in 15 positions in forest environments by mammologist Kyle Armstrong and herpetologist Stephen Richards (Figure 1). These units recorded audible sounds, including bird calls, continuously throughout the sampling period (Table 1). All SM3 recordings were screened for the calls of notable species, including conservation listed species and birds not detected during active survey periods, using iZotope RX 5 Audio Editor software.

Conventions used

Taxonomy and nomenclature (common and scientific names) follow the International Ornithological Congress (IOC) World Bird List (version 8.1) (Gill and Donsker 2018). Where species are mentioned in the text the scientific name appears with the common name on first mention and only the common name is used thereafter.

Species appearing in square brackets (in text, tables and appendices) were only provisionally identified to species level; though not definitively identified, encounters are considered most likely to have involved the species named and these records are included in the overall species tally. Records denoted by '?' in Appendix 1 are considered less certain and are not included in site totals.

Conservation listed species include those listed in the IUCN Red List of Threatened Species (IUCN 2017) as Threatened (Vulnerable—VU; no Endangered or Critically Endangered bird species were recorded or are expected to occur in the Lake Kutubu WMA), Near Threatened (NT) or Data Deficient (DD) and those listed as Protected (P) under the *PNG Fauna (Protection & Control) Act 1966*. The list of nationally protected species was obtained from Kula and George (1996). Restricted range (RR) species are those having a total global breeding range of less than 50,000 km^2 (Stattersfield et al. 1998).

A Garmin 60CSx GPS unit was used to record tracks and coordinates in the field.

Results

At least 215 bird species from 59 families have been recorded within and/or immediately adjacent to (Moro facilities area) the Lake Kutubu WMA (Appendix 1; the stated total excludes provisional records that may involve already recorded species). The number of species recorded by various workers is listed in Table 2. The actual number of species recorded within the WMA may be higher but there is uncertainty over the locality of some records reported by Burrows (1995) (see 'Existing data' above).

Table 2. The number of bird species recorded by various workers within the Lake Kutubu WMA.

Surveyors	No. species
Schodde 1961	104
Burrows 1994–95	71*
Jaensch 1997–99	107
Diamond and Bishop 1998–2003	165
Woxvold and Legra 2017	127
Total no. species recorded	215

*WMA species counts are likely to be higher but cannot be determined due to uncertainty over record localities (see 'Existing data' above).

During a review of earlier studies, adjustments were made to the status/identity of seven previously recorded taxa. Reasons for these adjustments are outlined in detail in Appendix 2. The changes include:

- Removal from the WMA list of four unconfirmed species whose presence requires a range extension and/or is better assigned to a more common locally occurring species—Southern Cassowary (*Casuarius casuarius*), Black-billed Brushturkey (*Talegalla fuscirostris*), crowned pigeon (*Goura* sp.) and Fan-tailed Cuckoo (*Cacomantis flabelliformis*).

- In the absence of confirmed records, where two closely related species may occur locally and are difficult to distinguish in the field, the expansion of single taxon listings to dual-possibility records—Papuan/White-throated Nightjar (*Eurostopodus papuensis/mystacalis*), Mountain/Uniform Swiftlet (*Aerodramus hirundinaceus/vanikorensis*) and Yellow-billed/Mountain Kingfisher (*Syma torotoro/megarhyncha*).

One-hundred and twenty-seven bird species from 44 families were recorded within the WMA during the 2017 surveys (Table 2; Appendix 1). Thirteen birds from eight species were mist netted and ten bird species were photographed by camera trap (Appendix 1). Camera trap rates (RAIs) for photographed species are displayed in Figure 2. The Pheasant Pigeon (*Otidiphaps nobilis*) was the most frequently camera trapped bird species; the number of photographic events for this species (24) was more than twice that of the next most frequently photographed birds—Papuan Pitta (*Erythropitta macklotii*; ten events) and Collared Brushturkey (*Talegalla jobiensis*; nine events).

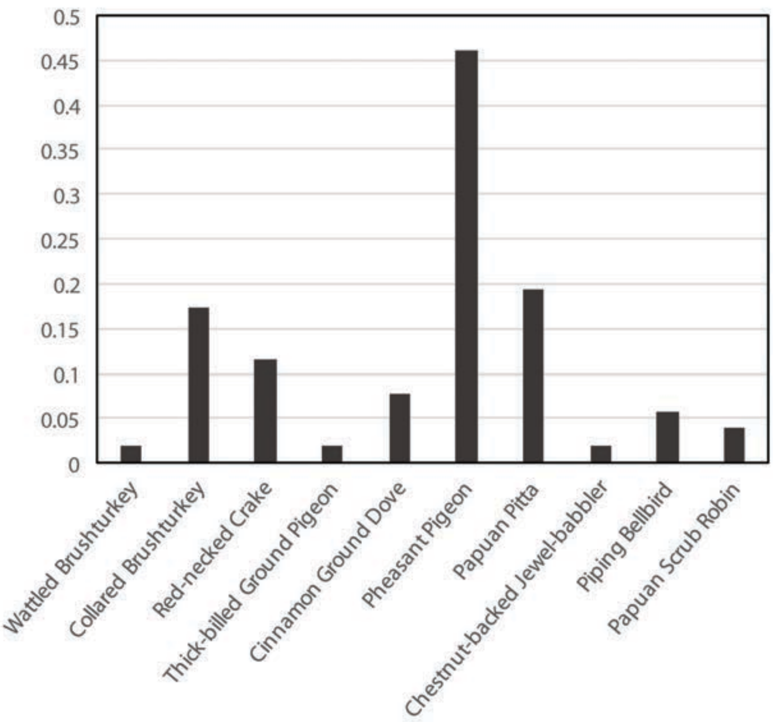

Figure 2. Camera trap rates (RAIs).

Eight species were recorded within the WMA for the first time in 2017 (Table 3), including the restricted-range Greater Melampitta (*Megalampitta gigantea*). Three of the 2017 additions were confirmed present by camera trapping alone—Wattled Brushturkey (*Aepipodius arfakianus*), Thick-billed Ground Pigeon (*Trugon terrestris*) and Cinnamon Ground Dove (*Gallicolumba rufigula*). One novel species was identified from mist net captures—Mottle-breasted Honeyeater (*Meliphaga mimikae*). All other recent additions were seen and/or heard during active searches and/or recorded by SM3 recorders.

Table 3. Bird species recorded within Lake Kutubu WMA for the first time in 2017.

Scientific Name	English Name	Status
Aepypodius arfakianus	Wattled Brushturkey	
Trugon terrestris	Thick-billed Ground Pigeon	
Gallicolumba rufigula	Cinnamon Ground Dove	
Tyto tenebricosa	Greater Sooty Owl	
Falco cenchroides	Nankeen Kestrel	
Meliphaga mimikae	Mottle-breasted Honeyeater	
Megalampitta gigantea	Greater Melampitta	RR
Passer montanus	Eurasian Tree Sparrow	

Resident/migratory species

Including data from all surveys, the Lake Kutubu WMA avifauna includes some 191 breeding resident species and 23 species that occur in the Kikori basin only or predominantly as non-breeding migrants (Appendix 1). The residency status of the *Eurostopodus* nightjar recorded by Schodde (Schodde and Hitchcock 1968) is uncertain—it may have been a resident species (Papuan Nightjar (*E. papuensis*)) or an Australian breeding migrant (White-throated Nightjar (*E. mystacalis*)) (see Appendix 2). At least five breeding resident species have local regional populations seasonally augmented by non-breeding visitors from Australia—Green Pygmy Goose (*Nettapus pulchellus*), Pacific Black Duck (*Anas superciliosa*), Australasian Grebe (*Tachybaptus novaehollandiae*), Pacific Koel (*Eudynamys orientalis*) and Oriental Dollarbird (*Eurystomus orientalis*).

Resident taxa include 181 species of terrestrial environments and ten potentially locally breeding wetland species. Recorded migrants include nine terrestrial species—Eastern Cattle Egret (*Bubulcus coromandus*), Australian Pratincole (*Stiltia Isabella*), Oriental Cuckoo (*Cuculus optatus*), Forest Kingfisher (*Todirhamphus macleayii*), Sacred Kingfisher (*T. sanctus*), Rainbow Bee-eater (*Merops ornatus*), Nankeen Kestrel (*Falco cenchroides*), Common Cicadabird (*Coracina tenuirostris*) and Gray's Grasshopper Warbler (*Locustella fasciolata*)—and 14 wetland species. Wetland bird species (resident and migratory) are discussed separately below (see 'Wetland environments' below).

Most migratory birds recorded within the WMA breed outside New Guinea in Australia (17/23; 73.9%). Six migratory species breed in the northern hemisphere and visit New Guinea during the austral summer—Sharp-tailed Sandpiper (*Calidris acuminata*), Red-necked Stint (*C. ruficollis*), Common Sandpiper (*Actitis hypoleucos*), Grey-tailed Tattler (*Tringa brevipes*), Oriental Cuckoo and Gray's Grasshopper Warbler.

Conservation listed species

Eighteen conservation listed species have been recorded within the WMA (Table 4). They include seven birds listed by the IUCN as Vulnerable or Near Threatened and 13 species that are Protected under Papua New Guinean law. Three restricted-range bird species are confirmed present—Striated Lorikeet (*Charmosyna multistriata*), Greater Melampitta and Banded Yellow Robin (*Poecilodryas placens*). Conservation listed and restricted-range species are discussed individually below (Species accounts).

Table 4. Conservation listed and restricted-range bird species recorded from Lake Kutubu WMA.

Status indicates species listed as globally threatened (VU—Vulnerable) or Near Threatened (NT) by the IUCN, those listed as Protected (P) under the *PNG Fauna (Protection & Control) Act 1966*, and restricted-range (RR) species.

Scientific Name	English Name	Status
Ardea alba	Great Egret	P
Ardea intermedia	Intermediate Egret	P
Egretta garzetta	Little Egret	P
Harpyopsis novaeguineae	Papuan Eagle	VU, P
Aquila gurneyi	Gurney's Eagle	NT
Calidris ruficollis	Red-necked Stint	NT
Tringa brevipes	Grey-tailed Tattler	NT
Rhyticeros plicatus	Blyth's Hornbill	P
Probosciger aterrimus	Palm Cockatoo	P
Psittrichas fulgidus	Pesquet's Parrot	VU, P
Charmosyna multistriata	Striated Lorikeet	NT, RR
Megalampitta gigantea	Greater Melampitta	RR
Manucodia chalybatus	Crinkle-collared Manucode	P
Ptiloris magnificus	Magnificent Riflebird	P
Diphyllodes magnificus	Magnificent Bird-of-paradise	P
Cicinnurus regius	King Bird-of-paradise	P
Seleucidis melanoleucus	Twelve-wired Bird-of-paradise	P
Paradisaea raggiana	Raggiana Bird-of-paradise	P
Poecilodryas placens	Banded Yellow Robin	NT, RR

Invasive alien species

One non-native bird species was recorded, the Eurasian Tree Sparrow (*Passer montanus*) having recently established itself across much of the Moro facilities area. Eurasian Tree Sparrow was first recorded in mainland PNG at Port Moresby in April 2009 (Gregory 2009). An accomplished colonist, its recent arrival has been followed by a rapid expansion into settled areas with the first record from nearby Gulf Province at Kerema in 2011 (Woxvold et al. 2015). This is the first reported occurrence from Southern Highlands Province, though it is likely already to be more widespread there. It is closely associated with areas of human settlement and almost exclusively occupies open and disturbed habitats.

Species accounts

Species accounts follow (in taxonomic order) for conservation listed taxa, restricted-range species, rarely recorded species, and wherever records extend a species' known geographic or elevational range. Accounts for IUCN Threatened species include a summary of threats and susceptibilities. Unless otherwise stated, summary information on status and distribution is taken from Beehler and Pratt (2016).

Green Pygmy Goose (*Nettapus pulchellus*)

Twenty-nine birds seen on the lake by Jaensch (Undated A) represent a high elevation record for this species (Coates 1985).

Collared Brushturkey (*Talegalla jobiensis*)

The Collared Brushturkey occupies northern New Guinea from Yapen Island and the Mamberamo basin east to Milne Bay. Until recently, confirmed records from the southern watershed were restricted to a few sites in the Owen Stanley Range (Aroa River area) and the upper Purari River basin (Jones et al. 1995; Mack and Wright 1996; Sinclair 2001, 2002; J. Ross Sinclair, *in litt.* 2015). The shy behaviour of megapodes, and the difficulty in distinguishing closely related species based on vocalisations alone, has meant that some prior southern upland records were reported only at the genus-level or followed earlier published authorities in assuming the species to be the southern lowland resident Black-billed Brushturkey (*Talegalla fuscirostris*). However, emerging evidence suggests that the Collared Brushturkey replaces the Black-billed Brushturkey in upland sites across much of southern mainland Papua New Guinea (Freeman and Class Freeman 2014; Beehler and Pratt 2016; Woxvold, unpublished data).

Camera trapping in 2017 showed the Collared Brushturkey to be fairly common (nine camera trap events on seven cameras; Figure 2; Plate 1A) in hill forest and at the edge of wooded swamps north of the lake. Collared Brushturkeys were also camera trapped at 925–1,400 m asl in forest approximately 3–5 km outside the WMA on limestone terrain on the Agogo Range (Woxvold and Legra, unpublished data). These are the first confirmed records from the Kikori basin.

New Guinea Scrubfowl (*Megapodius decollatus*)

Until recently, the New Guinea Scrubfowl was considered to be largely restricted to northern New Guinea, with the Orange-footed Scrubfowl (*M. reinwardt*) replacing it across most of the southern watershed (Jones et al. 1995). However, there is growing evidence that the New Guinea Scrubfowl is widespread along the southern slopes of the central cordillera where it replaces the Orange-footed Scrubfowl in upland environments (Woxvold et al. 2015; Woxvold, unpublished data). Unfortunately, many prior records of *Megapodius* from southern New Guinea, including from the Moro-Lake Kutubu-Agogo Range area (Diamond and Bishop, Undated), refer to the Common (Dusky) Scrubfowl (*M. freycinet*), within which both the New Guinea and Orange-footed Scrubfowls (*inter alia*) were formerly subsumed (Mayr 1938). Difficulties with observing these species in the field, and with collecting detailed and reliable information from local informants, mean that such records cannot be safely assigned to either taxon.

New Guinea Scrubfowls have been camera trapped at 920–1,400 m asl in forest on limestone on the Agogo Range, approximately 3–5 km outside the WMA (Woxvold and Legra, unpublished data), and to the southeast at 540 m asl in the Gobe operations area (Woxvold, unblished data). These are the first confirmed records from the Kikori basin. Within the WMA, *Megapodius* calls were recorded at three SM3 stations in 2017. Orange-footed Scrubfowl certainly occupies lowland habitats further downstream in the Kikori basin (see Chapters 1.5 and 2.5). However, based on a growing body of knowledge about the distribution and habitat requirements of these species in New Guinea's southern watershed (Woxvold, unpublished data), and on confirmed records from comparable habitats nearby, the Lake Kutubu WMA records are here provisionally assigned to New Guinea Srcubfowl.

Great Egret (*Ardea alba*), Intermediate Egret (*Ardea intermedia*), Little Egret (*E. garzetta*) (P)
Three nationally Protected egret species have been recorded at Lake Kutubu—Great Egret (*Ardea alba*), Intermediate Egret (*Ardea intermedia*) and Little Egret (*E. garzetta*) (Schodde and Hitchcock 1968; Jaensch, Undated A; K. D Bishop, *in litt*. 2018). Each occurs throughout New Guinea in a variety of wetland habitats, predominantly in the lowlands but occasionally up to montane elevations (Coates 1985). Their breeding status in New Guinea is poorly understood; some birds are present in all months, but each year there is a significant exchange of waterbirds between Australia and New Guinea with most birds occurring locally as non-breeding visitors (Coates 1985; Dingle 2004). Breeding at specific locations has been confirmed for the Great Egret (Aroa River, Trans-Fly) and Intermediate Egret (Trans-Fly) but not for the Little Egret (Bishop 2005). No egrets have been recorded breeding at Lake Kutubu.

Bat Hawk (*Macheiramphus alcinus*)
An unusual raptor, widespread in forest from Malaysia to New Guinea where it hunts bats and swiftlets at dawn and dusk. Rare in New Guinea from lowlands to above 1,100 m asl. On 18 October 2007 one was observed in flight by K. D. Bishop over a ridge above Kaimari Creek.

Papuan Eagle (*Harpyopsis novaeguineae*) (VU, P)
New Guinea's largest raptor, the Papuan Eagle (*Harpyopsis novaeguineae*) occupies forested habitats from sea-level to over 3,000 m. Visually inconspicuous (does not soar), it is most readily detected by its distinctive and far-carrying call.

The Papuan Eagle was recorded locally by Burrows (Hartshorn et al. 1994).

This low-density species is uncommon throughout its range and is vulnerable to habitat loss and hunting (Coates 1985; Watson and Asoyama 2001). In many areas it is actively targeted by hunters for its plumes which are used for ceremonial purposes. As a result, it is now rare or extirpated from areas near human settlement where hunting persists (Coates 1985; Watson and Asoyama 2001).

Gurney's Eagle (*Aquila gurneyi*) (NT)
A very large bird of prey (wingspan to 1.85 m) present throughout New Guinea where it is widespread though sparsely distributed in all forest habitats, mostly in the lowlands and hills. In 2001 Diamond and Bishop observed a pair high over forest near the Soror River, and in 2017 IW observed singles high over forest from KP 89–90 on 9 May and from Moro on 19 August.

White-bellied Sea Eagle (*Haliaeetus leucogaster*)
A large bird of prey, widespread from India to Australia along coasts, large inland watercourses and lakes. One was observed over Lake Kutubu on 9 May 2017. This is the highest elevation record from New Guinea (previously up to 540 m asl in New Guinea: Beehler and Pratt 2016; at 1,700 m asl on Sulawesi: Thiollay 1994).

Red-necked Stint (*Calidris ruficollis*) (NT), Grey-tailed Tattler (*Tringa brevipes*) (NT)
Two migratory shorebird species breeding in the northern hemisphere and seasonally present in New Guinea throughout the austral winter or *en route* to wintering grounds in Australia. They are present in greatest numbers in tidal environments along the coast, but also occur on the margins of freshwater rivers and lakes. They were recorded in small

numbers (Grey-tailed Tattler—"occasional groups of two to five birds"; Red-necked Stint—one bird) by Schodde on the edge of Lake Kutubu (Schodde and Hitchcock 1968, p. 23) in 1961. In 2007 Diamond and Bishop recorded a single Red-necked Stint at Moro airstrip (K. D. Bishop, *in litt.* 2018).

Thick-billed Ground Pigeon (*Trugon terrestris*)
A large terrestrial pigeon endemic to lowland and foothill forests of New Guinea and Salawati Island. An individual camera trapped in hill forest at 865 m asl on 7 May 2017 (Plate 1C) is the highest confirmed record for this species (previously up to 640 m asl).

