# Odonata of the Crater Mountain Wildlife Management Area, Papua New Guinea

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Neurobasis sp. nov., Calopterygidae

## Summary

The odonate fauna of Papua New Guinea (PNG) is species rich but poorly studied. Geographic ranges, ecology, and thus conservation status of many species are unknown. In this study I provide an inventory of two sites within the largest formally protected forest area in PNG, the Crater Mountain Wildlife Management Area. I sampled odonates for a total of 112 days in a pristine forest site and for 36 days in a traditional garden village, and worked with local communities to increase the awareness of dragonflies in the area. I found a total of 78 species (60 Zygoptera, 18 Anisoptera) from 13 families, including at least six currently undescribed species.

The pristine rainforest hosted more species (61) than the village (37), and a longer sampling period was required to reach an approximately equal level of the total species richness. I calculated species accumulation curves for both areas and found that 100 sampling days were required in the pristine forest, whereas 35 sampling days appeared sufficient in the modified forest. More than two-thirds of all species recorded in the pristine forest were observed in less than half of all the sampling sessions, indicating that species might be both rare and occur only during certain times of the year. The number of species recorded per sampling session indicated some seasonality in the odonate fauna of the pristine forest, which should be considered in future studies. The study suggests that modification of tropical rainforests will lead to a loss of species richness. Conservation of odonates in PNG is therefore dependent on the preservation of primary rainforests, which requires the education of native people living in these areas. Dragonflies were well known among local people inhabiting the study area, but did not play a major role in their culture. More work on dragonflies is needed to describe the diversity of the PNG odonate fauna.

## Introduction

Dragonflies (Odonata) are attractive insects that are considered important indicators for water quality as well as for general species richness (Corbet 1993; Dolný 2000; Chovanec & Waringer 2001; Sahlén & Ekestubbe 2001; Timm et al. 2001; Mustow 2002). The odonate fauna of many tropical rainforest areas is understudied, and this is especially the case for Papua New Guinea (Lieftinck 1942, 1949; Polhemus 1995; Mack 1998). Papua New Guinea is known for its very high biodiversity in many taxa that is partially due to a very rugged mountainous landscape that enhances local endemism (Heads 2001, 2002). The rugged terrain and high rainfall in many areas also supports a large variety of water bodies, rendering the forests of Papua New Guinea extremely interesting areas for odonatological studies.

As in many other tropical countries the human population in Papua New Guinea is growing rapidly. This increases the pressure on the remaining natural areas and water sources (Henderson 1997). Human modification of the landscape usually results in deforestation and degradation of streams and rivers as a result of pollution and erosion (Timm et al. 2001; Buss et al. 2002). Deforestation is a major cause of dragonfly population decline in tropical forests worldwide (Clausnitzer 2004; Dijkstra & Vick 2004; Orr 2004). Even though very little is known about the habitat requirements of Papuan odonates, deforestation and pollution of fast flowing mountain streams are likely to adversely affect the odonate communities of native forests.

In Papua New Guinea a large part of the population lives in rural, mainly forested areas. The land belongs to clans inhabiting the forests, and they survive on subsistence gardening and hunting. Conservation efforts must therefore address the people living in the forests, as their consent and support is crucial for the implementation of any conservation measure.

In 2004, I started a dragonfly project in the largest formally protected area in Papua New Guinea. The main goal of this study was to provide an inventory of the dragonflies of both a pristine lower montane rainforest site, and of a typical village where subsistence gardening, cutting of timber and firewood, hunting, and other human activities have modified the original forest landscape. Furthermore, I intended to increase the awareness of dragonflies by local people, and provide a baseline for future research in the area. This report presents a detailed account of the species found. Detailed analyses of habitat associations and community similarity are beyond the scope of this paper and will appear elsewhere in due time (Oppel in prep.-a, b, in press).

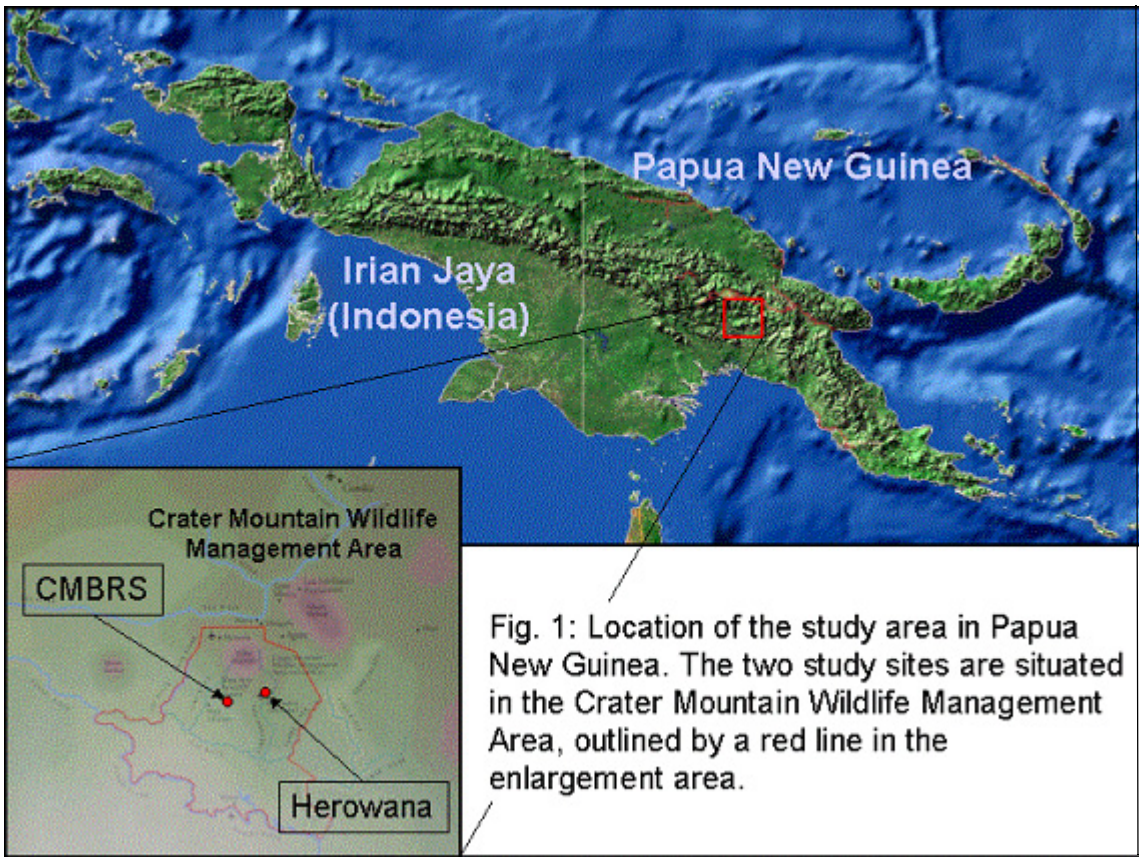


Fig. 1: Location of the study area in Papua New Guinea. The two study sites are situated in the Crater Mountain Wildlife Management Area, outlined by a red line in the enlargement area.