Blyth's Hornbill (*Rhyticeros plicatus*) (P)
Occurs throughout New Guinea in a variety of forest types up to 1,500+ m asl, but is most common in the lowlands and hills (Coates 1985; Kemp 2001). As New Guinea's only hornbill species, and one of the region's largest and most mobile frugivores, Blyth's Hornbill plays a critical role in forest ecosystem dynamics (Mack and Wright 2005; Kinnaird and O'Brien 2007).

This species is regularly encountered within the WMA—it was recorded by all surveyors (Appendix 1), with up to four birds seen almost daily in 2017. Elsewhere, Blyth's Hornbill is fairly common locally in forest (excluding mangroves) throughout the lower Kikori basin (see Chapters 1.5 and 2.5). As a mobile and easily detected species, multiple records at the same site may involve repeat encounters with the same individuals; although widespread, at the local scale hornbills may be present in fairly low numbers.

Palm Cockatoo (*Probisciger aterrimus*) (P)
A large and conspicuous species occurring throughout the New Guinea lowlands and hills (to 1,300 m asl) in rainforest, secondary forest and tropical savannah where birds feed on a variety of seeds and fruit.

It is regularly encountered within the WMA though less common than Blyth's Hornbill—recorded by all surveyors (Appendix 1); in 2017 heard twice and recorded at two SM3 stations. Elsewhere, Palm Cockatoos are uncommon but regularly encountered in forest (including mangroves) throughout the lower Kikori basin (see Chapters 1.5 and 2.5). As a mobile and easily detected species, multiple records at the same site may involve repeat encounters with the same individuals.

Pesquet's Parrot (*Psittrichas fulgidus*) (VU, P)
This unusual, large black-and-red parrot (Plate 1F) is a nomadic and specialist frugivore that feeds on a select variety of figs (Mack and Wright 1998). It is endemic to New Guinea where it inhabits hill and lower montane forest up to 1,200 m asl (occasionally to 2,000 m) (Coates 1985). Pesquet's Parrot has been listed as one of Papua New Guinea's rarest birds (Beehler 1993). However, recent surveys indicate that the species remains secure in large areas of suitable habitat in central and western mainland Papua New Guinea, much of which occurs in rugged terrain in areas with a low human population density (Woxvold, unpublished data).

This species is regularly encountered in small numbers within the WMA—it was recorded by all surveyors (Appendix 1) and was heard twice in 2017. It is a mobile and easily detected species and multiple records at the same site may involve repeat encounters with the same individuals. As a nomadic frugivore, numbers present in any one area are likely to change with seasonal patterns in food availability.

Hunting presents the major threat to Pesquet's Parrot. In some areas it is hunted for its plumes which are used for traditional ceremonial and trade purposes. As a result of hunting pressure it is now rare or extirpated from the vicinity of many settled areas (Coates 1985; Kocher Schmid 1993; Mack and Wright 1998; Igag 2002). Other threats include habitat loss and loss of food trees (*Ficus* spp.) and nesting trees. It has been observed in logged forest (Woxvold, unpublished data; this study), though the birds may rely on more mature forest for nest sites.

Yellow-capped/Buff-faced Pygmy Parrot (*Micropsitta keiensis/pusio*)

The distributional limits of pygmy parrots (*Micropsitta*) in southern New Guinea are poorly known. Of two similar-looking lowland species, the Yellow-capped Pygmy Parrot (*M. keiensis*) occurs in the west and the Buff-faced Pygmy Parrot (*M. pusio*) in the east, with a potential zone of contact/overlap somewhere in the Gulf of Papua hinterland. Recent field guides and regional checklists report both species in the Kikori basin (Pratt and Beehler 2015; Beehler and Pratt 2016; Gregory 2017), though it is unclear on what records these assessments are based (Beehler and Pratt (2016) cite Schodde and Hitchcock (1968) as the source for a Lake Kutubu record of Buff-faced Pygmy Parrot, though no such record appears in that report).

Both species apparently occur within the Lake Kutubu WMA, where Burrows observed a pair of Buff-faced Pygmy Parrots "along the swamp road, Lake Kutubu" (1995, p. 36) and Bishop sighted Yellow-capped Pygmy Parrots in 2007 (in addition to sightings of unidentified pygmy parrots in other years; K. D. Bishop, *in litt.* 2018). Burrows' record is the westernmost confirmed sighting of Buff-faced Pygmy Parrot from the southern watershed, while the Yellow-capped Pygmy Parrot occurs east at least as far as the lower Purari River basin (Woxvold, unpublished data). Other Kutubu area reports refer to Buff-faced/Yellow-capped Pygmy Parrot (Jaensch, Undated A) or to Buff-faced Pygmy Parrot without describing the encounter (Jaensch, Undated B).

The Kikori–Purari region may represent a zone of overlap within which these two species separate altitudinally. Elsewhere in the Kikori basin, all confirmed records involve Yellow-capped Pygmy Parrot at elevations below 200 m asl—at Iviri and Keboi Kerowa (Leary, Undated A), and within the Wau Creek proposed WMA and at Uro Creek (see Chapters 1.5 and 2.5). In the Purari basin, Buff-faced Pygmy Parrot was reported from uplands in the Crater Mountain WMA (above 850 m asl; Mack and Wright 1996), while Yellow-capped Pygmy Parrot is the only species confirmed present at lower elevations (all records below 250 m asl; Woxvold, unpublished data). Further observations are required to confirm this pattern.

Striated Lorikeet (*Charmosyna multistriata*) (NT, RR)

A rare and nomadic New Guinea endemic, this small parrot is restricted to the southern slopes of the central cordillera from the Snow Mountains in Indonesia east into PNG as far as Crater Mountain (Mack and Wright 1996) from the foothills to 1,800 m asl. On 5 May 1998 Diamond and Bishop observed a flock of six birds at 825 m asl near the Soror River at the north end of Lake Kutubu.

Rufous Monarch (*Monarcha rubiensis*)

An uncommon bird endemic to the lowland forests of western and central New Guinea. There are few reports from the southern watershed, including only one prior published record from southern mainland Papua New Guinea—in the Nomad River area (Strickland basin) (Bell 1970). In 1994, Burrows observed a "male seen at close range…in forest by the Moro camp" (Burrows 1995, p. 37). Not previously reported above 175 m asl, this "record represents a significant extension in both range and altitudinal distribution" (Burrows 1995, p. 37).

Greater Melampitta (*Megalampitta gigantea*) (RR)

One of New Guinea's most enigmatic birds, the Greater Melampitta is a near-specialist inhabitant of forested karst where it is believed to roost and nest underground (Diamond 1983; Gregory 1995). It is a restricted-range species known from a few localities across New Guinea at 500–1,400 m asl. On 7 May 2017 one was heard from the road in an area of limestone forest northwest of Lake Kutubu near the KP 89–90 section of the pipeline ROW. Elsewhere within the

Kikori basin it has been recorded in forested karst near Gobe and on the Agogo Range (Diamond and Bishop, Undated; Woxvold and Legra, unpublished data).

Crinkle-collared Manucode (*Manucodia chalybatus*) (P)

All birds-of-paradise (Paradisaeidae) are Protected under Papua New Guinean law.

The manucodes are a group of glossy black, rather crow-like birds-of-paradise. Unlike most birds-of-paradise, they are monogamous pair-forming and sexually monomorphic. The Crinkle-collared Manucode is endemic to mainland New Guinea and Misool Island (West Papuan Islands, Indonesia) where it occurs from the lowlands to 1,700 m asl, though it is most common in hill forest above 500 m asl (Coates 1990; Frith and Beehler 1998). It is predominantly frugivorous, feeding mostly on figs (*Ficus* spp.). Not recorded in 2017, though reported by most prior surveyors (Schodde and Hitchcock 1968; Jaensch, Undated B; Diamond and Bishop, Undated). Schodde found it to be "frequent…in primary forest about the lake" where it was "noisy and conspicuous" (Schodde and Hitchcock 1968, p. 60).

Magnificent Riflebird (*Ptiloris magnificus*) (P)

This species is widespread in lowland and hill forests across most of New Guinea and on Cape York Peninsula (Australia) (Coates 1990; Frith and Beehler 1998). In southern New Guinea it occurs as far east as the Purari basin. It was recorded by all surveyors within the WMA, with the advertising call of at least one male heard daily in 2017.

Magnificent Bird-of-paradise (*Diphyllodes magnificus*) (P)

Endemic to New Guinea and nearby satellite islands, this species is common and widespread in forest from the foothills to 1,780 m asl. It was recorded by all surveyors within the WMA, with one or two birds heard during most days in 2017.

King Bird-of-paradise (*Cicinnurus regius*) (P)

A common resident of lowland and foothill forests to c. 300 m asl (less commonly higher), including swamp forest, on New Guinea and nearby islands. It was recorded by all surveyors with up to three birds heard daily in 2017. Within the WMA it is likely to be most common in lower elevation forests about the lake.

Twelve-wired Bird-of-paradise (*Seleucidis melanoleuca*) (P)

Endemic to lowland forests of New Guinea and Salawati Island, especially swamp forest with sago (*Metroxylon sagu*) and pandanus (*Pandanus* spp.) (Coates 1990; Frith and Beehler 1998). Recorded by Diamond and Bishop (Undated; K. D. Bishop, *in litt.* 2018) in 2001 and 2003, the Lake Kutubu swamps are the highest recorded locality for this species (elsewhere up to 180 m asl).

Raggiana Bird-of-paradise (*Paradisaea raggiana*) (P)

Endemic to southern and northeast Papua New Guinea where it inhabits primary and disturbed lowland, hill and lower montane forest to c.1,800 m asl. Males engage in elaborate and conspicuous group displays with up to 10 or more birds performing at a 'lek', usually in the upper portion or top branches of a canopy tree (Coates 1990; Frith and Beehler 1998).

It is common within the WMA—reported by all surveyors, with up to six birds seen or heard daily in 2017.

Banded Yellow Robin (*Poecilodryas placens*) (NT, RR)

Endemic to New Guinea and Batanta Island (Indonesia), with isolated populations scattered across New Guinea in hill and lower montane forest at 100–1,450 m asl. It occupies the dark understorey of primary forest interior. It was first reported from the WMA by Schodde who collected one from forest near Moro (Schodde and Hitchcock 1968). It was also recorded on multiple surveys by Diamond and Bishop (2001, 2003, 2006, 2007; K. D. Bishop, *in litt.* 2018) and on 9 May 2017 two were heard in forest on limestone at c. 950 m asl along the KP 89–90 section of the pipeline ROW.

Biodiversity and conservation values

The Lake Kutubu WMA supports a rich and varied avifaunal community. Surveys conducted to date have recorded nearly one third of all bird species residing or regularly occurring in the New Guinea region (including satellite islands: 215/677; 31.8%). The high recorded species richness is attributable both to the diverse set of environments present, and to the high accumulated survey effort spanning more than 50 years. The diversity, conservation value and potential for additional species in each of the WMA's major environments are discussed in the following sections.

Forest environments

Forest habitats support the majority of bird species residing or regularly occurring within the WMA—of the 215 bird species recorded, 170 (79.1%) occur in forest environments and most of these are forest-dependent (cannot persist in converted habitats alone). All resident (non-migratory) conservation listed and restricted-range bird species confirmed present within the WMA are dependent on forest habitats.

The Lake Kutubu WMA supports a wide range of forest environments. Approximately 160 km^2 of upper hill and lower montane forest span a nearly 600 m elevational band across a variety of substrates, including limestone karst, non-calcareous sediments and nutrient-rich volcanic slopes. In addition, some 19.6 km^2 of swamp forest/woodland provide an unusually high example of a typically lowland forest ecosystem. Elevation exerts a marked influence on the structure of New Guinean bird communities (Diamond 1972; Beehler 1982), and while many forest birds are capable of utilising all of these environments, a number of species strongly prefer, or are specialist inhabitants of, just one or a few of these vegetation types. Resident forest birds typical of the upper hill–lower montane transition zone (around 1,000 m asl) on which the WMA is centred include (but are not limited to) Spotted Honeyeater (*Xanthotis polygrammus*), Goldenface (*Pachycare flavogriseum*), Black-shouldered Cicadabird (*Coracina incerta*) (Plate 2D), Pygmy Drongo (*Chaetorhynchus papuensis*), Black-winged Monarch (*Monarcha frater*), Greater Melampitta, Crinkle-collared Manucode, White-rumped Robin (*Peneothello bimaculata*) and White-eyed Robin (*Pachycephalopsis poliosoma*). A number of montane birds normally found above 1,000 m asl are also confirmed present, including Wattled Brushturkey (*Aepypodius arfakiensis*), Red-breasted Pygmy Parrot (*Micropsitta bruijnii*), Pygmy Lorikeet (*Charmosyna wilhelminae*), Goldie's Lorikeet (*Psitteuteles goldiei*), Mottled Berryhunter (*Rhagologus leucostigma*), Black Fantail (*Rhipidura atra*) and Papun White-eye (*Zosterops novaeguineae*). Finally, lowland forest species reported at record or unusually high elevations within the WMA include Thick-billed Ground Pigeon, Little Bronze Cuckoo (*Chrysococcyx minutillus*), Yellow-streaked Lory (*Chalcopsitta sintillata*), Streak-headed Honeyeater (*Pycnopygius stictocephalus*), Large-billed Gerygone (*Gerygone magnirostris*), Lowland Peltops (*Peltops blainvillii*), Rufous Monarch, King Bird-of-paradise, Twelve-wired Bird-of-paradise and Black-sided Robin (*Poecilodryas hypoleuca*). The well-integrated complex of multiple forest ecosystems present within the WMA thus supports a rich forest bird community that differs in composition among sites within a small geographic area.

The WMA forests are also well connected with large expanses of both similar and additional forest ecosystem types, including montane forest above 2,000 m asl and lowland forest below 500 m asl, both within 10 km of the WMA boundary. It is thus positioned to support a variety of wide-ranging landscape-level nomadic bird species, including various large frugivores and birds of prey, that may not permanently reside within the WMA.

The WMA's forests face a variety of pressures. Localised conversions to settlements and gardens were formerly largely confined to the lake's margins and islands (Schodde and Hitchcock 1968). Subsequent infrastructure development and local population growth (via immigration and endogenous growth) on the back of opportunities created by oil and gas operations (D'Cruz 2008) has seen these losses expand to areas along the road networks that run within the northwest and northeast margins of the WMA (Figure 1). As well as localised losses, resource harvesting has degraded some areas of forest near settlements and along the road network; for example, in 2017 a number of trees had recently been felled for canoe construction within one kilometre of the road at the KP 86–87 section of the pipeline ROW.

Other recent losses are industry based. While the Moro facilities area was excluded from the WMA limits, recent pipeline construction has converted a c. 8 km-long ROW of hill, lower montane and swamp forest environments within the northwest margin of the WMA (Figures 1 and 3).

Logging presents an additional threat (D'Cruz 2008). More than 49 km^2 of the proposed Kutubu–Poroma logging concession (Proposed under the PNG Forest Authority draft National Forest Plan) overlaps the Lake Kutubu WMA along its northeast edge (Figure 3). As of 2015 no commercial logging had taken place within the concession (PNG Forest Observatory, http://forest.pngsdf.com/). Its current status is unknown.

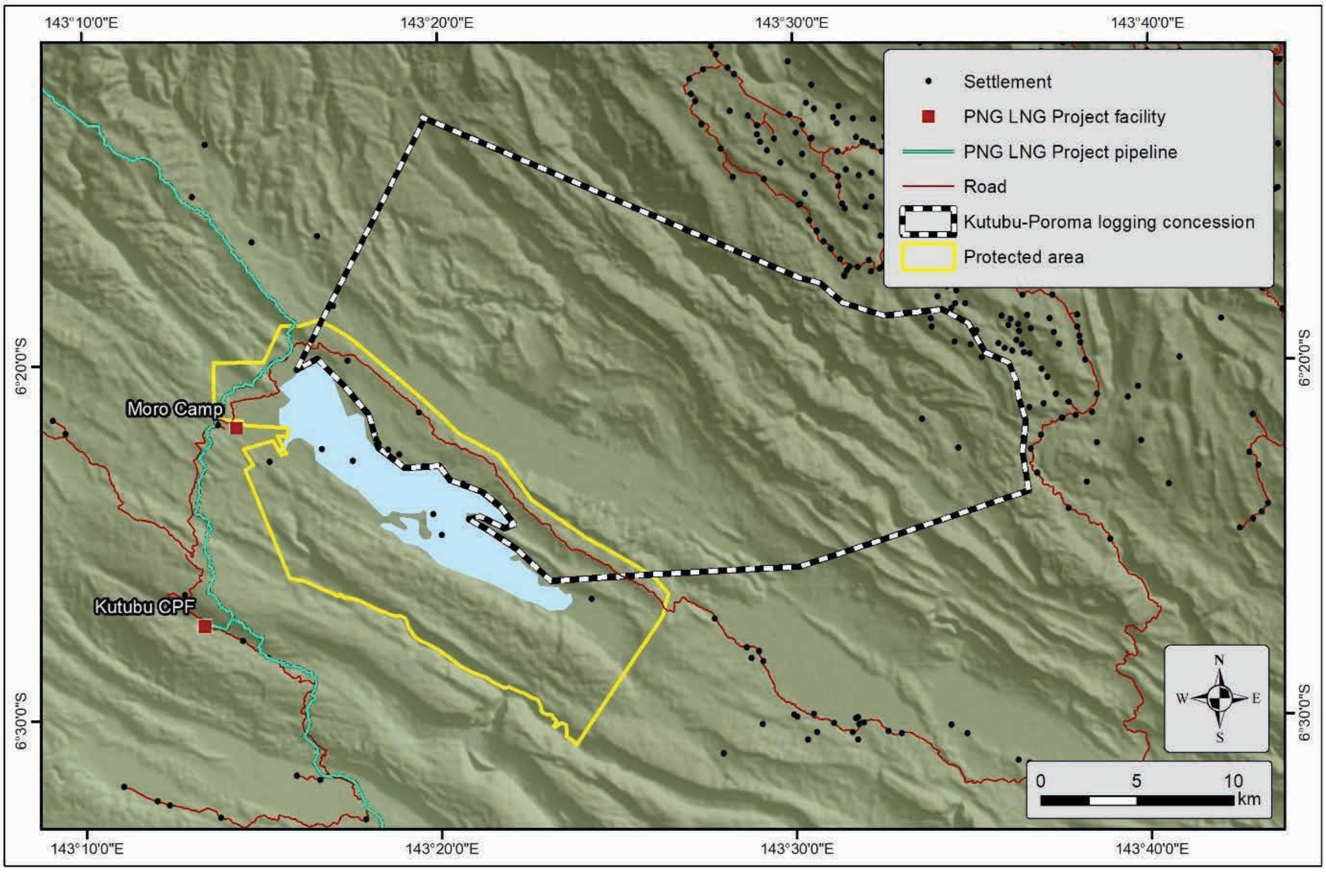

Figure 3. The Kutubu– Poroma logging concession.

Despite these threats, extensive areas of undisturbed forest remain within the Lake Kutubu WMA. These include much of the wooded swamps and approximately 80 km^2 of hill and lower montane forest on the broad limestone ridge of the Kutubu anticline south of the lake. Swamplands and forest on karst are generally unsuitable for gardening and settlement and are prohibited from logging under PNG law (PNGFA 1996); these areas are expected to remain largely intact into the foreseeable future, and are sufficient to support viable populations of most resident forest bird species.

Lake Kutubu and its surrounds are the most frequently surveyed area within the Kikori basin. Despite this effort, each new survey reveals the presence of additional birds, with the latest surveys in 2017 adding at six forest species to the Lake Kutubu WMA list (all except Nankeen Kestrel (*Falco cenchroides*) and Eurasian Tree Sparrow listed in Table 3), all of them resident breeders. It follows that additional species likely remain undetected within the WMA. Notably, the Kutubu anticline includes the highest point within the WMA, reaching over 1,380 m asl at Mount Kemenagi in the southeast, and its limestone forests remain unsurveyed.

The Agogo Range (including the Iagifu and Hedinia anticlines) lies immediately south of and parallel to the Kutubu anticline, and its forests have been visited by most ornithologists who have visited the Kutubu area (with the exception of Schodde). Given their proximity and the similarity in habitat and elevation, it is reasonable to expect that birds recorded on the Agogo Range also occur on the Kutubu anticline ridge within the southern sector of the Lake Kutubu WMA. Appendix 3 lists 26 bird species not recorded within the WMA, plus three species only provisionally recorded within the WMA, that were observed on the Agogo Range by Diamond and Bishop (Undated; K. D. Bishop, *in litt*. 2018), Burrows (1995) and/or the present authors. Nearly all of these (27/29; 93.1%) are forest bird species, including three nationally Protected birds-of-paradise—Queen Carola's Parotia (*Carola parotiae*), Superb Bird-of-paradise (*Lophorina superba*) and Black-billed Sicklebill (*Drepanornis albertisi*). Further survey of the Lake Kutubu WMA forests is thus likely to increase their known avifaunal diversity and the number of conservation listed species that they support.

Converted lands

Converted terrestrial environments include the airstrip, buildings and intervening bare ground, roadways, villages, grasslands and gardens. Twenty bird species recorded within the WMA are specialist occupants of these open and disturbed habitats (Table 5). They include at least 12 breeding residents and seven non-breeding migrants (the nightjars observed by Schodde may be either a resident or a migratory species). None are of conservation concern, and all are advantaged by the clearing or disturbance of native forest environments.

Table 5. Birds of converted lands.

Res/Mig status indicates: BR—breeding resident; M—non-breeding migrant; w—birds of wetlands; t—birds of terrestrial environments.

Scientific Name	English Name	Res/Mig
Bubulcus coromandus	Eastern Cattle Egret	Mwt
Circus spilothorax	Papuan Harrier	BRt
Amaurornis moluccana	Pale-vented Bush-hen	BRt
Stiltia isabella	Australian Pratincole	Mt
Eurostopodus papuensis/mystacalis	Papuan/White-throated Nightjar	BR/Mt
Caprimulgus macrurus	Large-tailed Nightjar	BRt
Todirhamphus macleayii	Forest Kingfisher	Mt
Todirhamphus sanctus	Sacred Kingfisher	Mt
Merops ornatus	Rainbow Bee-eater	Mt
Falco cenchroides	Nankeen Kestrel	Mt
Malurus alboscapulatus	White-shouldered Fairywren	BRt
Meliphaga albonotata	Scrub Honeyeater	BRt
Artamus maximus	Great Woodswallow	BRt
Coracina papuensis	White-bellied Cuckooshrike	BRt
Rhipidura leucophrys	Willie Wagtail	BRt
Hirundo tahitica	Pacific Swallow	BRt
Locustella fasciolata	Gray's Grasshopper Warbler	Mt
Megalurus macrurus	Papuan Grassbird	BRt
Saxicola caprata	Pied Bush Chat	BRt
Passer montanus	Eurasian Tree Sparrow	BRt
Lonchura leucosticta	White-spotted Mannikin	BRt

Wetland environments

Twenty-four wetland species have been recorded on the lake, rivers and adjacent low vegetated swamps. They are listed in Table 6, along with numbers reported by Schodde (Schodde and Hitchcock 1968) and Jaensch (Undated A).

Table 6. Birds of rivers and wetlands, their residency/migratory status (Res/Mig), and notes on abundance by Schodde (Schodde and Hitchcock 1968; 'RS') and Jaensch (Undated A; 'RJ').

Res/Mig status indicates: BR—breeding resident species; M—species that occur in New Guinea only as non-breeding migrants; BR/M—breeding residents with populations seasonally augmented by non-breeding visitors, and with widespread local breeding range potentially overlapping the study area; M(BR)—breeding residents augmented by non-breeding visitors but known breeding sites are localised and outside of the Kikori basin.

Scientific Name	English Name	Res/ Mig	RS	RJ
Nettapus pulchellus	Green Pygmy Goose	BR/M		29
Anas superciliosa	Pacific Black Duck	BR/M	Occasional pairs	10
Tachybaptus novaehollandiae	Australasian Grebe	BR/M		[3]
Nycticorax caledonicus	Nankeen Night Heron	M(BR)	Common, singles and groups of up to 10, adults and immatures	
Bubulcus coromandus	Eastern Cattle Egret	M		1
Ardea alba	Great Egret	M(BR)	Regular singles and duos	26
Ardea intermedia	Intermediate Egret	M(BR)	Regular singles and duos	22
Egretta picata	Pied Heron	M		3
Egretta novaehollandiae	White-faced Heron	M		
Egretta garzetta	Little Egret	M		7
Microcarbo melanoleucos	Little Pied Cormorant	M(BR)	Several groups of 20–30	65
Phalacrocorax sulcirostris	Little Black Cormorant	M(BR)	Regular singles and groups of 4–5	
Anhinga novaehollandiae	Australasian Darter	M(BR)	1+	
Haliaeetus leucogaster	White-bellied Sea Eagle	BR		
Porzana cinerea	White-browed Crake	BR		[2+]
Gallinula tenebrosa	Dusky Moorhen	BR		3
Charadrius dubius	Little Ringed Plover	BR		
Calidris acuminata	Sharp-tailed Sandpiper	M	1	
Calidris ruficollis	Red-necked Stint	M	1	
Actitis hypoleucos	Common Sandpiper	M	Regular singles	
Tringa brevipes	Grey-tailed Tattler	M	Occasional groups of 2–5	
Ceyx azureus	Azure Kingfisher	BR	Frequent singles	2
Monachella muelleriana	Torrent Flyrobin	BR		
Acrocephalus australis	Australian Reed Warbler	BR		c

Ten of these wetland species breed locally in southern New Guinea (those listed as BR and BR/M in Table 6). Breeding has not been reported within the WMA, though this may be an artefact of under-sampling. For species such as Green Pygmy Goose (*Nettapus pulchellus*), Pacific Black Duck (*Anas superciliosa*), Australasian Grebe (*Tachybaptus novaehollandiae*), White-browed Crake (*Porzana cinerea*), Dusky Moorhen (*Gallinula tenebrosa*) and Australian Reed Warbler (*Acrocephalus australis*), all of which prefer to breed along the vegetated margins of lakes and slow-moving freshwater systems, Lake Kutubu may represent an important breeding site within the local region (for example at the province scale). Other birds such as Little Ringed Plover (*Charadrius dubius*), Azure Kingfisher (*Ceyx azureus*) and Torrent Flyrobin (*Monachella muelleriana*) are better adapted to smaller waterways and/or fast flowing rivers that are well represented across the local region. The White-bellied

Sea Eagle (*Haliaeetus leucogaster*) is predominantly a bird of coastal and estuarine environments; Lake Kutubu may support one or more breeding pairs, or they may occur locally as non-breeding visitors. Understanding the importance of the WMA to breeding waterbirds would require additional survey of vegetated wetlands along the margins of the lake and larger watercourses and discussions with local residents.

Fourteen migratory wetland species have been recorded in the WMA (Table 6). Ten of these breed in Australia or are known to breed in New Guinea only outside of the Kikori–Purari area. Four species are Palaearctic migratory shorebirds that breed in the northern hemisphere—Grey-tailed Tattler (*Tringa brevipes*), Common Sandpiper (*Actitis hypoleucos*), Red-necked Stint (*Calidris ruficollis*) and Sharp-tailed Sandpiper (*C. acuminata*). The conservation of migratory shorebirds is of increasing international concern due to ongoing population declines along the East Asian–Australasian Flyway (Gosbell and Clemens 2006; Aharon-Rotman 2015; Szabo et al. 2016); two species recorded in the WMA are listed by the IUCN as Near Threatened with extinction—Grey-tailed Tattler and Red-necked Stint. Lake Kutubu does not contain extensive areas of tidal mudflats that are typically required to support large numbers of Palaearctic shorebirds. However, it may regularly host larger congregations of migrants that breed in Australia or elsewhere in New Guinea. For example, the numbers of Little Pied Cormorant (*Microcrbo melanoleucos*) recorded by Schodde and Jaensch (Table 6) may represent locally significant congregations—while they are significantly smaller than flock sizes recorded in the middle and lower Fly River wetlands of Western Province (Bishop 2005; up to c. 9,000 birds: Gregory et al. 1996), they represent the highest concentrations reported to date for the Kikori–Purari systems (Beehler and Pratt 2016; Woxvold, unpublished data).

Numerous additional wetland species have been observed in the expansive system of riverine and estuarine wetlands in the lower Kikori basin (summarised in Chapter 2.5), many of which may regularly visit Lake Kutubu.

Ecotourism potential

"Adventuring into eco-tourism activities" is one of four reasons for establishment of the Lake Kutubu WMA listed in its Protected Area Register. Bird watching is a key component of Papua New Guinea's ecotourism industry, with recent years seeing a perpetual flow of enthusiasts from around the globe (Zeppel 2006; Subbiah and Kannan 2012). Many positive features observed during the 2017 surveys suggest that 'birding'-based tourism may contribute to a sustainable local ecotourism industry. In addition to the spectacular scenery afforded by the lake and surrounding landscape:

- More than 240 bird species (combining lists in Appendix 1 and 3) have been recorded within the WMA or in immediately adjacent areas (Agogo Range), more than one third of all species residing or regularly occurring in the New Guinea region (242/677; 35.7%). Additional species are likely to occur.

- The WMA supports multiple bird habitats, including a variety of dryland forest, open-water wetland and swamp vegetation types, spanning an elevational range of nearly 600 m within a small geographic area, all of which are accessible by boat and existing road networks.

- Beyond the WMA, existing roads provide access to little-disturbed lower montane limestone forest on the Agogo Range, an analogue for difficult-to-reach habitats present within the nearby WMA.

- The WMA and surrounds support many bird species that may be considered significant 'drawcards' for international birdwatchers—these include endemic New Guinea birds that are charismatic, rare, restricted in range, taxonomically unique ('oddities' with few or no closely related taxa) and/or difficult to locate. Such species are expected to attract bird enthusiasts from around the globe. Relevant taxa include (but are not limited to) Dwarf Cassowary (*Casuarius bennetti*), Wattled Brushturkey (*Aepypodius arfakiensis*), Collared Brushturkey (*Talegalla jobiensis*), New Guinea Scrubfowl (*Megapodius decollatus*), Papuan Eagle, Pygmy Eagle (*Hieraaetus weiskei*), Gurney's

Eagle, Little Ringed Plover, Pheasant Pigeon (*Otidiphaps nobilis*), Blyth's Hornbill, Pesquet's Parrot, Striated Lorikeet, Tropical Scrubwren (*Sericornis beccarii*), Hooded Pitohui (*Pitohui dichrous*), Greater Melampitta, Banded Yellow Robin and a variety of birds-of-paradise (Paradisaeidae). Species such as Tropical Scrubwren and Banded Yellow Robin are not known to occur at established eco-lodges elsewhere in New Guinea, and many others are observed around Lake Kutubu with more reliability than at other sites within established bird-tour itineraries.

Levels of hunting pressure within the WMA are currently unknown. However, hunting of terrestrial wildlife is a core pursuit in subsistence cultures across New Guinea, and it is assumed that some hunting of birds within the WMA takes place. Unfortunately, hunting pressure is likely to be highest in areas most accessible both to local landowners and to potential tourists. At the local scale, current hunting practices may reduce the ecotourism potential of forest areas along road systems and navigable waterways within the WMA.

Recommendations

In terms of avifauna, the Lake Kutubu WMA is set in one of the world's most biologically diverse and endemically rich terrestrial regions (Olson and Dinerstein 1998; Brooks et al. 2006) and more than one third of all New Guinean bird species have to date been recorded locally (within the WMA and/or on the adjacent Agogo Range). It supports multiple conservation listed and restricted-range species, including five IUCN Threatened or Near Threatened bird species (Papuan Eagle, Gurney's Eagle, Pesquet's Parrot, Striated Lorikeet and Banded Yellow Robin), three restricted-range endemics (Striated Lorikeet, Greater Melampitta and Banded Yellow Robin) and a suite of additional nationally Protected and New Guinean endemic species. The area is potentially of great interest to international bird-watchers and its avifauna may play a key role in supporting a sustainable local ecotourism industry.

The following actions are recommended to enhance the conservation and potential ecotourism value of the Lake Kutubu WMA bird communities:

- Protect forest within the WMA from future logging.

- Establish wildlife management strategies to preserve biodiversity in areas that may be of interest to bird-watchers, including a variety of accessible forest types and wetland areas known to support multiple wetland bird species. In these areas control hunting, local resource extraction and the presence of dogs far as possible.

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Plate 1

A. Collared Brushturkey (*Talegalla jobiensis*)

B. Pygmy Eagle (*Hieraaetus weiskei*)

C. Thick-billed Ground Pigeon (*Trugon terrestris*)

D. Pheasant Pigeon (*Otidiphaps nobilis*)

E. Azure Kingfisher (*Ceyx azureus*)

F. Pesquet's Parrot (*Psittrichas fulgidus*)

Plate 2

A. Ochre-breasted Catbird (*Ailuroedus stonii*)

B. White-shouldered Fairywren (*Malurus alboscapulatus*)

C. Long-billed Honeyeater (*Melilestes megarhynchus*)

D. Black-shouldered Cicadabird (*Coracina incerta*)

E. Southern Variable Pitohui (*Pitohui uropygialis*)

F. Camera trap used to detect birds in the Kikori basin

Appendix 1. Birds recorded in the Lake Kutubu WMA and immediate surrounds by IW and LL in 2017, Schodde in 1961, Burrows in 1995, Jaensch in 1997–1999 and Diamond and Bishop (D&B) in 1998–2003.

Conservation status is shown for species listed by the IUCN as Vulnerable (VU) and Near Threatened (NT), species Protected (P) by law under the *PNG Fauna (Protection & Control) Act 1966* and restricted-range species (RR). Camera trap results are shown as Relative Abundance Index for all photographed species (ctRAI). Residency/migratory (Res/Mig) status indicates: BR—breeding resident species; M—species that occur in New Guinea only as non-breeding migrants; BR/M—breeding residents with populations seasonally augmented by non-breeding visitors, and with widespread local breeding range potentially overlapping the study area; M(BR)—breeding residents augmented by non-breeding visitors, but known breeding sites are localised and outside of the Kikori basin; t—birds of terrestrial environments, including forest, converted lands and aerial foraging species; w—birds of wetlands, including lakes, rivers and streams; wt—species of both wetland and open terrestrial environments; data from Coates (1985, 1990) and Beehler and Pratt (2016). The number of individuals captured by mist net is shown in brackets after the English Name.

Scientific Name	English Name	Status	2017	Schodde	Burrows	Jaensch	D&B	ctRAI	Res/Mig
CASUARIIDAE									
Casuarius bennetti	Dwarf Cassowary			[X]		[X]			BRt
ANATIDAE									
Nettapus pulchellus	Green Pygmy Goose					X			BR/Mw
Anas superciliosa	Pacific Black Duck			X		X	X		BR/Mw
MEGAPODIIDAE									
Aepypodius arfakianus	Wattled Brushturkey		X					0.0192	BRt
Talegalla fuscirostris	Black-billed Brushturkey			?					BRt
Talegalla jobiensis	Collared Brushturkey		X		[X]		[X]	0.1731	BRt
Megapodius decollatus	New Guinea Scrubfowl		[X]				[X]		BRt
PODICIPEDIDAE									
Tachybaptus novaehollandiae	Australasian Grebe					[X]			BR/Mw
ARDEIDAE									
Nycticorax caledonicus	Nankeen Night Heron			X					M(BR)w
Bubulcus coromandus	Eastern Cattle Egret					X			Mt
Ardea alba	Great Egret	P		X		X	X		M(BR)w
Ardea intermedia	Intermediate Egret	P		X		X			M(BR)w
Egretta picata	Pied Heron					X			Mw
Egretta novaehollandiae	White-faced Heron						X		Mw
Egretta garzetta	Little Egret	P				X			Mw
PHALACROCORACIDAE									
Microcarbo melanoleucos	Little Pied Cormorant			X		X			M(BR)w
Phalacrocorax sulcirostris	Little Black Cormorant			X					M(BR)w
ANHINGIDAE									
Anhinga novaehollandiae	Australasian Darter			X			X		M(BR)w

Scientific Name	**English Name**	**Status**	**2017**	**Schodde**	**Burrows**	**Jaensch**	**D&B**	**ctRAI**	**Res/Mig**
ACCIPTRIDAE									
Aviceda subcristata	Pacific Baza		X	X		X	X		BRt
Henicopernis longicauda	Long-tailed Honey Buzzard		X		X	X	X		BRt
Macheiramphus alcinus	Bat Hawk						X		BRt
Harpyopsis novaeguineae	Papuan Eagle	VU,P			X				BRt
Hieraaetus weiskei	Pygmy Eagle		X		X				BRt
Aquila gurneyi	Gurney's Eagle	NT	X				X		BRt
Accipiter hiogaster	Variable Goshawk					X	X		BRt
Accipiter poliocephalus	Grey-headed Goshawk				X		X		BRt
Accipiter cirrhocephalus	Collared Sparrowhawk					[X]			BRt
Circus spilothorax	Papuan Harrier				X				BRt
Circus approximans	Swamp Harrier						[X]		Mwt
Haliastur indus	Brahminy Kite		X	X	X	X	X		BRt
Haliaeetus leucogaster	White-bellied Sea Eagle		X						BRw
RALLIDAE									
Rallina tricolor	Red-necked Crake		X				X	0.1154	BRt
Amaurornis moluccana	Pale-vented Bush-hen			X			X		BRt
Porzana cinerea	White-browed Crake					X	X		BRw
Gallinula tenebrosa	Dusky Moorhen					X			BRw
CHARADRIIDAE									
Charadrius dubius	Little Ringed Plover		X				X		BRwt
SCOLOPACIDAE									
Calidris acuminata	Sharp-tailed Sandpiper			X					Mw
Calidris ruficollis	Red-necked Stint	NT		X			X		Mw
Actitis hypoleucos	Common Sandpiper			X					Mw
Tringa brevipes	Grey-tailed Tattler	NT		X					Mw
GLAREOLIDAE									
Stiltia isabella	Australian Pratincole			X					Mt
COLUMBIDAE									
Macropygia amboinensis	Amboyna Cuckoo-Dove		X		X	X	X		BRt
Macropygia nigrirostris	Bar-tailed Cuckoo-Dove		X	X			X		BRt
Reinwardtoena reinwardti	Great Cuckoo-Dove		X			X	X		BRt
Chalcophaps stephani	Stephan's Emerald Dove			X					BRt
Trugon terrestris	Thick-billed Ground Pigeon		X					0.0192	BRt
Gallicolumba rufigula	Cinnamon Ground Dove		X					0.0769	BRt
Alopecoenas jobiensis	White-breasted Ground Dove			X					BRt
Otidiphaps nobilis	Pheasant Pigeon		X				X	0.4616	BRt
Goura scheepmakeri/sclaterii	Scheepmaker's/Sclater's Crowned Pigeon	VU/NT,P		?					BRt
Ptilinopus magnificus	Wompoo Fruit Dove		X	X		X	X		BRt
Ptilinopus perlatus	Pink-spotted Fruit Dove		X	X	X		X		BRt