## Methods

I sampled dragonflies at the CMBRS between November 2003 and August 2004 on a total of 112 sampling days. During that time I recorded the sighting of every morphospecies. Later, after identification of all collected specimens had been completed, I was able to use the sighting records to establish a species accumulation curve with respect to sampling time. I also recorded the presence of every species for every fortnight of the sampling period in order to detect phenological trends. Every species was then classified in one of five temporal presence categories based on the number of sampling fortnights in which it was recorded. I used the following classification: rare (recorded in only one fortnight), occasional (2-4), irregular (5-7), regular (8-12), and permanent (13-14). Habitat use was recorded based on analyses of odonate assemblages in the study area (Oppel in prep.-a). I identified 10 distinct habitat types: open sunny areas without water (habitat type 1), forest interior without water (2), temporary puddles in the forest interior (3), temporary puddles in open sunny areas (4), fish-free permanent pond (5), large open river (6), small partially shaded river (7), small permanent mostly shaded creek (8), small temporary creek in the forest (9), and artificial ditch (10). For every encounter with an adult dragonfly or damselfly the habitat type and the number of individuals were recorded.

I trained two young men and two young women from the Gimmi tribe in Herowana to collect dragonflies and damselflies. After two weeks of instruction they carried out dragonfly sampling in Herowana in July, August, and October 2004 with two observers on a total of 36 days. For the first six weeks simultaneous sampling took place in Herowana and at CMBRS. Specimens were collected with butterfly nets and killed in jars lined with cotton buds soaked with ethanol. They were stored in paper envelopes and kept in a box filled with silica gel and naphtalene. All specimens were sent to John Michalski (Morristown, USA) for identification. John Michalski and Nick Donnelly (Binghampton, USA) carried out the determination of specimens.

For every species a preferred habitat type was defined as the habitat type where most individuals of that species were recorded. If equal proportions of a species' observed individuals were in different habitat types no preferred habitat was assigned to that species.

During the study period I spent three weeks in the village of Herowana and talked to village elders about the significance of dragonflies in the local culture and rituals.

### *Logistics of the project*

The Wildlife Conservation Society (WCS) operates out of Goroka, the provincial capital of the Eastern Highlands Province. Goroka has an airport and is serviced several times a day from major cities in PNG. WCS has a safe institution in Goroka with library and accommodation facilities that can be used by visiting researchers. I highly recommend that people who want to enter the CMWMA contact WCS prior to their travel to PNG to gather information. The CMWMA is accessed via missionary airplanes operating on an unnervingly random pattern out of Goroka. It is not uncommon that air services are suspended for unspecified times due to sick pilots, unscheduled routine inspections, or aircraft damage resulting from a collision with a pig crossing the runway. PNG is called 'island of the unexpected', and this label is very evident in rural air service. Patience and a high tolerance level towards inconveniences are essential for every trip.

Main access points to get to CMBRS are the hamlets of Haia and Herowana, both equipped with a grassy airstrip. I flew into Herowana three times on chartered aircraft, bringing with me supplies for three months on each occassion. In Herowana I hired porters to carry the supplies to CMBRS. The hike to CMBRS took roughly 8-15 hours, depending on my physical condition, skill, and water and mud levels. At CMBRS there is a fully equipped research station with UHF radio contact to the base in Goroka. It was a very comfortable home during the field work. Local workers are routinely hired by WCS for various maintenance jobs around the research station, and local garden produce is bought from the nearby villages. This ensures good contacts to the local inhabitants and provides some support for conservation issues. Despite all villages speaking their own language I managed to communicate with people and felt welcome on their land. Support from WCS was excellent and arranging the return journeys would have been impossible without determined staff booking and confirming aircraft charters to Herowana.

### *Use of money from IDF*

The money granted by IDF for this project was mostly spent on equipment and wages for local workers (Figs. 2 and 3). Local people were instructed how to find and catch dragonflies, and I developed a habitat key so they could record the habitat type for every dragonfly they encountered. The local workers were equipped with nets, sampling vials, field notebooks, preservation material, labels and storage boxes to record, capture and preserve dragonfly specimens independently over a 6-week period. Furthermore, some money was spent on guides and landowners to obtain the right to survey private gardens and forest areas.


Figure 2. Assistant Oliver and the author in Herowana.

## Results

### *Dragonflies and Humans*

Dragonflies and damselflies are well known to the native people inhabiting the CMWMA. They do not play a major role in human rituals or cultural myths among the Gimmi and Pawaian people inhabiting the study area. Dragonflies are neither regarded as food source nor as a potential hazard. The Gimmi name "jobese" is composed of the words "jobe" = salt and "se" = lick/eat, and refers to the salty taste people experience when licking a dragonfly's wing or abdomen. The traditional diet of garden food and hunted animals might be very poor in salt, and dragonflies might have in the past occasionally been used as saltlicks. Children also used to have playful competitions shooting dragonflies. Stalking around ponds or swamps they would try to spear as many dragonflies as possible in order to win against their competitor. These traditional games are becoming increasingly uncommon nowadays, being replaced by western sports such as rugby, soccer and basketball. The sporadic and opportunistic usage of dragonflies as taste supplement or play object might explain the exceptionally good knowledge of what constitutes a dragonfly and what does not. When instructing local workers a single demonstration odonate was sufficient to explain what I wanted them to catch. Despite the large variety in size, coloration and behaviour of the local odonate species, and the presence of several superficially very similar looking insects of various other orders, I was

never presented with a non-odonate specimen by any of my local assistants. This was in marked contrast to well educated western researchers working on other projects in the station, who frequently confused non-odonate insects with dragonflies.

Figure 3. Field assistants Joris and Amoli in a typical creek in the rainforest study area.

The low importance of dragonflies has both positive and negative implications for conservation. The lack of fear and nutritional value will prevent a depletion of the odonate fauna by direct persecution, as is often the case in other animal groups (i.e. birds, fish, snakes). However, given that the gravest dangers for dragonflies are probably habitat alterations, the little respect and low rank in local mythology will render it very difficult to persuade people to preserve dragonfly habitats if this conflicts with development and an assumed increase in economic value or living quality. As in many other tropical areas, education of indigenous people is required in order to increase the awareness for dragonflies and damselflies (Clausnitzer 2004; Paulson 2004; Rowe 2004).

### *Odonates recorded in the CMWMA*

I found a total of 78 species, of which 21 occurred in both the village and the pristine rainforest site. The pristine rainforest hosted 61 species, while the village site was home to 37 species. A total of 13 families was recorded, 10 in Herowana, and all 13 at CMBRS. The ratio of Zygoptera to Anisoptera was high in both areas, 28:9 in Herowana (78% Zygoptera), and 45:16 at CMBRS (74% Zygoptera).

The sampling period at CMBRS was three times as long as the sampling period in Herowana, but sampling in Herowana was conducted with two observers and in a larger area. The species accumulation curve at CMBRS showed an asymptotic tendency after c. 100 sampling days (Fig. 4). In Herowana, the species accumulation curve showed a similar pattern after 31 sampling days (Fig. 5). Equal sampling periods (36 days) yielded different rates of species detection for the two study areas, with only 72% of the observed species richness being recorded at CMBRS.

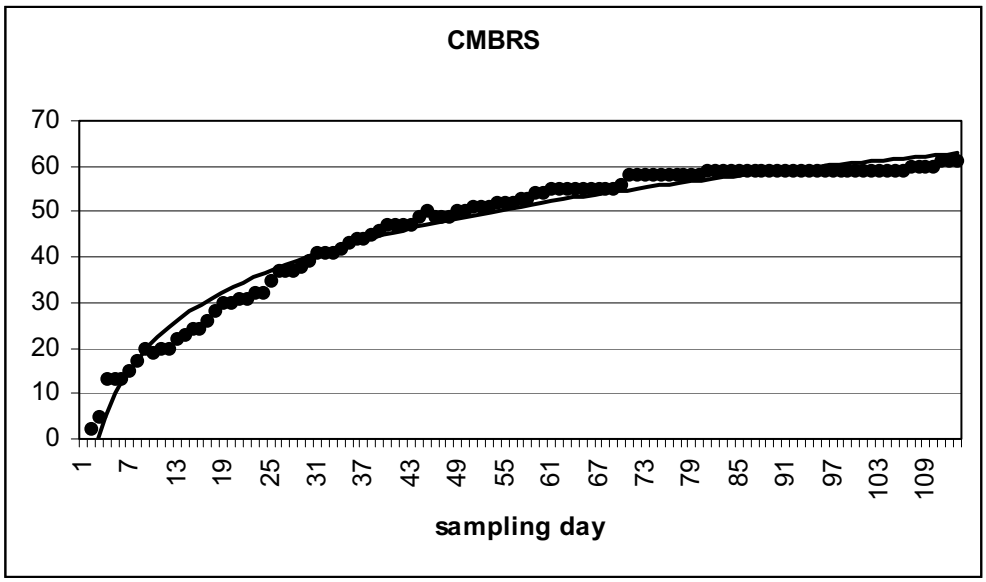


Figure 4. Species accumulation curve (total number of species recorded in relation to time spent sampling) for CMBRS.

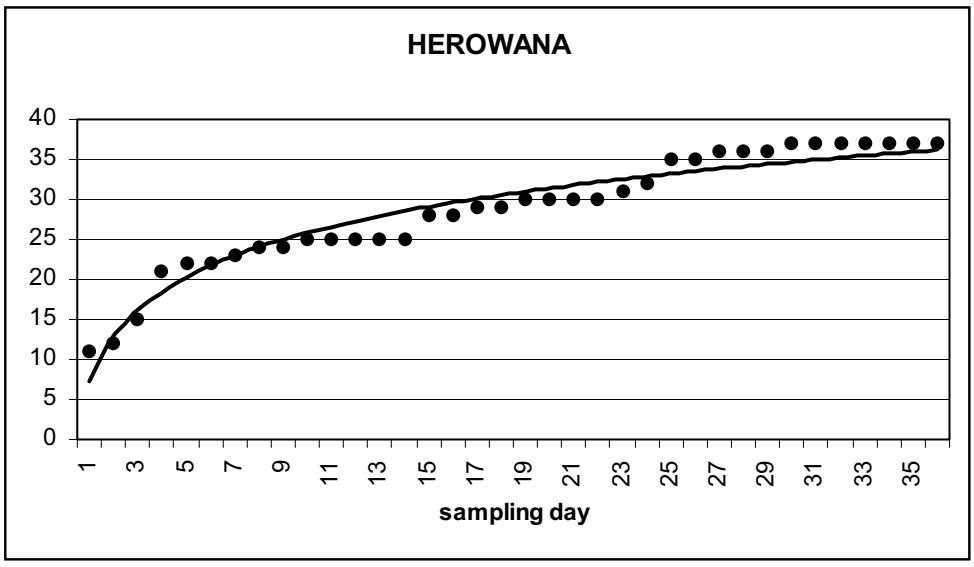


Figure 5. Species accumulation curve (total number of species recorded in relation to time spent sampling) for Herowana.

At CMBRS the phenological presence of species varied throughout the study period. In the second half of January and the second half of March significantly more species could be observed than during June and July (Fig. 6). A classification of species into bins of relative presence resulted in 69% of species being recorded in less than half of the sampling fortnights. Only 11% of species were recorded in more than 90% of all sampling fortnights (Fig. 7).