Scientific Name	English Name	Status	2017	Schodde	Burrows	Jaensch	D&B	ctRAI	Res/Mig
Ptilinopus ornatus	Ornate Fruit Dove		X			X	X		BRt
Ptilinopus superbus	Superb Fruit Dove		X	X	X	X	X		BRt
Ptilinopus pulchellus	Beautiful Fruit Dove		X	X		X	X		BRt
Ptilinopus iozonus	Orange-bellied Fruit Dove						X		BRt
Ptilinopus nainus	Dwarf Fruit Dove				X		X		BRt
Ducula rufigaster	Purple-tailed Imperial Pigeon		X			X	X		BRt
Ducula chalconota	Rufescent Imperial Pigeon				X	X			BRt
Ducula pinon	Pinon's Imperial Pigeon						X		BRt
Ducula zoeae	Zoe's Imperial Pigeon		X	X	X	X	X		BRt
Gymnophaps albertisii	Papuan Mountain Pigeon		X		X	X	X		BRt
CUCULIDAE									
Centropus menbeki	Ivory-billed Coucal		X		X	[X]	X		BRt
Microdynamis parva	Dwarf Koel		X				X		BRt
Eudynamys orientalis	Pacific Koel		X			[X]	X		BR/Mt
Chrysococcyx meyerii	White-eared Bronze Cuckoo			X		X	X		BRt
Chrysococcyx minutillus	Little Bronze Cuckoo		X				X		BRt
Cacomantis leucolophus	White-crowned Cuckoo		X				X		BRt
Cacomantis castaneiventris	Chestnut-breasted Cuckoo		X		X	[X]	X		BRt
Cacomantis variolosus	Brush Cuckoo		X			X	X		BRt
Cuculus optatus	Oriental Cuckoo						X		Mt
TYTONIDAE									
Tyto tenebricosa	Greater Sooty Owl		X						BRt
STRIGIDAE									
Ninox theomacha	Papuan Boobook		X	X			X		BRt
PODARGIDAE									
Podargus ocellatus	Marbled Frogmouth		X				X		BRt
Podargus papuensis	Papuan Frogmouth		X				X		BRt
CAPRIMULGIDAE									
Eurostopodus papuensis/ mystacalis	Papuan/White-throated Nightjar			X					BR/Mt
Caprimulgus macrurus	Large-tailed Nightjar						X		BRt
AEGOTHELIDAE									
Aegotheles sp.	Owlet-nightjar sp.						X		BRt
HEMIPROCNIDAE									
Hemiprocne mystacea	Moustached Treeswift		X	X		X	X		BRt
APODIDAE									
Collocalia esculenta	Glossy Swiftlet		X	X	X	X	X		BRt
Aerodramus hirundinaceus/ vanikorensis	Mountain/Uniform Swiftlet		X	X	X	X	X		BRt
CORACIIDAE									
Eurystomus orientalis	Oriental Dollarbird		X	X	X	X	X		BR/Mt

Scientific Name	English Name	Status	2017	Schodde	Burrows	Jaensch	D&B	ctRAI	Res/Mig
ALCEDINIDAE									
Melidora macrorrhina	Hook-billed Kingfisher		X	X	X		X		BRt
Dacelo gaudichaud	Rufous-bellied Kookaburra		X	X	X	X	X		BRt
Todirhamphus macleayii	Forest Kingfisher			X					Mt
Todirhamphus sanctus	Sacred Kingfisher			X		X	X		Mt
Syma torotoro	Yellow-billed Kingfisher						X		BRt
Syma torotoro/megarhyncha	Yellow-billed/Mountain Kingfisher		X			X			BRt
Ceyx solitarius	Papuan Dwarf Kingfisher		X				X		BRt
Ceyx azureus	Azure Kingfisher (1)		X	X	X	X	X		BRw
MEROPIDAE									
Merops ornatus	Rainbow Bee-eater		X	X	X	X	X		Mt
BUCEROTIDAE									
Rhyticeros plicatus	Blyth's Hornbill	P	X	X	X	X	X		BRt
FALCONIDAE									
Falco cenchroides	Nankeen Kestrel		X						Mt
Falco severus	Oriental Hobby			[X]			X		BRt
Falco peregrinus	Peregrine Falcon					X	X		BRt
CACATUIDAE									
Probosciger aterrimus	Palm Cockatoo	P	X	X	X	X	X		BRt
Cacatua galerita	Sulphur-crested Cockatoo		X	X	X	X	X		BRt
PSITTACIDAE									
Psittrichas fulgidus	Pesquet's Parrot	VU,P	X	X	X	X	X		BRt
Micropsitta keiensis	Yellow-capped Pygmy Parrot						X		BRt
Micropsitta pusio	Buff-faced Pygmy Parrot				X	[X]	?		BRt
Micropsitta bruijnii	Red-breasted Pygmy Parrot					X			BRt
Alisterus chloropterus	Papuan King Parrot		X				X		BRt
Eclectus roratus	Eclectus Parrot		X	X	X	X	X		BRt
Geoffroyus geoffroyi	Red-cheeked Parrot		X	X		X	X		BRt
Geoffroyus simplex	Blue-collared Parrot		X		X		X		BRt
Charmosyna multistriata	Striated Lorikeet	NT,RR					X		BRt
Charmosyna wilhelminae	Pygmy Lorikeet		[X]				X		BRt
Charmosyna placentis	Red-flanked Lorikeet		[X]				X		BRt
Charmosyna pulchella	Fairy Lorikeet						X		BRt
Lorius lory	Black-capped Lory		X	X	X	X	X		BRt
Chalcopsitta scintillata	Yellowish-streaked Lory		X			X	X		BRt
Pseudeos fuscata	Dusky Lory		X	X		X	X		BRt
Psitteuteles goldiei	Goldie's Lorikeet						X		BRt
Trichoglossus haematodus	Coconut Lorikeet		X	X		X	X		BRt
Psittaculirostris desmarestii	Large Fig Parrot					X	X		BRt
Cyclopsitta gulielmitertii	Orange-breasted Fig Parrot		X		X	X	X		BRt
Cyclopsitta diophthalma	Double-eyed Fig Parrot						X		BRt

Scientific Name	English Name	Status	2017	Schodde	Burrows	Jaensch	D&B	ctRAI	Res/Mig
Loriculus aurantiifrons	Orange-fronted Hanging Parrot			X		X	X		BRt
PITTIDAE									
Erythropitta macklotii	Papuan Pitta		X				X	0.1924	BRt
Pitta sordida	Hooded Pitta						X		BRt
PTILONORHYNCHIDAE									
Ailuroedus stonii	Ochre-breasted Catbird (1)		X	X			X		BRt
MALURIDAE									
Sipodotus wallacii	Wallace's Fairywren					X			BRt
Malurus cyanocephalus	Emperor Fairywren		X	X	X	X	X		BRt
Malurus alboscapulatus	White-shouldered Fairywren		X	X	X	X	X		BRt
MELIPHAGIDAE									
Myzomela eques	Ruby-throated Myzomela						X		BRt
Myzomela adolphinae	Mountain Myzomela						?		BRt
Glycichaera fallax	Green-backed Honeyeater						X		BRt
Pycnopygius ixoides	Plain Honeyeater						X		BRt
Pycnopygius stictocephalus	Streak-headed Honeyeater		X				X		BRt
Xanthotis polygrammus	Spotted Honeyeater			X			X		BRt
Xanthotis flaviventer	Tawny-breasted Honeyeater		X	X	X	X	X		BRt
Philemon meyeri	Meyer's Friarbird					[X]	X		BRt
Philemon novaeguineae	New Guinea Friarbird		X	X	X	X	X		BRt
Melilestes megarhynchus	Long-billed Honeyeater (2)		X	X	X	X	X		BRt
Caligavis obscura	Obscure Honeyeater		X	X			X		BRt
Meliphaga mimikae	Mottle-breasted Honeyeater (1)		X						BRt
Meliphaga albonotata	Scrub Honeyeater		X	X	X	X	X		BRt
Meliphaga analoga	Mimic Honeyeater			X			X		BRt
Meliphaga aruensis	Puff-backed Honeyeater (2)		X				X		BRt
Meliphaga sp.						X			BRt
ACANTHIZIDAE									
Pachycare flavogriseum	Goldenface		X				X		BRt
Crateroscelis murina	Rusty Mouse-warbler		X	X	X	X	X		BRt
Sericornis beccarii	Tropical Scrubwren			X					BRt
Gerygone magnirostris	Large-billed Gerygone						X		BRt
Gerygone chrysogaster	Yellow-bellied Gerygone		X			X	X		BRt
Gerygone chloronota	Green-backed Gerygone		X		X	X	X		BRt
Gerygone palpebrosa	Fairy Gerygone		X			X	X		BRt
MELANOCHARITIDAE									
Melanocharis nigra	Black Berrypecker (1)		X	X			X		BRt
Oedistoma iliolophus	Dwarf Longbill		X	X			X		BRt
Oedistoma pygmaeum	Pygmy Longbill		X	X			X		BRt
Toxorhamphus poliopterus	Slaty-headed Longbill					X			BRt

Scientific Name	English Name	Status	2017	Schodde	Burrows	Jaensch	D&B	ctRAI	Res/Mig
PSOPHODIDAE									
Ptilorrhoa castanonota	Chestnut-backed Jewel-babbler		X			X	X	0.0192	BRt
MACHAERIRHYNCHIDAE									
Machaerirhynchus flaviventer	Yellow-breasted Boatbill			X			X		BRt
ARTAMIDAE									
Artamus maximus	Great Woodswallow		X	X	X	X	X		BRt
Peltops blainvillii	Lowland Peltops			X	X		X		BRt
Peltops montanus	Mountain Peltops		X			X	X		BRt
Melloria quoyi	Black Butcherbird		X	X			X		BRt
Cracticus cassicus	Hooded Butcherbird		X	X	X	X	X		BRt
RHAGOLOGIDAE									
Rhagologus leucostigma	Mottled Berryhunter			X					BRt
CAMPEPHAGIDAE									
Coracina caeruleogrisea	Stout-billed Cuckooshrike				X	X			BRt
Coracina boyeri	Boyer's Cuckooshrike		X	X	X	X	X		BRt
Coracina papuensis	White-bellied Cuckooshrike			X					BRt
Coracina tenuirostris	Common Cicadabird				X				M(BR)t
Coracina incerta	Black-shouldered Cicadabird		X		X		X		BRt
Coracina schisticeps	Grey-headed Cuckooshrike		X		X	X	X		BRt
Coracina melas	Black Cicadabird		X	X		X	X		BRt
Campochaera sloetii	Golden Cuckooshrike		X			X	X		BRt
Lalage leucomela	Varied Triller		X		X	X	X		BRt
OREOICIDAE									
Ornorectes cristatus	Piping Bellbird		X	X	X		X	0.0577	BRt
PACHYCEPHALIDAE									
Pachycephala hyperythra	Rusty Whistler			X					BRt
Pachycephala simplex	Grey Whistler		X	X			X		BRt
Pseudorectes ferrugineus	Rusty Pitohui (4)		X	X	X		X		BRt
Colluricincla megarhyncha	Little Shrikethrush		X	X	X	X	X		BRt
ORIOLIDAE									
Pitohui uropygialis	Southern Variable Pitohui (1)		X	X	X	X	X		BRt
Pitohui dichrous	Hooded Pitohui			X	X	X			BRt
Oriolus szalayi	Brown Oriole		X	X	X	[X]	X		BRt
DICRURIDAE									
Dicrurus bracteatus carbonarius	(Papuan) Spangled Drongo		X	X	X	X	X		BRt
RHIPIDURIDAE									
Rhipidura leucophrys	Willie Wagtail		X	X	X	X	X		BRt
Rhipidura rufiventris	Northern Fantail		X	X	X	X	X		BRt
Rhipidura threnothorax	Sooty Thicket Fantail		X				X		BRt
Rhipidura leucothorax	White-bellied Thicket Fantail			X		X	X		BRt

Scientific Name	English Name	Status	2017	Schodde	Burrows	Jaensch	D&B	ctRAI	Res/Mig
Rhipidura maculipectus/ leucothorax	Black/White-bellied Thicket Fantail		X				X		BRt
Rhipidura atra	Black Fantail			X					BRt
Rhipidura hyperythra	Chestnut-bellied Fantail			X			X		BRt
Rhipidura rufidorsa	Rufous-backed Fantail					[X]	X		BRt
Chaetorhynchus papuensis	Drongo Fantail		X	X					BRt
MONARCHIDAE									
Symposiachrus guttula	Spot-winged Monarch			X		X	X		BRt
Monarcha rubiensis	Rufous Monarch				X				BRt
Monarcha frater	Black-winged Monarch			X			X		BRt
Carterornis chrysomela	Golden Monarch		X	X		X	X		BRt
Arses telescophthalmus	Frilled Monarch		X		X	X	X		BRt
Myiagra alecto	Shining Flycatcher		X	X			X		BRt
CORVIDAE									
Corvus tristis	Grey Crow		X	X	X	X	X		BRt
MELAMPITTIDAE									
Megalampitta gigantea	Greater Melampitta	RR	X						BRt
PARADISAEIDAE									
Manucodia ater	Glossy-mantled Manucode						?		BRt
Manucodia chalybatus	Crinkle-collared Manucode	P		X		X	X		BRt
Ptiloris magnificus	Magnificent Riflebird	P	X	X	X	X	X		BRt
Diphyllodes magnificus	Magnificent Bird-of-paradise	P	X	X	X	X	X		BRt
Cicinnurus regius	King Bird-of-paradise	P	X	X	X	X	X		BRt
Seleucidis melanoleucus	Twelve-wired Bird-of-paradise	P					X		BRt
Paradisaea raggiana	Raggiana Bird-of-paradise	P	X	X	X	X	X		BRt
PETROICIDAE									
Poecilodryas hypoleuca	Black-sided Robin		X	X	X		X		BRt
Poecilodryas placens	Banded Yellow Robin	NT,RR	X	X			X		BRt
Peneothello bimaculata	White-rumped Robin		X	X			X		BRt
Pachycephalopsis poliosoma	White-eyed Robin						X		BRt
Monachella muelleriana	Torrent Flyrobin						X		BRw
Microeca flavovirescens	Olive Flyrobin		X		X	[X]			BRt
Drymodes beccarii	Papuan Scrub Robin		X				X	0.0385	BRt
HIRUNDINIDAE									
Hirundo tahitica	Pacific Swallow		X	X	X	X	X		BRt
ACROCEPHALIDAE									
Acrocephalus australis	Australian Reed Warbler					X	X		BRw
LOCUSTELLIDAE									
Locustella fasciolata	Gray's Grasshopper Warbler						X		Mt
Megalurus macrurus	Papuan Grassbird			X					BRt

Scientific Name	English Name	Status	2017	Schodde	Burrows	Jaensch	D&B	ctRAI	Res/Mig
ZOSTEROPIDAE									
Zosterops minor	Black-fronted White-eye		X			X			BRt
Zosterops novaeguineae	Papuan White-eye						X		BRt
STURNIDAE									
Aplonis metallica	Metallic Starling						X		BRt
Mino dumontii	Yellow-faced Myna		X	X	X	X	X		BRt
MUSCICAPIDAE									
Saxicola caprata	Pied Bush Chat		X		X	X	X		BRt
DICAEIDAE									
Dicaeum geelvinkianum	Red-capped Flowerpecker		X			X	X		BRt
NECTARINIIDAE									
Leptocoma aspasia	Black Sunbird		X	X	X	X	X		BRt
PASSERIDAE									
Passer montanus	Eurasian Tree Sparrow		X						BRt
ESTRILDIDAE									
Erythrura trichroa	Blue-faced Parrotfinch						X		BRt
Lonchura leucosticta	White-spotted Mannikin						X		BRt
			126	104	71	107	169		

Appendix 2

The following accounts outline reasoning for adjustment to the status/identity of prior recorded species. They exclude recent taxonomic adjustments where there is no confusion over the identity of the recorded species.

Southern Cassowary *(Casuarius casuarius)*—A lowland species (most records below 300 m asl) replaced in upland environments, and on steep terrain in some lowland areas, by the Dwarf Cassowary (*Casuarius bennetti*). The identity of cassowaries within the WMA is yet to be confirmed. Schodde and Hitchcock (1968) presumed both species present based on reports from local residents and European officers. This is above all confirmed localities for Southern Cassowary in New Guinea and, given the unreliability of many second-hand accounts, requires confirmation from direct field sightings (Beehler and Pratt 2016). Until there is evidence to prove otherwise, all WMA records are provisionally referred to Dwarf Cassowary, which is known to occur locally outside the WMA on the Agogo Range (Woxvold and Legra, unpublished data).

Black-billed Brushturkey *(Talegalla fuscirostris)*—A lowland species with one confirmed record above 400 m asl, on the Sogeri Plateau in Varirata National Park near Port Moresby where the species is known to breed (e.g. Richards and Rowland 1995). Emerging evidence suggests that the Collared Brushturkey replaces the Black-billed Brushturkey in upland sites across much of southern mainland Papua New Guinea (Beehler and Pratt 2016; Woxvold, unpublished data), with the latter potentially occupying isolated hill-zone sites of relatively gentle terrain (such as at Varirata).

Schodde and Hitchcock (1968) report flushing a bird with "pale yellowish feet" (R. Schodde, *in litt.* 2015), implicating Black-billed Brushturkey, in the Mubi River valley. The Mubi River valley includes the largest area of flat alluvial terrain present within the local region, though this lies mostly outside of the WMA boundary. On similar terrain within the WMA (see Species accounts), camera trapping revealed Collared Brushturkey to be fairly common with no images taken of Black-billed Brushturkey. Given the fleeting nature and uncertain location (with respect to the WMA boundary) of Schodde's sighting, his record of Black-billed Brushturkey is here treated as uncertain (Appendix 1) and excluded from the WMA species total.