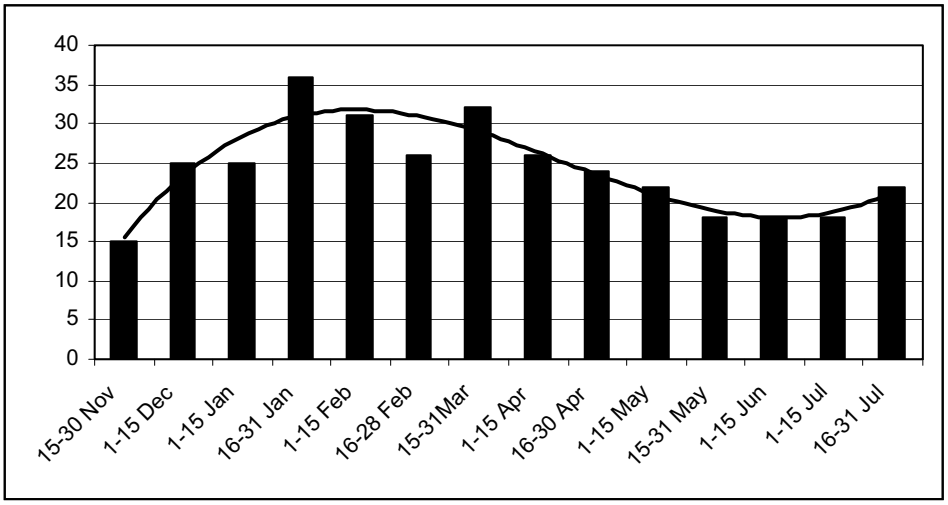


Figure 6. Number of species recorded at CMBRS during each sampling fortnight.

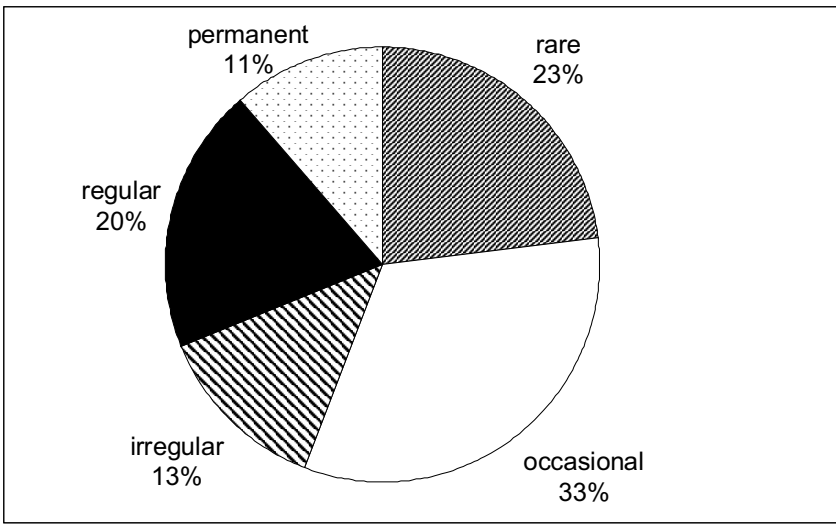


Figure 7.Temporal presence of all species encountered between November 2003 and August 2004 at CMBRS. For definition of presence categories see text.

## Annotated species list

All species encountered during the study are listed in Table 1. For every species the preferred habitat type is given as the habitat type where most individuals of that species were recorded. The abundance indicates the number of individuals observed during the entire study period. Species without a preferred habitat type were recorded in equal proportions in different habitat types.

Table 1. All species recorded during the study period at the two study areas, and the number of individuals recorded in each study area (abundance). Note that abundance at CMBRS is based on a longer sampling period and might therefore be significantly higher for species with equal density and detectability. See text above for habitat preference.

**Table 1.** All species recorded during the study period at the two study areas, and the number of individuals recorded in each study area (abundance). Note that abundance at CMBRS is based on a longer sampling period and might therefore be significantly higher for species with equal density and detectability. See text above for habitat preference.

| Species name | CMBRS | | Herowana | |
|---|---|---|---|---|
| | preferred habitat type | N | preferred habitat type | N |
| **Calopterygidae** | | | | |
| *Neurobasis* sp. nov. | 8 | 207 | 8 | 52 |
| **Chlorocyphidae** | | | | |
| *Rhinocypha tincta* (Rambur) | 8 | 58 | 8 | 66 |
| **Lestidae** | | | | |
| *Indolestes tenuissimus* (Tillyard) | 5 | 132 | | 0 |
| **Megapodagrionidae** | | | | |
| *Argiolestes kirbyi* (Förster) | 7 | 78 | 8 | 76 |
| *Argiolestes* sp. nov. A | 9 | 3 | 10 | 3 |
| *Argiolestes sidonia* (Martin) | 8 | 40 | 8 | 14 |
| *Argiolestes* sp. C | 9 | 2 | 8 | 6 |
| *Argiolestes* sp. D | | 2 | 1 | 1 |
| *Argiolestes microstigma* (Lieftinck) | 8 | 23 | | 0 |
| *Argiolestes* sp. nov. B | 7 | 9 | | 0 |
| *Argiolestes saltuarius* (Lieftinck) | | 0 | 8 | 16 |
| *Podopteryx selysi* (Förster) | 2 | 3 | | 0 |
| **Coenagrionidae** | | | | |
| *Xiphiagrion cyanomelas* (Selys) | 5 | 151 | | 0 |
| *Xiphiagrion truncatum* (Lieftinck) | | 0 | 5 | 10 |