Burrows (Hartshorn et al. 1994) and Diamond and Bishop (Undated) also reported Black-billed Brushturkey from the Moro/Kutubu and Agogo Range areas. However, Collared Brushturkey is the only *Talegalla* confirmed present from the Agogo Range (Woxvold and Legra, unpublished data) and Lake Kutubu WMA, and it is likely that, as many have done before them, these surveyors were interpreting fleeting glimpses and/or aural encounters based on incomplete distribution data available at the time. Until there is evidence to prove otherwise, these records are provisionally ascribed to Collared Brushturkey.

Scheepmaker's/Sclater's Crowned Pigeon *(Goura scheepmakeri/sclaterii)*—The world's largest pigeons, crowned pigeons are terrestrial-foraging species endemic to the lowlands of New Guinea where they prefer forest on gentle terrain. Schodde and Hitchcock (1968, p.29) stated that "*Goura* pigeons, undoubtedly of this species, were reported by the CSIRO Resources Survey forest botanist…from the primary rainforest between Kutubu station and the Mubi River". There are no other reports of crowned pigeons from above 500 m asl, and this record is excluded from subsequent regional handbooks or checklists (Coates 1985; Beehler and Pratt 2016). Without good views, inexperienced observers may confuse other large terrestrial birds such as Pheasant Pigeon (*Otidiphaps nobilis*), Thick-billed Ground Pigeon (*Trugon terrestris*) or even megapodes for crowned pigeons. The Kutubu *Goura* record is here treated as uncertain (Appendix 1) and excluded from the WMA species total.

Fan-tailed Cuckoo *(Cacomantis flabelliformis)*—A "tentative identification" by Jaensch (Undated A) for the Moro/Lake Kutubu area, potentially within range of the rarely recorded migratory Australian subspecies (*C. f. flabelliformis*; distribution poorly known) but below that of the resident montane subspecies (*C. f. excitus*) (Beehler and Pratt 2016).

The locality is within the elevational range of the common resident Chestnut-breasted Cuckoo (*C. castaneiventris*), a bird confirmed present by other observers, and Jaensch's record is here provisionally reassigned to that species.

Papuan/White-throated Nightjar *(Eurostopodus papuensis/mystacalis)*—The Papuan Nightjar is a poorly known night-bird endemic to the lowlands of New Guinea and Salawati Island. Schodde reported *Eurostopodus* nightjars from forest clearings near Moro, "tentatively" identifying them as Papuan Nightjar "on account of the absence of large white marks in the wings and tail and the general locality and habitat, which should exclude [Archbold's Nightjar] *E. archboldi*" (Schodde and Hitchcock, p. 34). Another possible species (not discussed by Schodde) is White-throated Nightjar (*E. mystacalis*), a non-breeding migrant from Australia that may remain in the area as late as September–October (Beehler and Pratt 2016). The highest reported elevation for Papuan Nightjar is 400 m asl; that for White-throated Nightjar is above 1,500 m asl (Coates 1985; Beehler and Pratt 2016). Until their identity is confirmed, and rather than invoking an elevational record for the Papuan Nightjar, the Moro nightjars are here provisionally recorded as Papuan/White-throated Nightjar.

Mountain/Uniform Swiftlet *(Aerodramus hirundincaeus/vanikorensis)*—The Lake Kutubu WMA is located in an elevational zone of overlap between two common and widespread *Aerodramus* species that are not distinguishable in flight—Mountain Swiftlet (*A. hirundinaceus*) and Uniform Swiftlet (*A. vanikorensis*). *Aerodramus* swiftlets are common in the WMA and have been reported variously as 'Uniform? Swiftlet' (Schodde and Hitchcock 1968), 'Mountain Swiftlet' (Hartshorn et al. 1994; Burrows 1995; Jaensch and Kulmoi, Undated), 'Mountain? Swiftlet' (Jaensch, Undated A), '*Aerodramus* sp.' (Jaensch, Undated B) and Mountain and/or Uniform Swiftlet (Diamond and Bishop, Undated). Until identifications are confirmed (requiring birds in the hand), all *Aerodramus* records are here presented as Mountain/Uniform Swiftlet (Appendix 1). It is acknowledged that the rare Bare-legged Swiftlet (*A. nuditarsus*) and/or Three-toed Swiftlet (*A. papuensis*) may also occur locally; we consider that these larger species are (at least by some observers) distinguishable in the field and, if present, would occur at lower density than the common smaller species, so that Mountain/Uniform Swiftlets would account for some, if not all, *Aerodramus* swiftlets observed by various workers.

Appendix 3. Possible additional species recorded in comparable habitats on the nearby Agogo Range by IW and LL in 2017, Diamond and Bishop (D&B) in 1998–2003 and Burrows in 1995.

Some birds recorded by Burrows may have been recorded within the WMA but this cannot be ascertained from his report; see text. Records indicate: X—species recorded on the Agogo Range and not within the WMA; Xc—species confirmed present on the Agogo range and only provisionally recorded within the WMA; [X]—species provisionally recorded on the Agogo Range and not recorded within the WMA; X?—species recorded by other workers on the Agogo Range that require confirmation from further observation. Conservation status is shown for IUCN Near Threatened species (NT) and species Protected (P) by law under the *PNG Fauna (Protection & Control) Act 1966*. Residency/migratory (Res/Mig) status indicates: BR—breeding resident species; M—species that occur in New Guinea only as non-breeding migrants; BR/M—breeding residents with populations seasonally augmented by non-breeding visitors, and with widespread local breeding range potentially overlapping the study area; M(BR)—breeding residents augmented by non-breeding visitors, but known breeding sites are localised and outside of the Kikori basin; t—birds of terrestrial environments, including forest, open areas and aerial foraging species; w—birds of wetlands, including lakes, rivers and streams; data from Coates (1985, 1990) and Beehler and Pratt (2016).

Scientific Name	English Name	Status	IW-LL	D&B	IB95	Res/ Mig
Casuarius bennetti	Dwarf Cassowary		Xc	Xc		BRt
Megapodius decollatus	New Guinea Scrubfowl		Xc			BRt
Accipiter cirrhocephalus	Collared Sparrowhawk			Xc	Xc	BRt
Accipiter meyerianus	Meyer's Goshawk				X	BRt
Gymnocrex plumbeiventris	Bare-eyed Rail		X			BRt
Henicophaps albifrons	New Guinea Bronzewing		X	X	X	BRt
Gallicolumba beccarii	Bronze Ground Dove		X			BRt
Ptilinopus rivoli	White-bibbed Fruit Dove		X	X		BRt
Aegotheles insignis	Feline Owlet-nightjar			X		BRt
Falco berigora	Brown Falcon			X	X	BRt
Charmosyna josefinae	Josephine's Lorikeet			X		BRt
Ailuroedus melanotis	Spotted Catbird		X	X	X	BRt
Myzomela cruentata	Red Myzomela				X	BRt
Myzomela nigrita	Papuan Black Myzomela		X	X	X	BRt
Myzomela adolphinae	Mountain Myzomela			X	X	BRt
Meliphaga orientalis	Mountain Honeyeater			X		BRt
Sericornis spilodera	Pale-billed Scrubwren		[X]	X		BRt
Sericornis arfakianus	Grey-green Scrubwren		X			BRt
Melanocharis longicauda	Mid-mountain Berrypecker				X?	BRt
Coracina montana	Black-bellied Cuckooshrike		X	X	X	BRt
Symposiachrus axillaris	Black Monarch		X	X		BRt
Parotia carolae	Queen Carola's Parotia	P	X	X		BRt
Lophorina superba	Superb Bird-of-paradise	P		X		BRt
Drepanornis albertisi	Black-billed Sicklebill	P		X		BRt
Tregellasia leucops	White-faced Robin		X	X		BRt
Microeca griseoceps	Yellow-legged Flyrobin		[X]	X		BRt
Petrochelidon nigricans	Tree Martin			X		Mt
Phylloscopus maforensis	Island Leaf Warbler		X	X		BRt
Zoothera heinei	Russet-tailed Thrush		X			BRt

Chapter 3.6. Mammals of the Lake Kutubu Wildlife Management Area, Southern Highlands Province, Papua New Guinea

Enock Kale, Kyle N. Armstrong, Pita Amick and Iain Woxvold

A Small Dorcopsis (*Dorcopsulus vanheurni*) that was camera trapped at Lake Kutubu

Summary
The Lake Kutubu Wildlife Management Area (WMA) features the largest mid-altitude lake in Oceania and remarkable mid-altitude forest habitats that accommodate a number of Threatened and Near Threatened mammal species. In this rapid assessment survey, we aimed to document mammal diversity at the north-western edge of Lake Kutubu. The purpose of the survey was to build on the knowledge from past efforts by adding contemporary records of the terrestrial mammals occurring in the WMA, ultimately to support efforts for the long-term conservation of the local mammal fauna and biodiversity in general.

The survey was conducted between 6 and 9 May 2017. While brief, the survey incorporated numerous techniques to maximise detection of species. Non-volant (non-flying) mammals were surveyed by live trapping with Elliott box traps (181 trap-nights), camera trapping with unattended movement-triggered cameras (16 sites), and by conducting spotlighting searches at night. Bats were surveyed by trapping with harp traps (six sites) and mist nets (five nets over three sites), and by recording their echolocation calls with electronic bat detectors (15 recording nights/sites).

The survey resulted in the detection of six native non-volant mammal species in six genera from two marsupial families (Peroryctidae—1 sp., Macropodidae—1 sp.), and one rodent family (Muridae—4 spp.). All species were encountered using camera traps, with nil detections by Elliott trap and night searches. The most significant non-volant mammal species encountered was the Small Dorcopsis (*Dorcopsulus vanheurni*), which has an IUCN Red List conservation status of Near Threatened because of a declining population size from over-hunting. Pigs (*Sus scrofa*) and dogs (*Canis familiaris*) were also detected on camera traps.

A total of 22 bat species was detected on the survey. Seven species of bat were captured (total 54 individuals; 49 small fruit bats and blossom bats from three species in the family Pteropodidae,and five individuals of four insectivorous species). Nineteen species of bat in five families were detected from their echolocation calls. None of the bat species are listed by the IUCN as Threatened or Near Threatened. One taxon listed as Data Deficient was present—the horseshoe bat *Rhinolophus mcintyrei*.

The detection of 28 native mammal species over a three-night period is indicative of a diverse and intact mammal assemblage that is worthy of conservation. The conservation efforts for biodiversity in the WMA area could be enhanced by considering 'umbrella' species such as the Small Dorcopsis and other species previously documented such as Eastern Long-beaked Echidna and Goodfellow's Tree Kangaroo as flagship species, and by engaging with local people to help them protect biodiversity on their traditional lands. Further efforts to detect species expected to occur could target arboreal non-volant species, searches for colonies of cave-roosting bats, and some identities from camera traps and bat detectors need to be confirmed by follow-up trapping and genetic work, especially taxonomically-unresolved or morphologically-similar taxa. The hunting of pigs should be promoted over native mammal species, especially larger species such as the Small Dorcopsis and Goodfellow's Tree Kangaroo. Control of both domestic and wild dogs will help to reduce pressure on larger mammal species as well, and education and capacity-building in local communities will help to emphasise good management of these sensitive species.

Introduction
Lake Kutubu and its surrounds (Lake Kutubu Wildlife Management Area; LKWMA) is a biologically, ecologically and culturally significant environment in the Southern Highlands Province of Papua New Guinea. It is significant within Oceania as being the largest mid-altitude lake, and provides habitat for 12 species of fish found nowhere else in the world (Regis 2000). Lake Kutubu and its associated wetland habitat were listed under the Ramsar Convention on Wetlands on 25 September 1998, bringing it within the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources. Lake Kutubu is also culturally significant because of the rich folklore that explains the relationships between the formation of the Lake and the presence of hydrocarbons

beneath the earth (Regis 2000) that are now being developed and exported to meet global energy demands. Lake Kutubu was first registered as a Wildlife Management Area on 25 June 1992 by the Foi clans who inhabit the Lake Kutubu area (Regis 2000). The Foi clans seek to protect both the rich biodiversity and cultural sites from effects on the environment associated with energy resource developments.

The entire Kikori basin, a land area of 2.3 million hectares that includes Lake Kutubu, is highly diverse in terms of mammalian fauna. By 1997, a total of 97 mammal species had been recorded from the basin, representing approximately 45% of the native terrestrial mammals of mainland New Guinea, and in a land area less than 6% of that of PNG (Leary and Seri 1997; a more recent compilation documented 105 species; Namo 2004). Within the WMA at Mt. Kemenagi (between 900 m and 1130 m asl; Figure 1), Leary and Seri (1997) recorded 19 mammal species, comprising 14 non-volant (non-flying) species and five bat species. This included species listed on the IUCN Red List as Threatened (taxonomy and conservation status have been updated): Eastern Long-beaked Echidna (*Zaglossus bartoni*; IUCN Vulnerable), Goodfellow's Tree Kangaroo (*Dendrolagus goodfellowi*; IUCN Endangered), and Small Dorcopsis (*Dorcopsulus vanheurni*; IUCN Near Threatened).

The number of terrestrial mammal species present is likely to be higher (Regis 2000), and the list is likely to further expand as more surveys are conducted. For instance, the recent biodiversity monitoring work conducted nearby under the programmed biodiversity monitoring activities of the PNG LNG project more than 200 m higher in elevation than the WMA recorded several more rodent species (Aplin and Opiang 2017), and these are also likely to occur in the WMA. Additional species of conservation significance that are predicted to be within the WMA include: New Guinea Pademelon (*Thylogale browni*; IUCN Vulnerable), Plush-coated Ringtail (*Pseudochirops corinnae*; IUCN Near Threatened), Western White-eared Giant Rat (*Hyomys dammermani*; IUCN Data Deficient), Small Melanesian Bent-winged Bat (*Miniopterus macrocneme*; IUCN Data Deficient), and a newly recognised horseshoe bat (*Rhinolophus mcintyrei*: IUCN Data Deficient).

Aims

In this rapid assessment survey, we aimed to document the mammal diversity of the Lake Kutubu WMA near the north-western edge of the Lake, in both regrowth and primary forest. The purpose of the survey was to build on the knowledge from past efforts by adding contemporary records of mammals occurring in the WMA, ultimately to support efforts for the long-term conservation of the local mammal fauna and biodiversity in general.

Methods

Non-volant mammals

Several methods were employed to survey non-volant (non-flying) mammals: live trapping with Elliott box traps, camera trapping with unattended movement-triggered cameras, and by opportunistically detecting mammal species when conducting spotlighting searches at night.

Trapping was conducted between 6 and 9 May 2017, with a total effort of 181 trap-nights at three locations (Figure 2). Two sizes of Elliott box traps were used: small (37 x 10 x 10 cm) and large (15 x 15 x 46 cm). Small traps were baited with a mixture of sweet potatoes and fresh peanuts. Fresh sweet bananas sourced from the local market were added to the large traps in addition to the sweet potato and peanuts to attract larger-bodied rodents and bandicoots.

Data from 16 Reconyx Hyperfire HC550/PC850 automatic 'camera traps' that were deployed by IW in the vicinity of KP 87 between 6 and 18 May 2017 are incorporated into this report. The location of each camera trap was recorded with a Garmin GPS unit. They were placed on small animal tracks and fruiting trees that had signs of feeding by animals to increase the probability of animal detection, and were positioned away from study transects to avoid disturbance by the investigators of the other taxon survey groups. Further details of camera trap deployment methods are described in Chapter 3.5 and their locations are illustrated in Figure 2.

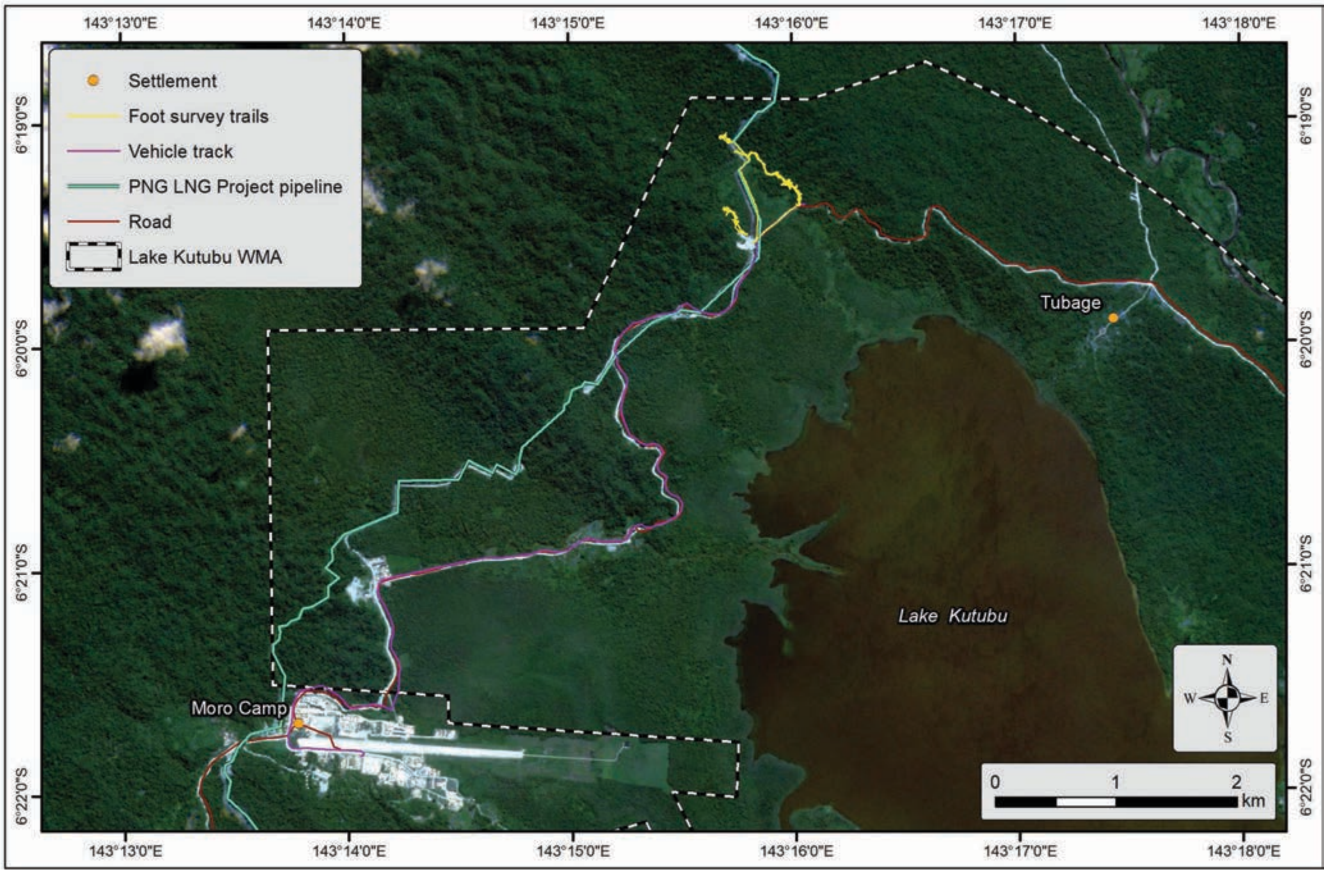

Figure 1. The location of past sites of mammal surveys at the north-western end of Lake Kutubu.