| | | | | |
|---|---|---|---|---|
| *Papuagrion* sp. B | 2 | 10 | 1 | 1 |
| *Papuagrion* sp. C | 7 | 2 | | 5 |
| *Papuagrion* sp. D | | 8 | 10 | 2 |
| *Papuagrion* sp. nov. A | 2 | 6 | | 0 |
| *Papuagrion occipitale* (Selys) | | 0 | 8 | 1 |
| *Papuagrion degeneratum* (Lieftinck) | | 0 | 8 | 1 |
| *Papuagrion auriculatum* (Lieftinck) | | 0 | 1 | 1 |
| *Papuagrion flavipedum* (???) | | 0 | 10 | 1 |
| *Teinobasis scintillans* (Lieftinck) | 9 | 43 | 10 | 90 |
| *Teinobasis* sp. A | 8 | 1 | | 0 |
| *Teinobasis* sp. B | | 7 | | 0 |
| *Teinobasis* sp. C | 5 | 85 | | 0 |
| *Teinobasis* sp. D | 3 | 1 | | 0 |
| *Teinobasis stigmatizans* (Lieftinck) | | 0 | 10 | 2 |
| *Teinobasis dominula* (Lieftinck) | | 0 | 4 | 1 |
| *Palaiargia* sp. A | 8 | 3 | 8 | 1 |
| *Palaiargia halcyon* (Lieftinck) | | 0 | 6 | 1 |
| *Palaiargia charmosyna* (Lieftinck) | | 0 | 2 | 2 |
| *Palaiargia* sp. B | | 0 | 10 | 2 |
| *Pseudagrion* sp. A | 7 | 1 | | 0 |
| *Pseudagrion* sp. B | 9 | 1 | | 0 |
| *Pseudagrion* sp. nov. C | | 0 | 8 | 13 |
| **Isostictidae** | | | | |
| *Selysioneura cornelia* (Lieftinck) | 7 | 17 | | 0 |
| *Selysioneura* sp. A | | 1 | | 0 |
| *Selysioneura* sp. nov. B | | 0 | 8 | 1 |
| **Platycnemidae** | | | | |
| *Idiocnemis obliterata* (Lieftinck) | 3 | 9 | | 0 |
| *Idiocnemis strumidens* (Lieftinck) | 2 | 62 | | 0 |
| *Idiocnemis australis* (Gassmann) | 2 | 11 | | 0 |
| *Idiocnemis leonorae* (Lieftinck) | | 8 | | 0 |
| *Arrhenicnemis* sp. | 9 | 1 | | 0 |
| *Rhyacocnemis prothoracica* (Lieftinck) | | 19 | 10 | 3 |
| *Rhyacocnemis filicornis* (???) | | 0 | | 1 |
| *Paramecocnemis stilla-cruroris* (Lieftinck) | | 0 | 7 | 1 |
| Gen. nov., sp. nov. | 8 | 9 | | 0 |
| **Platystictidae** | | | | |
| *Drepanosticta* sp. A | 2 | 12 | | 0 |
| *Drepanosticta* sp. B | 7 | 2 | | 0 |
| *Drepanosticta* sp. C | 7 | 4 | | 0 |
| *Drepanosticta* sp. D | 6 | 3 | | 0 |
| *Drepanosticta* sp. E | 9 | 5 | | 0 |
| *Drepanosticta* sp. F | 7 | 1 | | 0 |
| *Drepanosticta* sp. G | 9 | 1 | | 0 |
| *Drepanosticta* sp. H | 9 | 9 | | 0 |

| | | | | |
|---|---|---|---|---|
| *Drepanosticta* sp. I | 7 | 2 | | 0 |
| *Drepanosticta* sp. J | 8 | 2 | | 0 |
| *Drepanosticta* sp. K | 2 | 1 | | 0 |
| **Protoneuridae** | | | | |
| *Nososticta finisterrae* (Förster) | 7 | 190 | 8 | 44 |
| **Aeshnidae** | | | | |
| *Anax selysi* (Förster) | 5 | 101 | 4 | 8 |
| **Corduliidae** | | | | |
| *Macromia* sp. | 6 | 33 | 1 | 2 |
| *Procordulia leopoldi* (Fraser) | 5 | 194 | | 0 |
| **Synthemistidae** | | | | |
| *Synthemis primigenia* (Förster) | 3 | 3 | | 0 |
| **Libellulidae** | | | | |
| *Diplacina callirrhoe (Lieftinck)* | 8 | 10 | 2 | 8 |
| *Diplacina smaragdina* (Selys) | 6 | 36 | | 0 |
| *Nannophlebia amphicyllis* (Lieftinck) | 7 | 53 | | 1 |
| *Bironides glochidion* (Lieftinck) | 8 | 3 | | 0 |
| *Huonia epinephela* (Förster) | 6 | 194 | | 0 |
| *Huonia hylophila* (Lieftinck) | | 0 | 10 | 59 |
| *Agrionoptera longitudinalis* (Selys) | 9 | 6 | | 5 |
| *Pantala flavescens* (Fabricius) | | 0 | 1 | 6 |
| *Orthetrum villosovittatum* (Brauer) | 5 | 192 | 10 | 193 |
| *Orthetrum glaucum* (Brauer) | 1 | 64 | 4 | 66 |
| *Orthetrum* sp. | 6 | 2 | | 0 |
| *Neurothemis stigmatizans* (Fabricius) | 1 | 13 | | 0 |
| unidentified libellulid B | 5 | 10 | | 0 |
| unidentified libellulid A | 5 | 2 | | 0 |

In the following annotated species list I account for all species found on more than one occasion in either of the two study areas.

# ZYGOPTERA

## Calopterygidae

### *Neurobasis sp. nov.*

This species was common and widespread throughout both study areas, and occurred mainly in intermediate-sized bouldery creeks with incomplete canopy cover. Population density was highly variable, but highest concentrations (ca. 10 Ind./30 m) occurred near sunny areas with eroded banks. The eroded banks are a prime site for oviposition since small rootlets exist underneath the water surface. Females oviposit fully submerged into small rootlets along the bank. Only two oviposition incidents were recorded in seven months. The species

did not appear to suffer from water pollution in the settled area, and was moderately tolerant towards forest removal. As long as at least 30% of the streambed was shaded, the species would still occur. Further data on dispersal, survival rates and habitat selection were presented elsewhere (Oppel in press).

## Chlorocyphidae

### *Rhinocypha tincta*

This species occurred in small creeks with sandy or gravel substrate. It was widespread, but limited by the presence of sunny spots in creeks. Individuals were rarely found further than 5m away from a sunny area in a creek, probably rendering extended stretches of fully shaded small streams unsuitable.

The species was slightly more common in the garden landscape, probably as a result of forest clearing and sunnier creeks. It appeared to be tolerant to moderate water pollution.

Several teneral individuals were found in fern clearings or reed beds far away from permanent water sources in disused gardens near Herowana.