An overall list of species identified in the camera trap images was compiled. Abundance cannot be estimated from the images, so instead a Relative Abundance measure was calculated to provide a rough indication of how common each species was. This is simply the proportion of camera trapping sites with one or more images of each species (e.g. a value of 0.6 indicates the species was detected at 6 out of 10 camera trapping sites).

Bat trapping

Bats were surveyed using mist nets (double-stranded nylon 'bird' mist nets), triple-bank harp traps (three rectangular frames 2 m high and 5 cm apart containing fishing line strung vertically, and positioned over a catch bag), and 'bat detectors' that record the ultrasonic echolocation calls of bats. Harp traps (two traps at a total of six positions) and mist nets (five nets at a total of three positions) were set in the forest understorey across gullies, in the gaps amongst vegetation and on tracks to maximise the capture of bats flying through the understorey (Figure 3).

Identification of captures and sample collection

Identifications were based on information in Flannery (1995), Bonaccorso (1998), and the unpublished notes of the authors. Nomenclature follows the IUCN Red List accounts (http://www.iucnredlist.org/initiatives/mammals) except where these are out of date.

Most captured mammals were released after taking a small biopsy sample of skin for later genetic analysis. Biopsies were taken from the wing membrane of bats with a 4 mm dermal punch, and from the tail of rodents and small marsupials by cutting <5 mm from the tail tip. A subset of animals (2 individual bats: *Kerivoula 'muscina'* and *Miniopterus* sp.) was retained to aid verification of identifications. Vouchers were fixed whole in 10% formalin and then transferred to 70% ethanol for long-term storage. Tissue biopsy samples were preserved in 95% ethanol.

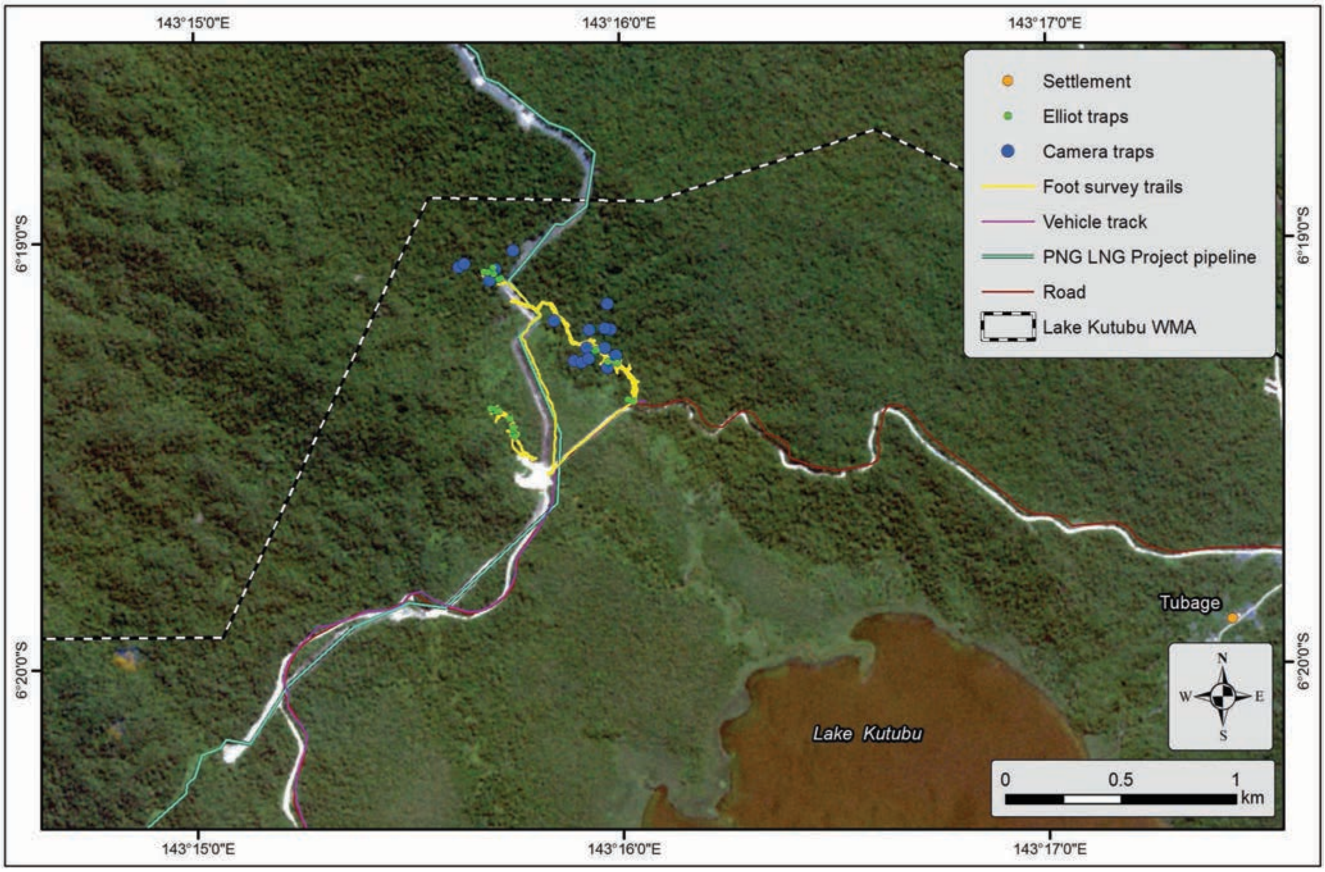

Figure 2. Elliott box trap and camera trapping sites in the northern part of the WMA.

Bat echolocation call recordings

Most small, insect-eating bat species can be distinguished from each other based on the frequency and pulse shape characteristics of their ultrasonic echolocation calls. Recordings of bat calls were made in high quality full spectrum WAV format with five Pettersson Elektronik D500X bat detectors between 6 and 9 May 2017 (three nights each, total 15 full recording nights; Figure 3). Bat detectors were waterproofed in plastic boxes, and microphones on a 3 m extension cable were attached to tree trunks c. 2.5 m high, with a funnel made from a plastic drink bottle placed over the microphone tip to protect it from moisture. The detectors were placed in a variety of habitats including adjacent to streams, within forest, along tracks, facing into clearings, and in open habitats. They were set in position before dusk and collected after dawn, and were moved to a new location each day. Reference echolocation recordings were made from captured bats with a Titley Scientific Walkabout bat detector (sampling frequency 500 kHz) to aid the identification of bat calls from the D500X recordings.

Acoustic processing of bat echolocation calls and summary of data

With high quality 'full spectrum' recordings, the datasets are typically many gigabytes, and not every sound file out of the many thousands recorded can be examined in a spectrogram. Thus, a customised, multi-step acoustic processing procedure that can filter large bat echolocation recording datasets from Papua New Guinea (Armstrong and Aplin 2014a; Armstrong et al. 2016) was applied to the recordings. This approach has been used on numerous published exploratory surveys in PNG, and details of this procedure are presented in Appendix 1.

An overall list of species identified in the recordings was compiled. Abundance cannot be estimated from recordings of echolocation, so instead a Relative Abundance measure was calculated to provide a rough indication of how common each species was. This is simply the proportion of recording sites with detections of each species (e.g. a value of 0.6 indicates the species was detected at 6 out of 10 recording sites).

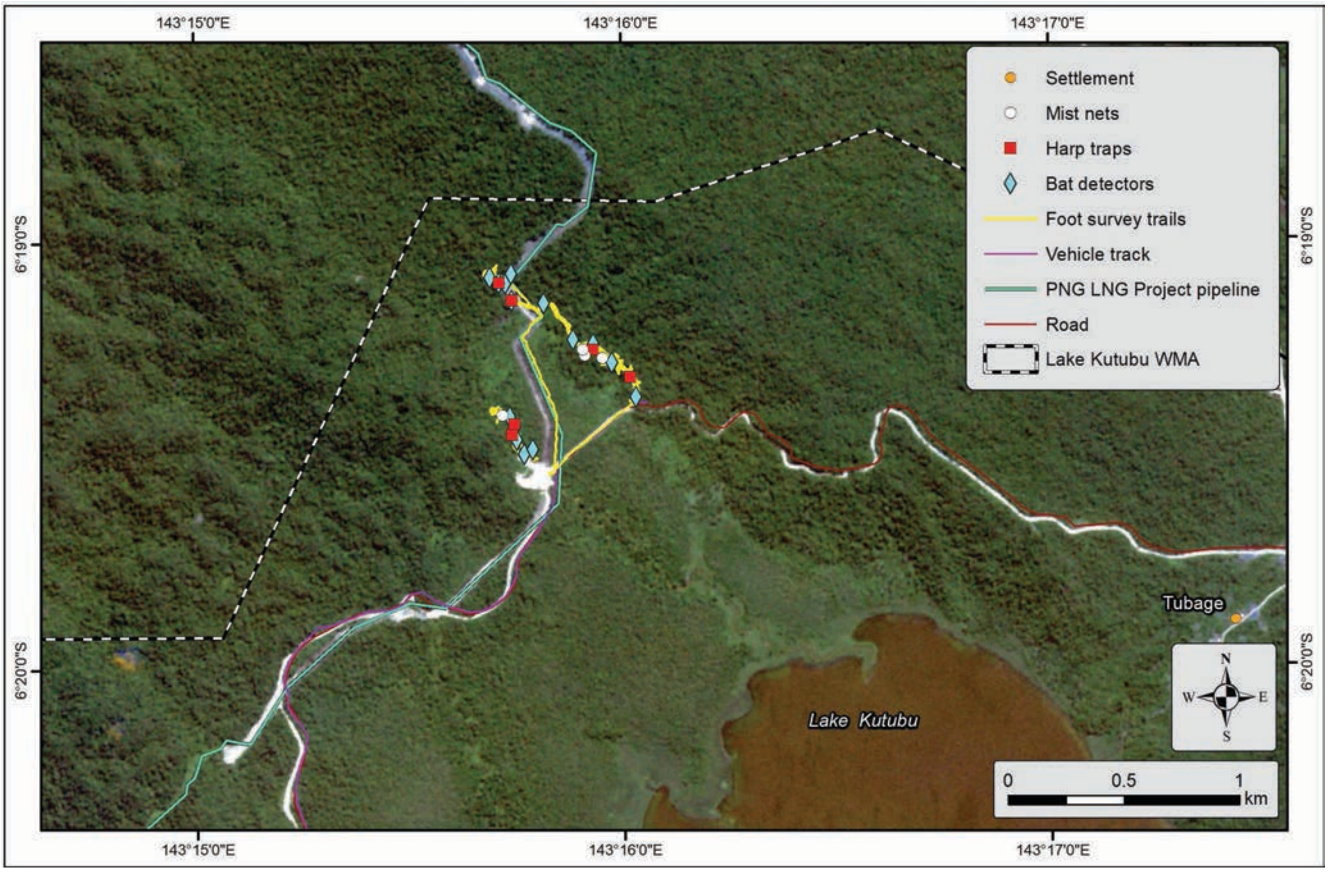

Figure 3. Deployment of bat trapping equipment (harp traps and mist nets) and bat detectors in the northern part of the WMA.

Results

Non-volant mammals

At least six native non-volant mammal species in six genera from two marsupial families and one rodent family were detected (Table 1). In addition, two non-native species, the Pig (*Sus scrofa*) and Dog (*Canis familiaris*; Plate 1E), were detected relatively infrequently compared to some of the native species. The rodent family Muridae was the most species-rich with four species, and each marsupial family was represented by only one species.

All non-volant mammal species (native and non-native) were detected through camera trapping (Table 1). No species were detected during two nights of general searching; and the 181 trap-nights of Elliott trapping resulted in nil trap success.

The most commonly observed species were small bandicoots, probably the Common Echymipera (*Echymipera kalubu*; Relative Abundance of 0.9; Plate 1A) and the White-tailed Giant Rat (*Uromys caudimaculatus*; Relative Abundance of 0.6; Plate 1D), which was recognised from its relatively large body size and the mottled colouring of the distal end of the tail. The small rodent identifications were challenging because some diagnostic parts of the animal are small and were not visible in photographs. However, some species are conspicuous because of their size as well as patterning—for example, the Large Leptomys (*Leptomys elegans*) was recognised from the black areas on the face in addition to its chestnut-coloured dorsal fur and pale underside (Plate 1C).

The most significant species encountered through camera trapping was the Small Dorcopsis (*Dorcopsulus vanhuerni*), which has an IUCN Red List conservation status of Near Threatened (Leary et al. 2016a; Plate 1B). It had a Relative Abundance of 0.3.

Further details on selected species are discussed in Appendix 2.

Table 1. List of non-volant native mammal species encountered during the 2017 survey.
(sp.: species could not be identified; IUCN: conservation status on the IUCN Red List; CT: Relative Abundance values from camera trapping).

Family	Common name	Genus species	IUCN	CT
Marsupials				
Peroryctidae	Common Echymipera/ and/or Long-nosed Echymipera?	*Echymipera kalubu/* and/or *E. rufescens*?	LC	0.9
Macropodidae	Small Dorcopsis	*Dorcopsulus vanheurni*	NT	0.3
Rodents				
Muridae	Large Leptomys	*Leptomys elegans*	LC	0.1
	Common Lowland Paramelomys	*Paramelomys platyops*	LC	0.3
	Unidentified rat	*Rattus* sp.	—	0.2
	White-tailed Giant Rat	*Uromys caudimaculatus*	LC	0.6
Domesticated/Feral				
Suidae	Pig, Wild Boar	*Sus scrofa*	LC	0.3
Canidae	Dog	*Canis familiaris*	—	0.1

Bats

A total of 22 bat species was detected on the survey, which included three species in the family Pteropodidae and 19 species of echolocating insectivorous bat in five families (Table 2; Figure 4). Three of these species were not expected to occur in the WMA based on their previously known distributions (Appendix 3). None of the species encountered are listed by the IUCN as Threatened or Near Threatened. One taxon listed as Data Deficient was present—a horseshoe bat that was renamed after a recent taxonomic revision of the *Rhinolophus arcuatus* species complex, which is now known as *Rhinolophus mcintyrei* (Patrick et al. 2013; Patrick and Ruedas 2017).

Three species of bat in the family Pteropodidae were captured in both mist nets and harp traps (total 49 individuals), mostly the Common Blossom Bat (*Syconycteris australis*; 42 individuals), and at least two species of tube-nosed fruit bat (subfamily Nyctimeninae; Table 2). No large flying-foxes were observed. Four species of small insectivorous echolocating bats were also captured, all in harp traps (Plate 2). The total number of captures was therefore 54 individuals (Table 2). The capture of Wollaston's Leaf-nosed Bat (*Hipposideros wollastoni*) was especially useful for confirming its presence in the area and its echolocation call frequency (compared with the Fly River Leaf-nosed Bat (*Hipposideros muscinus*)). Similarly, the capture of the Fly River Woolly Bat (*Kerivoula muscina*) was useful for being able to compare its calls with those of the Flute-nosed Bat (*Murina florium*) (recorded elsewhere; K.N. Armstrong unpublished data).

Most echolocation call types could be attributed with confidence to a single species. However, some calls could not be associated with a species reliably because either the calls of certain species are too similar to distinguish unambiguously, or there are taxonomic issues that prevent attributions to a particular species. The most obvious example are calls that are attributable to bent-winged bats (*Miniopterus* spp.)—because identification of the members in this genus from body characters is problematic, the identification of their calls is also unreliable. These call types are also very similar to calls produced by species of (Pipistrelle *Pipistrellus* spp.) Despite these difficulties, bat detectors produced records of 15 more echolocating bat species than trapping alone. Further comments on identifications and taxonomic issues are presented in the individual species accounts that follow.

The most commonly recorded species was the New Guinea Horseshoe Bat (*Rhinolophus euryotis*; Relative Abundance of 0.8), as well as the Lesser Sheath-tailed Bat (*Mosia nigrescens*) and the horseshoe bat (*Rhinolophus mcintyrei*; Relative Abundance of 0.7; Table 3). The presence of cave-roosting bats in the Hipposideridae and Rhinolophidae indicates that caves suitable for diurnal roosting are nearby.

Of particular note was the second record of a likely new species of bat affiliated with the Dusky Leaf-nosed Bat (*Hipposideros ater*). This species generally produces calls with a characteristic frequency of around 150 kHz (K.N. Armstrong and K.P. Aplin unpublished data). The detection of a single call sequence with pulse frequencies at c. 172 kHz is significantly higher and probably indicative of a separate species (Figure 4; Armstrong 2017).

Further details on selected species are discussed in Appendix 2

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Table 2. Species and echolocation call types of bats recorded at Lake Kutubu, with an estimate of Relative Abundance .
('Rel Ab'; colour scale below table) to indicate how common each was (asterisks indicate presence was expected based on information on the IUCN Red List, see Appendix 3).

Common name	Genus species	Call type	Rel Ab	Captures
Pteropodidae—3				
*Common Tube-nosed Fruit Bat	*Nyctimene* sp. cf. *albiventer*	—	—	3
*Green Tube-nosed Fruit Bat	*Paranyctimene* sp. cf. *raptor*	—	—	4
*Common Blossom Bat	*Syconycteris australis*	—	—	42
Emballonuridae—3				
*New Guinea Sheath-tailed Bat	*Emballonura furax*	*55 i.fFM.d*	0.1	
*Raffray's Sheath-tailed Bat	*Emballonura raffrayana*	*45 i.fFM.d*	0.2	
*Lesser Sheath-tailed Bat	*Mosia nigrescens*	*65 i.fFM.d*		
Hipposideridae—6				
*Temminck's Leaf-nosed Bat	*Aselliscus tricuspidatus*	*115 sCF*	0.6	
Dusky Leaf-nosed Bat	*Hipposideros* sp. cf. *ater*	*172 sCF*	0.1	
*Fawn-coloured Leaf-nosed Bat	*Hipposideros cervinus*	*140 sCF*	0.2	
*Diadem Leaf-nosed Bat	*Hipposideros diadema*	*58 mCF*	0.4	
Maggie Taylor's Leaf-nosed Bat	*Hipposideros maggietaylorae*	*125 mCF*	0.1	
*Wollaston's Leaf-nosed Bat	*Hipposideros wollastoni*	*89 mCF*	0.5	1
Rhinolophidae—5				
*a horseshoe bat	*Rhinolophus mcintyrei*	*70 lCF*		2
*New Guinea Horseshoe Bat	*Rhinolophus euryotis*	*52 lCF*		
*Eastern Horseshoe Bat	*Rhinolophus megaphyllus*	*66 lCF*	0.3	
*Large-eared Horseshoe Bat	*Rhinolophus* sp. cf. *philippinensis*	*47 lCF*	0.1	
Greater Large-eared Horseshoe Bat	*Rhinolophus* sp. cf. *robertsi*	*33 lCF*	0.3	
Miniopteridae—3				
*Unidentified Bent-winged Bat 1	*Miniopterus* sp. 1 'large'	*38 st.cFM*	0.5	
*Unidentified Bent-winged Bat 2	*Miniopterus* sp. 2 'medium'	*45 st.cFM*	0.3	
*Unidentified Bent-winged Bat 3	*Miniopterus* sp. 3 'small'	*53 st.cFM*	0.4	1
Vespertilionidae—2				
*Fly River Woolly Bat	*Kerivoula muscina*	*60 bFM*	0.1	1
Maluku Myotis	*Myotis moluccarum*	*40 bFM*	0.3	
Total captures				**54**
Total Species Richness				**22**

Relative Abundance colour scale shading for camera trapping.

Note: All Miniopteridae are marked as expected species for the area, despite that they are all unidentified, given that there are candidates listed for each of the call types in Appendix 3.

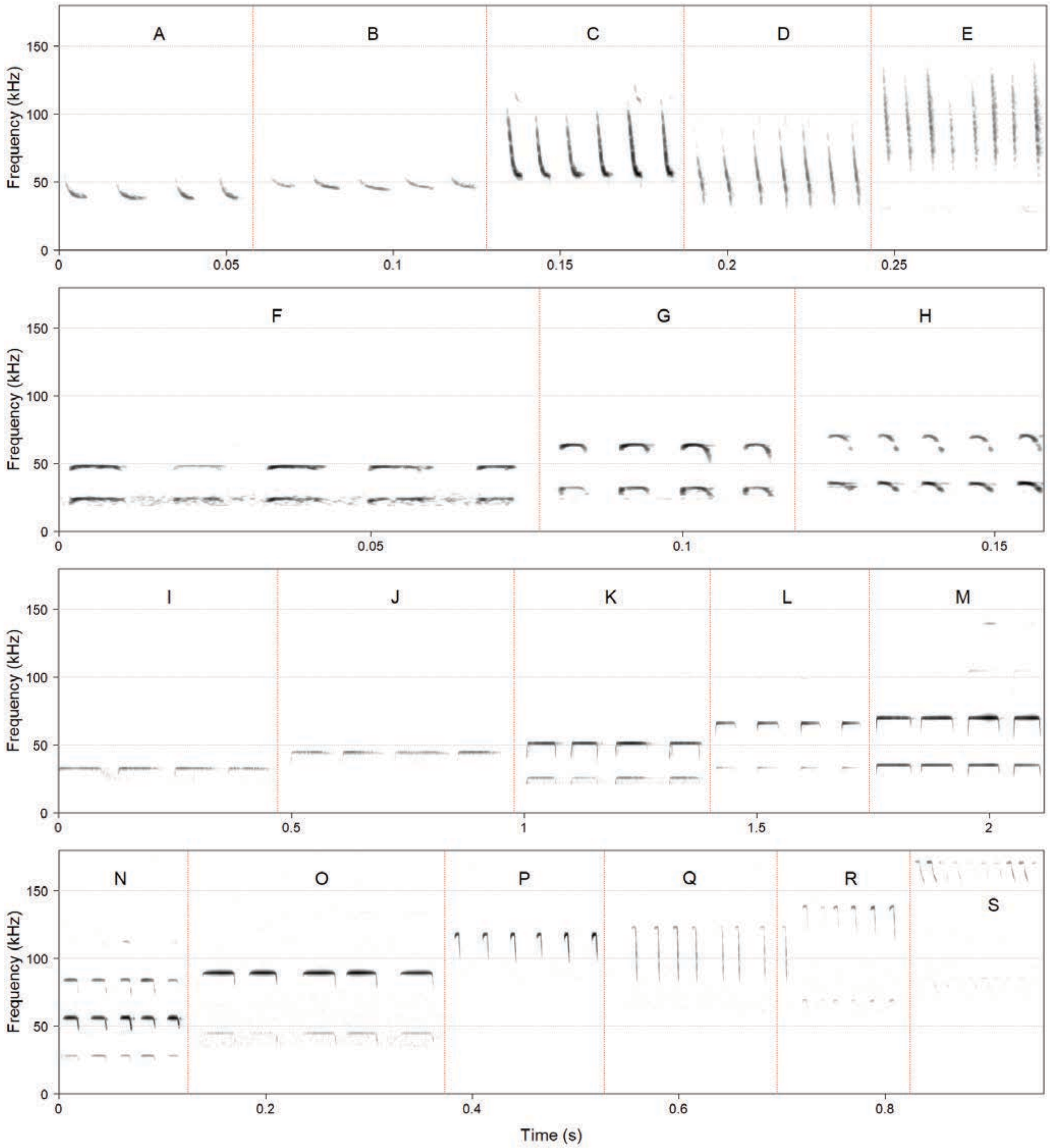

Figure 4. Examples of each echolocation call type (time is compressed between pulses; note the x-axes are scaled differently in each plot).

A: *38 st.cFM Miniopterus* sp. 1 'large'; B: *45 st.cFM Miniopterus* sp. 2 'medium'; C: *53 st.cFM Miniopterus* sp. 3 'small'; D: *40 bFM Myotis moluccarum*; E: *60 bFM Kerivoula muscina;* F: *45 i.fFM.d Emballonura raffrayana;* G: *55 i.fFM.d Emballonura furax;* H: *65 i.fFM.d Mosia nigrescens;* I: *33 lCF Rhinolophus* sp. cf. *robertsi;* J: *47 lCF Rhinolophus* sp. cf. *philippinensis;* K: *52 lCF Rhinolophus euryotis;* L: *66 lCF Rhinolophus megaphyllus;* M: *70 lCF Rhinolophus mcintyrei;* N: *58 mCF Hipposideros diadema;* O: *89 mCF Hipposideros wollastoni;* P: *115 sCF Aselliscus tricuspidatus;* Q: *125 sCF Hipposideros maggietaylorae;* R: *140 sCF Hipposideros cervinus;* S: *172 sCF Hipposideros* sp. cf. *ater.*

Discussion

The variety of approaches to surveying mammals in the Lake Kutubu WMA (camera trapping, Elliott trapping, observational surveys, harp trapping, mist netting and recording echolocation calls) detected a total of 28 species of native mammal, with most being detected by camera traps and bat detectors.

In terms of return for effort, the number of mammal species detected compares well with past surveys of similar length at similar elevations, though there was an under-representation of marsupial species. A survey in several areas in and around the WMA at Mt Kemenagi, a track on the north side of the lake (Henry's Trail, 1,050 m asl) and Iagifu Ridge (Leary and Seri 1997) recorded a total of 26 mammal species (one monotreme, eight marsupials, eight rodents and nine bats) from a longer survey period (14 days) than the present survey. Clearly, the use of remote detection equipment that was not available two decades ago brings efficiencies to mammal surveys.

Non-volant mammals

Camera trapping was the most successful technique used for non-volant mammals during this survey, detecting all non-volant mammal species encountered. The two most common animals on the camera, the bandicoot (*Echymipera* sp.) and White-tailed Giant Rat (*Uromys caudimaculatus*), were even observed to spend up to ten minutes foraging in front of the camera, and were obviously not disturbed by the camera flash. Other recent studies in PNG at Iagifu Ridge (just to the south of the WMA) have also shown that species rarely captured are detected more readily with camera traps, recording 21 species of mammal in relatively short deployment periods (20 camera traps, 5–9 days per camera), and with detections of species of conservation significance (Western Montane Tree Kangaroo (*Dendrolagus notatus*), forest wallaby (*Dorcopsulus vanheurni*), New Guinea Quoll (*Dasyurus albopunctatus*), Woolley's Three-striped Dasyure (*Myoictus leucrura*); Woxvold and Aplin 2017).

For those taxa that were photographed, not all could be identified to species unambiguously. It is clear from the present survey that camera trapping is superior in terms of detection, but not all photographs contained sufficient information to make a robust identification. Furthermore, camera trapping does not provide the opportunity to confirm identifications through examination of external morphology or take samples for confirmation with genetic testing, hence the degree of uncertainty in identification discussed for some taxa (Appendix 2). There was also an under-representation of arboreal species, despite the likely presence of numerous species (Namo 2004). Further use of camera traps has the potential to add significantly to an understanding of mammal diversity in the WMA, especially if heir placement favours detection of arboreal species.

By contrast, live-trapping using Elliott traps and night surveys failed to detect any mammals. Low trap success rate contrasted with a survey at similar elevations on the Iagifu Ridge in the Agogo Range (7.6%; Aplin and Opiang 2017). Given suitable attention to trap function and rebaiting, it is difficult to reconcile the two experiences, however the Relative Abundance of small rodents on camera traps was also low (0.3 or less) compared with species such as small bandicoots that rarely enter Elliott traps (*Echymipera* sp.; 0.9).

Bats

Of the 32 species of bat expected to occur at Lake Kutubu based on the most current information available from the IUCN Red List website (see Appendix 3), 18 were encountered during this survey. Four species that were detected were not expected to occur in the area, and they bring the total number of bat species documented to 22. All species not recorded previously in this area were detected from their echolocation calls, and the taxonomic status of two of them remains uncertain (Appendix 2).

Newly-encountered species in the area include one of the two PNG 'phonic types' of the Large-eared Bat (*Rhinolophus philippinensis*) species complex that are likely to be separate species (here referred to as Greater Large-eared Horseshoe

Bat (*Rhinolophus* sp. cf. *robertsi*) and Large-eared Horseshoe Bat (*Rhinolophus* sp. cf. *philippinensis*)). Until recently when bat detectors were employed on biodiversity surveys (Richards 2005, 2008), only one species affiliated with the '*R. philippinensis*' species complex was known from New Guinea (Flannery 1995; Bonaccorso 1998). Since that time, they have been recorded at the base of the P'nyang Range (Armstrong et al. 2014), near Moro (Armstrong 2017), and several other sites in PNG (K.P. Aplin and K.N. Armstrong unpublished reports), including the recent surveys at Wau Creek and Uro Creek in the Kikori delta (see Chapters 1.6 and 2.6).

The record of Maggie Taylor's Leaf-nosed Bat (*Hipposideros maggietaylorae*) is notable despite it being a common species because it is generally found at lower elevations, from sea level up to around 380 m asl (Bonaccorso 1998; Bonaccorso and Leary 2008). The record at Lake Kutubu seems to be real because the call seen in the recordings is very typical of the species—a higher frequency than Temminck's Leaf-nosed Bat (*Aselliscus tricuspidatus*) by about 5 kHz, slightly shorter pulse length and a much longer terminating broadband frequency component. An alternative identification is a lower frequency phonic type of the Spurred leaf-nosed Bat (*Hipposideros calcaratus*), but they are also mostly found in lowland areas (up to c. 600 m asl; Bonaccorso and Reardon 2008). Both of these species roost in caves, and are likely to be present because suitable rocky outcrop is available for roosting in the WMA. The third species detected but not expected for the area is the Maluku Myotis (*Myotis moluccarum*), but this species is reportedly widespread and found at elevations up to 1,200 (Bonaccorso 1998), and clearly its distribution is not fully understood.

The most notable bat record is of the putative new species of leaf-nosed bat (*Hipposideros*) that calls at 172 kHz. This is only the second record of the call type in PNG, and it is the highest frequency call of any bat in Australasia. The first record of the call type was in a patch of primary forest next to Arakubi Quarry not far from Moro on the Agogo Range (Armstrong 2017). Thus, the species producing the call is likely to be found throughout the WMA. The call frequency and pulse shape indicate that it is very likely a sister taxon to the Dusky Leaf-nosed Bat (*Hipposideros ater*), which has a call frequency of around 150 kHz in PNG (K.P. Aplin and K.N. Armstrong unpublished data). While some level of difference in call frequency is common amongst geographic groups of the Hipposideridae and Rhinolophidae (e.g. Armstrong and Coles 2007), a difference of around 20 kHz in broadly continuous habitat is very likely an indication that the higher call frequency is from a completely distinct and undescribed species. This small bat has so far eluded capture, which remains an exciting challenge.

Using electronic survey tools in rapid assessments—relevant considerations

Rapid biodiversity assessments such as the present study rely on techniques that can increase the rate of encounter of mammal species in a short time period with relatively little effort or specialised skill involved in their deployment. Camera trapping and the recording of diagnostic echolocation calls with bat detectors are not limited by the many factors that influence the success of a trapping program. They simply rely on the animals coming into close proximity to the equipment. Such devices allow deployment by non-specialists, low-cost field studies, and much longer deployment periods that further increase the chance of animal encounters. Given the diversity of mammals detected in the present study area in just a few nights with mostly remote-detection (non-trapping) methods, further efforts are likely to reveal the presence of additional species, especially those that are rare and seldom-seen. Such efforts are certainly desirable so that future conservation and management actions in the Wildlife Management Area consider the whole mammal assemblage. But there are two challenges that must first be resolved.

Firstly, while the camera traps and bat detectors allowed the compilation of a diverse list of taxa, there were still numerous examples where the identifications were problematic—because small diagnostic features (e.g. tail scalation patterns and nipple patterns in smaller rodents) were not visible in photographic images (see comments in Appendix 2 under the entry for *Rattus*); or else the identification of echolocation call types was made difficult by the similarity of certain calls amongst some species (Appendix 2). Further trapping in the short-term would therefore be especially valuable. It would reduce considerably the number of unidentified species by providing the opportunity to examine captures of these problematic taxa. Mammal diversity could then be more reliably quantified with remote methods. In the case of species that are difficult to identify even after capture, and when there is a constraint on the collection of whole-animal vouchers for museum-based comparisons, the application of genetics-based identification will provide greater clarity from a small non-lethal biopsy sample. The utility of genetics-based identification was demonstrated in the Uro Creek study (see Chapter 2.6).

Secondly, rapid assessments are not only limited by how possible it is to identify species from electronic images or acoustic recordings, they are also constrained by the state of taxonomic knowledge of some common PNG mammal groups. Mammal identification can be difficult because of the high prevalence of cryptic species—where a described species contains more than one morphologically-similar but genetically-distinct taxon. There is also a lack of published resources allowing the accurate identification of PNG mammals based on their morphology, which first requires their taxonomic resolution. There has been relatively little application of modern methods in mammal taxonomy to resolve species complexes in PNG, specifically the use of genetic markers. However, genetic markers can be used to make identifications before formal taxonomic description work. One recent ecological study on PNG vertebrates successfully used the DNA barcoding approach to ensure that taxa were identified reliably and consistently, and in some cases highlighted that some 'species' actually had taxonomically distinct forms at different elevations (on the Agogo Range and Hides Ridge; Aplin and Opiang 2017; Armstrong 2017; Armstrong and Aplin 2017; Richards and Armstrong 2017). The application of genetic markers to identification will provide greater clarity, and also allow future recognition of the same captured taxon even if it is undescribed or completely novel.

Thus, further trapping effort combined with genetic work could provide the baseline data against which more accurate remote-detection surveys can be conducted by non-specialists. The strategic use of trapping, remote-detection methods, and genetics-based identification will each have an important role in a successful approach for long-term biodiversity management.

Biodiversity and Conservation Values

The area around Lake Kutubu is already a gazetted as a Wildlife Management Area. Therefore, we anticipate that the additional information contained in the present report will be of use for the continued management of the area, including for mammal diversity. One particular addition that this study brings is the updated references to taxonomy and consequently the understanding of species distributions, plus which species might be of particular relevance for management actions based on current information in their IUCN Red List profiles. Background information on mammals is around two decades old (Leary and Seri 1997).

Leary and Seri (1997) surveyed several areas in and around the WMA, and recorded four mammal species of conservation significance, with all records from the Mt Kemenagi area (taxonomy and IUCN conservation status has been updated to current): Eastern Long-beaked Echidna (IUCN Vulnerable), Doria's Tree Kangaroo (IUCN Vulnerable), Goodfellow's Tree Kangaroo (IUCN Endangered), and Small Dorcopsis (IUCN Near Threatened) (Leary and Seri 1997). The record of Doria's Tree Kangaroo needs confirmation because this species is currently recognised as occurring in upland areas east of Wau. The Lowland Tree Kangaroo (*Dendrolagus spadix*) was reported to be at Mt Kemenagi, and at Wasi Falls (c. 420 m asl) by local hunters (Leary and Seri 1997), so this may be a possible alternative identification. Their comments about the pelage invite doubt about the identifications. A specimen of Doria's Tree Kangaroo shot in the Mt Kemenagi area had "an unusual golden ring at the base of its tail", while another specimen of Goodfellow's Tree Kangaroo "shot on Mt Faru about one hours walk north-west of Kantobo village" (near Wasi Falls) had no golden tail rings, though it did have the characteristic two golden dorsal rump stripes (Leary and Seri 1997). Taking into consideration the uncertainty around identifications, there does seem to be sufficient evidence for at least one (Goodfellow's Tree Kangaroo) and probably two species of tree kangaroo in the WMA and surrounding areas. The presence of these species reflects not only the remoteness of surrounding habitats as sources of replenishment after hunting, but also that hunting pressure has not led to their local extirpation. Given that no tree kangaroos were detected on the present survey, we cannot say how common they are after the 20 years since the study of Leary and Seri (1997), but the presence on camera traps of another species favoured by hunters—Small Dorcopsis (*Dorcopsulus vanheurni*)—is a good sign of relatively low hunting pressure from both people and dogs.

No signs of other species of conservation significance that may occur were reported by Leary and Seri (1997)—New Guinea Pademelon (IUCN Vulnerable), Plush-coated Ringtail (IUCN Near Threatened), Western White-eared Giant Rat (IUCN Data Deficient), Small Melanesian Bent-winged Bat (IUCN Data Deficient)—or on the present survey. But the detection of the horseshoe bat *Rhinolophus mcintyrei* (Data Deficient) was a new record from the area, though this species is relatively common, and was assessed as Data Deficient mainly because of recent taxonomic changes (Appendix 2). With additional and broader-scale effort for camera trapping at both ground level and targeting arboreal species it should be possible to make unambiguous identifications of the marsupial and rodent species. The presence of the Small Melanesian Bent-winged Bat can be considered after taxonomic studies have been completed (K.N. Armstrong and S. Wiantoro, unpublished data).

It is clear that despite relatively low detection returns of marsupials and rodents from this rapid assessment survey, there is an intact and high-value mammal assemblage in the WMA. The capacity of the community to effectively manage the biodiversity value of the WMA through local decision-making can be further enhanced, with some recent experience providing a good demonstration of this. For instance, with the support of ExxonMobil PNG Limited, Kale (2016) facilitated a workshop for five villages (Tugiri, Yo'obo, Gesege, K-Point and Wasami) on ecosystem services analysis where the locals identified key ecosystem services provided by their immediate environment in the WMA. The workshop enhanced understanding of the complex ecosystem and the services it provides to local communities, which prompted conservation actions among the landowners and wildlife management committees. Such workshops among the local people on other practical topics in conservation can enhance learning, knowledge transfer and provoke conservation actions among the local communities. For instance, the list of mammals surveyed so far from WMA can be reviewed with local communities to determine the number of local species, conservation significant species based on IUCN status, and culturally significant species to generate multiple conservation values for each mammal species thereby enhancing conservation actions by local communities.