## Lestidae

### *Indolestes tenuissimus*

The only species of that family was confined to the forest pond at CMBRS. It was fairly common there, observable on most sunny days in good numbers of up to 20 individuals. Copulation and oviposition was observed throughout the year, and the species occurred in the bank vegetation of the pond, ovipositing in erect standing plants while in tandem formation.

## Megapodagrionidae

### *Podopteryx selysi*

This large and colourful damselfly was found on four occasions in seven months, generally well away from any water source in sunny clearings of the rainforest. Obvious habitat associations were not apparent, but water filled tree-holes were widespread and it is also possible that this species breeds in water puddles forming in *Pandanus sp.* leaf internodes. It was not observed in Herowana, and this species was unknown to local people, suggesting that it is intolerant towards habitat modification.

### *Argiolestes kirbyi*

This was the most common *Argiolestes* species in the study area, and it was common and widespread in all types of shady streams and creeks, with some individuals even occurring along major rivers and others at small temporary seepages. Shading seemed to be crucial though, as this species did not occur along those streams in Herowana where much of the canopy had been removed. Still, *A. kirbyi* was very common in Herowana and minor water pollution did not seem to affect its occurrence.

Several teneral individuals were observed on ridgelines, either in sunny places or along mossy and shady rock walls, but in all cases far away (> 300m) from any water source. The very prominent yellow pterostigma rendered them easy to recognize. In June 2004, for the first time, freshly emerged individuals were found along a medium-sized bouldery creek. The individuals were hidden along the vegetation on a steep and shady bank. It could not be discerned whether the creek had been the larval habitat, but given the tenderness of the wings and abdomen it appeared very likely that these individuals had emerged close by.

*Argiolestes sp. nov.*

This species was rare and found on only 3 occasions in 7 months at CMBRS. It seemed to occur in very small or even temporary streams or mud puddles along steep hillsides in very dense rainforest. It showed no preference for sunny places but remained in the shade. It was not found in Herowana.

*Argiolestes saltuarius*

This species was only found in Herowana, where it was moderately common in running waters of different sizes, ranging from large rivers to shady temporary streams. One individual was found along an artificial ditch and one was found in the forest interior.

*Argiolestes microstigma*

This mostly black damselfly was uncommon, and only occurred at CMBRS. All individuals were discovered in small creeks under closed canopy, ca. 1-2 m wide with very irregular water flow and gravel bed. The creeks were fully shaded, and the species was never found in the sun, even where a creek was adjacent to a sunny clearing.

*Argiolestes sidonia*

This species was very easy to discover due to its bright red legs. Teneral individuals had more ochre-colored legs and were initially believed to belong to a different species. It was found in both study areas, and was invariably associated with extremely steep, almost waterfall-like streams with a solid rock bed or very coarse gravel. Individuals perched on plants or rocks adjacent to, or in the stream, and were never found away from water. They were mostly found in open sections of the respective creek, with extensive sunny areas and little moss cover of the rocks. The habitat physiognomy was not substantially different between such creeks at CMBRS and near Herowana, so that the presence of this species at both sites is hardly surprising. Since the creeks near Herowana were very steep, and originated from steep slopes, the catchment area would have been minimal. The pollution of these water sources is therefore almost negligible.

*Argiolestes sp. nov.*

This species was found in the same small gravel stream as A. microstigma, as well as in temporarily dry flood channels adjacent to a larger river. It appeared to be a shade-loving species avoiding sunny spots along the watercourses, and was found in areas with high moss cover. It was confined to CMBRS and not found in Herowana.

*Argiolestes spec.*

In both study areas two further species of Argiolestes were discovered, but since only female specimens could be obtained they could not be identified to species level. For analysis it was assumed that species were identical between sites, which might underestimate the turnover rate of the two study areas.

**Coenagrionidae**

With 24 members of this family being recorded from the two study areas, this family was the most species rich in this study. There was remarkably little overlap between the two study sites, and the only species that occurred in both areas was Teinobasis scintillans. For four further species, which were only identified to genus level (3 *Papuagrion*, 1 *Palaiargia*), the common identity could not be resolved and turnover rate might therefore be underestimated.

*Pseudagrion spec.*

Only one individual of this striking species with bright orange dorsal coloration of the abdominal segments 8 and 9 was found at CMBRS. It perched on a boulder next to a gravel pool in a flood channel of a larger river. The flood channel was a very slow trickle at this time. The species was absent from Herowana.

*Pseudagrion sp. nov.*

This undescribed species was uncommon and only found in Herowana. It was a typical creek species that was found almost exclusively along a shady forest creek of gentle gradient, with few boulders and numerous lagges. One individual was found near a ditch with high water level.

*Palaiargia spec. A*

Only three teneral individuals of this species were observed, one on the porch of the research station, the other two in a small shallow creek with gravel bed that flows through a small sunny clearing in the forest. This species was not found in Herowana.

*Palaiargia spec. B*

This species occurred only in Herowana and was found exclusively along ditches in sunny areas. The species was only discovered in October and was not seen during other times of the year.

### *Palaiargia charmosyna*

This species was only found in Herowana. A pair in tandem formation was collected in the forest interior, away from obvious water sources in depleted secondary forest with closed canopy.

### *Teinobasis spec.*

Together with *Indolestes tenuissimus* and *Xiphiagrion cyanomelas* this species was one of the three damselflies inhabiting the pond in the study area at CMBRS. It seemed to be most common during overcast or cooler weather, whereas I. tenuissimus was mostly found in sunny and hot conditions. Like I. tenuissimus, it was found along the vegetated banks of the pond and mating and oviposition were observed almost anytime throughout the year. Oviposition took place in tandem formation, and the eggs were laid into small soft wooden branches that were sticking out of the water. Most of the wood was dead driftwood from the surrounding forest, but some tandems were observed among the live vegetation along the banks. In Herowana this species could not be found, instead *T. scintillans* was present near the pond.

### *Teinobasis scintillans*

This species was common in both study areas. At CMBRS it occurred under closed canopy forest and was associated with temporary streams that left puddles behind. These streams were confined to gentle terrain, with muddy soil texture. In Herowana, *T. scintillans* occurred mostly along ditches, which had a similar water flow rate as the temporary streams at CMBRS. It was also found near a pond, along temporary streams and near puddles in sunny and shady areas. It appears that this species is fairly tolerant to deforestation as long as suitable water sources remain.