Balancing the needs of mammal conservation, cultural traditions and subsistence

Balancing the needs of biodiversity conservation with a recognition of the importance of bushmeat to rural or remote communities is challenging (e.g. Eisemberg et al. 2011). The take of bushmeat can be considerable, with one study recording 1.2 tons of wild meat sourced mainly from 37 large bodied mammal genera, including *Dendrolagus*, *Zaglossus* and *Phalanger* (Mack and West 2005). Such a reliance on bushmeat is likely to be common, since a large proportion of PNG people live in remote locations and at the fringe of the cash economy with few options for sourcing their protein from farm or domestic stocks (Mack and West 2005). In many IUCN Red List accounts for larger PNG mammals, hunting was identified as a threatening process that causes population decline (e.g. Leary et al. 2016a).

For communities that wish to manage their land for biodiversity conservation within a formally-recognised Wildlife Management Area, they could make a commitment to stop hunting certain vulnerable species. Alternatively, recognising that a complete ban may not be desirable or achievable, they could develop a plan to manage their take sustainably, and monitor the persistence of these species.

An additional strategy for the sustainable management of species vulnerable to hunting pressure might be to encourage a greater-than-normal focus on feral pigs. The presence of pigs has several negative consequences for native biodiversity. They are destructive to the forest understorey and create significant soil disturbance, compete with native fauna for invertebrates and worms (Howarth 1985) and may also spread disease pathogens to native fauna (Hampton et al. 2004). However, their numbers are unlikely to be controllable because of the continuity of the WMA with the extensive surrounding forest that would presumably be the source of continued replenishment following reductions within the WMA. By shifting a significant level of hunting pressure away from the native mammals and onto feral pigs, it could help to maintain mammal diversity and the quality of their habitat.

Even more helpful would be the reduction of wild dogs that are known to have a significant impact on some macropod populations (e.g. *Dorcopsulus vanheurni*; Leary et al. 2016a). The combination of some level of cultural change, together with active management of pigs and dogs, could be sufficient to maintain viable populations of the more sensitive species, and ensure that the area continues to meet the standards for a Wildlife Management Area. In this way, larger-bodied native mammals can serve as 'umbrella' species for the remainder of the mammal assemblage and their habitat. If the community was keen to promote the area or their management of it, then these species could also be used as 'flagship' species whose persistence demonstrates the effectiveness of their actions.

Recommendations

- Use more targeted trapping and genetic ID to resolve ambiguous identifications on a subsequent survey so that longer-term monitoring is based on verified knowledge of species presence and taxa with no ambiguity around their identification.

- Continue monitoring for mammals periodically to assess longer term patterns, using primarily camera traps and bat detectors and engaging with researchers for analysis and reporting.

- Promote the hunting of pigs over native mammal species, especially larger species such as Dorcopsis and tree kangaroos, and control wild and domestic dog numbers.

- Review a list of local mammals species with local communities in the WMA to further understand local species occurrence, including those with elevated IUCN conservation status, and those with particular cultural significance to compile a more comprehensive understanding of conservation values for each mammal species; and work to have this incorporated into programs of conservation action by the local communities

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Plate1

A. Camera trap image of one of the small *Echymipera* bandicoots in the Peroryctidae

B. The Small Dorcopsis (*Dorcopsulus vanheurni*)

C. Camera trap image of the Large Leptomys (*Leptomys elegans*)

D. A male White-tailed Giant Rat (*Uromys caudimaculatus*)

E. Camera trap image of domesticated or wild dogs out hunting at night in the Lake Kutubu WMA.

Plate 2

A. Wollaston's Leaf-nosed Bat (*Hipposideros wollastoni*)

B. The horseshoe bat (*Rhinolophus mcintyrei*)

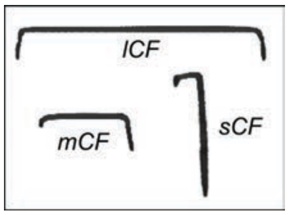
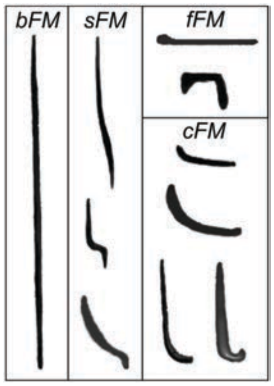
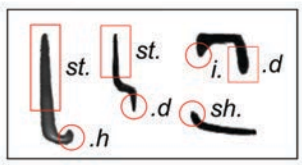
C. Unidentified bent-winged bat (*Miniopterus* sp.)

D. Fly River Woolly Bat (*Kerivoula muscina*)

Appendix 1. Processing of bat detector recordings.

Processing first involved the recognition of bat echolocation 'call types', followed by a separate step of allocating a species identification to each of these. The 'call types' are defined based on a standardised naming scheme that has been used in many published and unpublished surveys across Papua New Guinea and Wallacea in recent years (Armstrong and Aplin 2011, 2014b; Armstrong et al. 2014, 2015a,b; Armstrong 2017; K.N. Armstrong and K.P. Aplin unpublished reports; Supplementary Table 1). The provision of illustrated examples of identified call types provides the opportunity for future verification of call identifications and retrospective correction of species names on the basis of updated information.

Supplementary Table 1. Echolocation call categories based on the shape of search-phase calls (adapted from de Oliveira 1998a,b; Corben and O'Farrell 1999; Gannon et al. 2004; Armstrong and Aplin 2011, 2014a; Armstrong et al. 2014, 2015a,b; examples are not scaled equally). Echolocation calls generally consist of three main sections: an initial frequency sweep (IFS), followed by the main body (BST: Body Sub Type), and ending in a terminating frequency sweep (TFS). The overall call shape is represented by the codes in the form 'IFS.BST.TFS', prefixed by a value representing the mean characteristic frequency in kHz. Note that most CF pulses have a recognisable initial upward frequency sweep, and all have a terminating frequency sweep, so the IFS and TFS descriptors are not used for this Body Sub Type.

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

The WAV files were scanned for bat echolocation calls using SCAN'R version 1.7.7 (Binary Acoustic Technology) and a custom [R] statistical computing language script was then used to perform a Discriminant Function Analysis to compare bat calls from each nightly recording with data from reference calls and representative call types of Papua New Guinean bats (Armstrong and Aplin 2014b; Armstrong et al. 2014, 2015a; K.N. Armstrong and K.P. Aplin unpublished data). Verification of each call type was made from the original WAV files in a spectrogram within Adobe Audition CS6 version 5.0.2 software. Species were identified from the scored call types based on information in Armstrong and Aplin (2011, 2014b), Leary and Pennay (2011), Robson et al. (2012), Armstrong et al. (2014, 2015a), and K.N. Armstrong and K.P. Aplin (unpublished data).

Appendix 2. Species accounts—supporting information on selected species.

Brief species accounts are presented for selected species that have elevated conservation status on the IUCN's Red List, had an ambiguous identification, are part of a species complex with taxonomic issues that make identification difficult, or that are range extensions.

Order Peramelemorphia; Family Peroryctidae

Common Echymipera (*Echymipera kalubu*; IUCN Least Concern)

Long-nosed Echymipera (*Echymipera rufescens*; IUCN Least Concern)

The camera traps photographed at least one species of small peroryctid bandicoot, which could have been either the Common Echymipera (*Echymipera kalubu)* or the Long-nosed Echymipera (*E. rufescens*). The Common Echymipera is the most likely candidate given that it is indeed relatively common and has an elevational range that extends to 1,500 m asl (Flannery 1995; Menzies 1991). However, the Long-nosed Echymipera, while less common, is variable in coat colour and size and could be misidentified in photographs. Both species are known from the Kikori basin (Namo 2004), although Flannery (1995) indicated that *E. rufescens* has a preference for drier habitats. Hunting dogs may pose threats to bandicoot populations in the WMA, and it is an important game animal for local hunters.

Order Diprotodontia; Family Macropodidae

Small Dorcopsis (*Dorcopsulus vanheurni*; IUCN Near Threatened)

This species is widespread, especially in the montane forest habitats of New Guinea's central cordillera and on the Huon Peninsula (Flannery 1995). However, while it used to be common, it is now uncommon in most parts of its range, and has been extirpated from some areas, such as the Hunstein, Schrader, and the Torricelli ranges. It is considered unlikely to be found near human settlements. This decline has arisen from hunting pressure, including from wild dogs, and conversion of forest to subsistence agricultural use and general human encroachment. Its numbers appear to be stable or increasing in protected areas such as YUS (Leary et al. 2016a), and its presence at Lake Kutubu is therefore significant.

Order Rodentia; Family Muridae

Unidentified rats *Rattus* sp. and similar sized rodents

Identifying *Rattus* from photographs is challenging because small diagnostic characters on the body cannot be seen. Candidate species present in the WMA study area may include not only species of *Rattus* (several according to the list compiled by Leary and Seri 1997 and Namo 2004*; R. niobe*, *R. novaeguineae*, *R. steini*, *R. verecundus*; Aplin 2016a; Dickman et al. 2016, Leary et al. 2016b, Wright et al. 2016a), but also *Paramelomys* (e.g. *P. mollis, P. platyops, P. rubex*; Aplin 2016b, Leary et al. 2016c, Wright et al. 2016b)*, Melomys* (e.g. *M. leucogaster, M. rufescens;* Aplin 2016c, Wright et al. 2016c) and *Pogonomys* (e.g. *P. loriae, P. macrourus, P. sylvestris*; Leary et al. 2016d,e,f). Capture, examination of external morphology, and ideally genetic work are required to make robust identifications in such groups where there are several candidate species, known taxonomic issues and cryptic taxa.

Order Chiroptera; Family Pteropodidae

Common Tube-nosed Fruit Bat (*Nyctimene* sp. cf. *albiventer*)

Green Tube-nosed Fruit Bat (*Paranyctimene* sp. cf. *raptor*)

Tube-nosed fruit bats are recognised by their large eyes, dark and yellow spots on the skin of the wing membranes (usually on the top of wing bones) and ears, the dark stripe down its back (*Nyctimene* only; *Paranyctimene* lacks this stripe) and the long, divergent tubular nostrils. The spotting on the skin helps with camouflage as they rest amongst tree foliage during the day. At night they feed mostly in undisturbed forest on fruits, and are an important pollinator and seed disperser in the forest.

There are unresolved taxonomic issues in the genera *Nyctimene* and *Paranyctimene*. There are several cryptic taxa within the *Nyctimene 'albiventer'* complex and others which are similar closely-related species that are easily misidentified (*N.*

certans, N. draconilla) so we refer the Lake Kutubu species to *Nyctimene* sp. cf. *albiventer* pending further studies. The species of *Paranyctimene* present in the WMA also needs genetic studies to confirm its identity.

Common Blossom Bat (*Syconycteris australis*; IUCN Least Concern)

This is a small light-brown blossom bat that is very similar in appearance to the Dagger-toothed Long-nosed Blossom Bat (*Macroglossus minimus*), but it has a shorter snout and no indication of a tail membrane or tail. They are typically very common and can be captured easily with mist nets and harp traps (42 individuals were captured on the present survey). Preliminary unpublished genetic and morphological studies (K.N. Armstrong and K.P. Aplin unpublished data) have shown that there are at least two forms of the Common Blossom Bat on mainland New Guinea—one in the lowland habitats below around 1,200 m asl with short, reddish brown fur, and an upland species that often overlaps with the lowland species at its upper elevational limit, which has slightly longer, greyer or darker fur. The identity of those captured at Lake Kutubu was most likely the lowland form.

Order Chiroptera; Family Emballonuridae

Most small species of sheath-tailed bat (*Emballonura* spp.) are relatively common and have an IUCN conservation status of Least Concern. However, they can be vulnerable to disturbance in their roosts, especially from hunting because they aggregate into colonies that range in size from a few individuals to hundreds in some cases (Bonaccorso 1998). This includes the two species detected on the survey: Raffray's Sheath-tailed Bat (*Emballonura raffrayana)* (call type *45 i.fFM.d*) and New Guinea Sheath-tailed Bat (*Emballonura furax)* (call type *55 i.fFM.d*).

Order Chiroptera; Family Hipposideridae

Most species of hipposiderids bat are relatively common and have an IUCN conservation status of Least Concern. However, they can be vulnerable to disturbance in their roosts, especially from hunting because they aggregate into colonies that range in size from a few individuals to hundreds in some cases (Bonaccorso 1998). Such species include: Temminck's Leaf-nosed Bat (*Aselliscus tricuspidatus*) (call type *115 sCF*), Fawn-coloured Leaf-nosed Bat (*Hipposideros cervinus*) (call type *140 sCF*), Diadem Leaf-nosed Bat (*Hipposideros diadema*) (call type *58 mCF*) and Maggie Taylor's Leaf-nosed Bat (*Hipposideros maggietaylorae*) (call type *125 mCF*).

Order Chiroptera; Family Rhinolophidae

Most species of rhinolophid bat are relatively common and have an IUCN conservation status of Least Concern. However, they can be vulnerable to disturbance in their roosts, especially from hunting because they aggregate into colonies that range in size from a few individuals to hundreds in some cases (Bonaccorso 1998). Such species include: the horseshoe bat *Rhinolophus mcintyrei*, New Guinea Horseshoe Bat (*Rhinolophus euryotis*), Eastern Horseshoe Bat (*Rhinolophus megaphyllus*), and Large-eared Horseshoe Bat (*Rhinolophus philippinensis*) (see comments on taxonomy below).

A horseshoe bat *Rhinolophus mcintyrei*; Call type *70 lCF*

The Arcuate Horseshoe Bat (*Rhinolophus arcuatus*) is encountered commonly on acoustic surveys in PNG, and its presence has been reported under this name in numerous published and unpublished reports that the author KA has been involved in. When revising the conservation status of mammals in the South East Asian region, the IUCN chose to follow a taxonomic study that revised the taxonomy of this species, which split those occurring in New Guinea from the remainder in the Philippines and Indonesia and elevated them to species status (Patrick et al. 2013). The PNG representative of the *R. arcuatus* 'species complex' is now called *R. mcintyrei*, which does not have a common name. Despite its wide distribution in New Guinea, it was assessed as Data Deficient (Patrick and Ruedas 2017), but is unlikely to be facing significant threats.

Greater Large-eared Horseshoe Bat (*Rhinolophus* sp. cf. *robertsi*; Call type *33 lCF*)

Large-eared Horseshoe Bat (*Rhinolophus* sp. cf. *philippinensis*; Call type *47 lCF*)

These two forms are currently regarded as 'phonic types' (=having different echolocation calls) of the Large-eared Bat (*Rhinolophus philippinensis*), which is a species complex ranging from the Philippines to northern Australia that requires thorough taxonomic revision (Sedlock et al. 2008). In both New Guinea and northern Australia, two phonic types are present together in the same habitats (in sympatry), which probably suggests they are different species. The lower frequency call type *33 lCF* was only recorded recently in New Guinea (Richards 2005, 2008), and may never have been collected. All forms are clearly recognisable by their 'over-sized' ears and noseleaf. They roost in shallow caves but do not form larger colonies like some cave-roosting bat species.

Order Chiroptera; Family Miniopteridae

Unidentified bent-winged bat (*Miniopterus* sp. 1 'large'; Call type *38 st.cFM*)

Unidentified bent-winged bat (*Miniopterus* sp. 2 'medium'; Call type *45 st.cFM*)

Unidentified bent-winged bat (*Miniopterus* sp. 3 'small'; Call type *53 st.cFM*)

Three call types are allocated to species of bent-winged bat, with varying degrees of confidence. The *38 st.cFM* call type is similar to reference calls collected elsewhere in southern New Guinea from a large species of *Miniopterus*. The other two *st.cFM* call types with characteristic frequencies of around 45 kHz and 53kHz are likely to be from medium- and small-sized *Miniopterus*, though *Pipistrellus* is also a possibility for some examples. These two genera are very difficult to distinguish reliably, except where characteristic feeding buzzes are recorded. The reliable identification of bent-winged bats in PNG will not be possible until completion of a taxonomic study currently in progress (K.N. Armstrong and S. Wiantoro unpublished data).

All species of bent-winged bat aggregate in colonies that can number many thousands, typically females that congregate for the birth and development of young. Males also roost in caves but typically in smaller aggregations, and bats disperse to other caves outside the breeding season. Little is known about reproduction of bent-winged bats in Melanesia (Bonaccorso 1998). However, their aggregatory behaviour in caves make them vulnerable to disturbance and hunting.

Appendix 3. A list of bats expected and present (X) or not detected (—) from Lake Kutubu based on information in the IUCN Red List maps for each species.

An additional three species of bat were encountered during the survey (Table 2).

Common name	Scientific name	IUCN	Presence
Pteropodidae			
Lesser Bare-backed Fruit Bat	*Dobsonia minor*	LC	—
Moluccan Naked-backed Fruit Bat	*Dobsonia moluccensis*	LC	—
Dagger-toothed Long-nosed Fruit Bat	*Macroglossus minimus*	LC	—
Common Tube-nosed Fruit Bat	*Nyctimene albiventer*	LC	X
Mountain Tube-nosed Bat	*Nyctimene certans*	LC	—
Green Tube-nosed Fruit Bat	*Paranyctimene raptor*	LC	X
Steadfast Tube-nosed Bat	*Paranyctimene tenax*	LC	—
Common Rousette	*Rousettus amplexicaudatus*	LC	—
Common Blossom Bat	*Syconycteris australis*	LC	X
Emballonuridae			
Large-eared Sheath-tailed Bat	*Emballonura dianae*	LC	—
New Guinea Sheath-tailed Bat	*Emballonura furax*	LC	X
Raffray's Sheath-tailed Bat	*Emballonura raffrayana*	LC	X
Lesser Sheath-tailed Bat	*Mosia nigrescens*	LC	X
Hipposideridae			
Temminck's Leaf-nosed Bat	*Aselliscus tricuspidatus*	LC	X
Dusky Leaf-nosed Bat	*Hipposideros ater*	LC	—
Fawn-coloured Leaf-nosed Bat	*Hipposideros cervinus*	LC	X
Diadem Leaf-nosed Bat	*Hipposideros diadema*	LC	X
Fly River Leaf-nosed Bat	*Hipposideros muscinus*	LC	—
Wollaston's Leaf-nosed Bat	*Hipposideros wollastoni*	LC	X
Rhinolophidae			
a horseshoe bat	*Rhinolophus mcintyrei*	DD	X
New Guinea Horseshoe Bat	*Rhinolophus euryotis*	LC	X
Eastern Horseshoe Bat	*Rhinolophus megaphyllus*	LC	X
Large-eared Horseshoe Bat	*Rhinolophus philippinensis*	LC	X
Vespertilionidae			
Maluku Myotis	*Myotis moluccarum*	LC	X
Short-winged Pipistrelle	*Philetor brachypterus*	LC	—
Mountain Pipistrelle	*Pipistrellus collinus*	LC	—
Papuan Pipistrelle	*Pipistrellus papuanus*	LC	—
Miniopteridae			
Little Bent-winged Bat	*Miniopterus australis*	LC	X
Small Melanesian Bent-winged Bat	*Miniopterus macrocneme*	DD	—
Large Bent-winged Bat	*Miniopterus magnater*	LC	—
Medium Bent-winged Bat	*Miniopterus medius*	LC	X
Greater Bent-winged Bat	*Miniopterus tristis*	LC	X
Total Expected			**32**
Total Observed			**18**