### *Teinobasis stigmatizans*

Only two individuals were found, one in a sandy creek under closed canopy and one near a sunny puddle in Herowana. The species was not found at CMBRS.

### *Papuagrion sp. nov. A*

This species was caught once. A copulating pair was found next to a sunny clearing in the forest, perching on vegetation 2 m above the ground. There were no water sources nearby, but several *Pandanus sp.* trees, which might serve as larval habitat for that species.

### *Papuagrion spec. D*

At CMBRS, a female of this species was found near *Pandanus sp.* trees. A male of this species was caught along a medium sized creek, but this might have been foraging habitat, which might explain the scarcity of encounters. The same (?) species was also found in Herowana, either along ditches or near shady puddles in the forest.

*Papuagrion occipitale*

At CMBRS, a species that resembled *P. occipitale* was fairly common, but usually only found on warm and sunny days when individuals were basking in sunny spots in the forest. Some of these areas were next to small creeks, but most individuals were found far away from water, and there is a possibility that this species, too, is affiliated with Pandanus sp. trees. In Herowana only one individual was found next to a creek.

*Xiphiagrion cyanomelas*

This species was common at the standing ponds in CMBRS. Copulation and oviposition were observed almost throughout the entire study period, but flight activity was generally confined to warmer days with sunshine. Oviposition occurred in tandem formation and the species appears to oviposit in green floating or standing vegetation along the banks of still waters.

*Xiphiagrion truncatum*

As the above species, *X. truncatum* occurred exclusively along a small pond in Herowana. It appeared to be the ecological equivalent of *X. cyanomelas* at CMBRS.

**Isostictidae**

*Selysioneura cornelia*

This species was commonly encountered in two slightly different habitats. Several adults were observed along gravel sections of creeks with low inclination and incomplete shading, often bordered by herb-fields, which were used as perches. Teneral individuals were mostly found along dark and moist rock faces or similar steep, mossy places adjacent to larger creeks or small rivers. The species was confined to CMBRS and absent from Herowana.

**Platycnemidae**

*Idiocnemis strumidens and australis*

Recorded as one morphospecies during fieldwork, these two species were the most common interior forest damselflies at CMBRS, and might be indicator species for primary forests since none were found near Herowana. Individuals seemed to be quite variable in coloration, rendering identification difficult. The species were not generally found near water, but could be found almost anywhere in the closed-canopy forest. Nonetheless several individuals were observed along small streams or creeks of various sizes, but this might have been coincidental. Both species were generally found in gentle terrain, where the muddy forest floor and frequent rain created puddles that persisted for several days.

*Idiocnemis obliterata*

An uncommon species only found at CMBRS. The specimens were collected in equal portions either along shady small rivers in the forest, or in the forest interior away from permanent water sources.

*Idiocnemis leonorae*

All eight individuals of this species were found at CMBRS, however, all were found in a different habitat type. One individual was found near a temporary puddle in the forest, the remaining seven were collected near running waters ranging from large river to small temporary stream. Despite this eurytopic occurrence the species was absent from Herowana.

*Gen. nov. sp. nov.*

This strikingly short-winged species was found on several occasions along small streams and creeks with a generally sandy or gravel substrate. It comprises a new genus within the Platycnemidae, and was found only at CMBRS. Individuals perched in small sunny spots along the creek banks. One individual was found along a river in a shady and mossy area.

*Rhyacocnemis prothoracica*

This species occurred in both study areas and was generally found along shady waterways ranging in size from small streams to small rivers. Most of these water sources had a sandy or gravel substrate. Two teneral individuals were found in sunny spots in the forest on a steep ridgeline, with the nearest permanent water source being > 300m downhill. In Herowana only two individuals were observed in sunny areas without obvious affinity to a water source.

*Torrenticnemis sp. nov.*

A seemingly undescribed species of this genus was discovered in the upper reaches of one of the larger rivers of the study area. It appeared to be fairly common near a large waterfall (> 50m), where boulders and rocks were covered with a thick layer of moss. It also occurred in shady river sections further downstream, and it is likely that moss-covered boulders are an important habitat feature for this species.

**Platystictidae**

Eleven morphospecies of this family were found, exclusively at CMBRS. No member of the Platystictidae was found in Herowana. The species delineation of the genus Drepanosticta is highly complex and currently under revision (Orr 2004). None of the members of this genus could therefore be identified to species level. The actual species richness of the study site at CMBRS might therefore deviate from the one reported here.

None of the species was common, and most species were only recorded from 1-2 specimens. All but two species were associated with running water systems, ranging from larger rivers to small temporary streams. The remaining two species were found in the forest interior.

**Protoneuridae**

*Nososticta finisterrae*

This was one of the most common and widespread species in both study areas, it was found in almost any creek or river of large enough size. Males appeared to be dependent on sunny patches, therefore small creeks with complete canopy shading remained unoccupied. The species was especially abundant around pools with sandy or fine gravel substrate, which could be the main habitat for larvae.

**ANISOPTERA**

**Aeshnidae**

*Anax selysi*

This species was present at larger ponds with floating macrophytes in both study areas. Up to 25 individuals could be observed chasing each other on sunny days at CMBRS, whereas the smaller pond in Herowana featured a maximum of two individuals on any day. Oviposition was observed regularly, and the species seems to occur throughout the year. Floating debris like branches, twigs, or other plant material are used for ovipositing, with the female inserting the eggs into the plant material just underneath the water surface. The species was a strong flier and the most commonly observed dragonfly above the forest, at high altitudes above clearings, on the airstrip and sports ground in Herowana, or in other places very far from water. In Herowana another similar species with blue-black thorax and orange eyes was observed at the pond, but it could not be captured.

**Synthemistidae**

*Synthemis primigenia*

This species was caught twice accidentally in mist nets set up for a bird study. It is possible that this species is crepuscular. The capture locations were on ridgelines in wet forest, more than 200 m away from permanent water sources, and give no indication of habitat since individuals were on passage when captured. Since only two individuals were caught in ca.100,000 net meter hours (i.e. a row of nets of 100 m length set up for a total of 1,000 hrs), it can be assumed that this species is not common in the study area. One female was observed in what is likely its reproductive habitat. It was flying very low up and down a tiny temporary stream with a coarse sandy-gravel substrate. The stream was less than a meter wide, and at that time reduced to several puddles of about 20 cm2 and 2 cm depth. The puddles were filled with rotting leaf litter. The female hovered

above these puddles, repeatedly dipping the abdomen into the shallow water body, apparently ovipositing. Due to the year-round high rainfall pattern these tiny streams rarely, if ever, dry out, and the moist leaf litter might provide additional protection from desiccation for the eggs or larvae. After heavy rain the puddles are connected to a stream and would enable larvae to travel up- or downstream.

**Corduliidae**

*Procordulia leopoldii*

This was the most common and regular species at the pond in the pristine forest at CMBRS, but it was absent from Herowana. Up to 35 individuals were observed chasing above the water surface, and aggressive interactions were common, even though no territoriality was apparent. The species oviposited into similar structures as *A. selysi*, and occurred as regularly as this species. During rainy or overcast days this was often the only species flying at that pond, suggesting that it does not require as much thermal energy as other species and could therefore exist in shady ponds in the forest.

*Macromia spec.*

This large dragonfly was seen regularly along shady and bouldery rivers and larger creeks. Females were repeatedly observed to oviposit by dropping the end of the abdomen into pools of stagnant water with gravel/sandy bottom along the course of swift mountain creeks or larger rivers. Only one copulation was observed, but the male could not be captured. Since a key exists only for males, the female specimens could not be identified to species level. A *Macromia spec.* was also observed in similar habitat in Herowana, but it was less common and no specimen could be obtained. At CMBRS, two individuals were captured in mist-nets near the research station, and the flying activity of this species extended into the forest during late afternoon. It might be a crepuscular species.

**Libellulidae**

With 14 recorded species in both study areas this was the most species-rich dragonfly family. Two of the very conspicuous dragonflies observed at the forest pond at CMBRS could not be captured and could therefore not be identified. This was a species with bright red wings, and a smaller black species with black wingtips.

*Diplacina callirhoe*

This species was common in all types of swift rivers and creeks with boulders and stagnant pools. Oviposition took place into the water of pools with sandy substrate. It did not occur in shady rivers, but required at least 40-40% of the riverbed exposed to the sun. The species occurred both at CMBRS and in Herowana.

### *Diplacina smaragdina*

This species was only found at CMBRS, and was mostly recorded in open sunny rivers. Two individuals were also observed in smaller creeks, although only along sunny areas. A *Diplacina* spec. was frequently observed on the sunny helicopter landing pad at CMBRS, and this might have been *D. smaragdina*.

### *Nannophlebia amphicyllis*

This was a fairly common species along sunnier banks of larger creeks or rivers in both study areas. It was generally found in braided sections of a creek or river, with sandy substrate and standing pools. Females were ovipositing into standing pools with sandy substrate by dipping the tip of their abdomen into the water while hovering above the pool. Males were generally observed sun basking on large boulders, but competitive interactions or territoriality could not be observed.

### *Bironides glochidon*

Three individuals were found in similar habitat as *N. amphicyllis* in a creek at CMBRS.

### *Agrionoptera longitudinalis*

This species was uncommon in both study areas, and occurred in somewhat different habitat types. In Herowana several individuals were observed along a deep (1.5 m), straight, temporarily dry and overgrown ditch along the airstrip, in a generally very sunny area outside the forest. In contrast, the individuals observed at CMBRS were in the forest interior, patrolling low above muddy pools or puddles, and perching on small sticks a few cm above the mud surface. This might have been reproductive habitat, but no oviposition could be observed.

### *Neurothemis stigmatizans*

This species occurred only temporarily, and was confined to an unnatural clearing created for a new research station. The dragonflies there were hovering around ephemeral puddles on clay soil. Despite its affinity to a habitat arising from deforestation, the species was only observed at CMBRS and was absent from Herowana. *N. stigmatizans* is a common and widespread species of secondary habitats in PNG lowlands, and might reach its altitudinal limit above CMBRS.

### *Orthetrum glaucum*

This species was abundant in Herowana, and confined to an artificial clearing created for a new research station at CMBRS. It did not occur in the forest or along rivers, but appeared to be confined to temporary puddles in very sunny areas. This and the following species are widespread generalists that benefit from deforestation.

*Orthetrum villosovittatum*

By far the most numerous species in Herowana, found along all kinds of sunny water bodies from temporary puddles on the airstrip, to straight ditches or semi-natural ponds in sunny gardens. It was also quite common at CMBRS, albeit confined to artificial clearings or the large forest pond. It appeared that this species was intolerant of running water, and had very high thermal requirements, making it a typical species benefiting from forest destruction and creation of open habitat.

*Huonia epinephela*

Commonly observed between November 2003 and May 2004, this species almost vanished from the study area from June on. This might have been due to the inclement weather, as this species appeared to have elevated thermal requirements. It was generally found in the largest creeks and rivers, perching on hot sunny boulders, and was patchily distributed along the course of the main rivers of the study area. Males were often observed to chase each other and appeared to compete for certain boulders in the riverbed. Copulation events were uncommon and oviposition could not be observed. Despite its commonness at CMBRS the species was absent from Herowana.

*Huonia hylophila*

This species was widespread in Herowana and absent from CMBRS. It is probably the ecological equivalent to *H. epinephela* at CMBRS, although it occurred in a wider range of habitats. It was most commonly observed along major rivers, but also occurred along smaller creeks in gardens where the streambed was exposed to the sun.

*Pantala flavescens*

This species was only found in Herowana and is probably a typical representative of the opportunistic species benefiting from deforestation. This widespread species was absent from the forested region of CMBRS, and only found in artificial open habitat types around Herowana.

## Discussion

The CMWMA in Papua New Guinea hosts a rich and diverse odonate fauna. The species richness is comparable to very species-rich areas in Africa (Samways 1989; Clausnitzer 1999; Vick 1999, 2002; Clausnitzer 2003; Dijkstra & Lempert 2003) and the Neotropics (Novelo Gutierrez et al. 1988; de Marmels 1998; Ramirez et al. 2000; Paulson 2002). The species richness is also higher than in lowland sites of PNG (Polhemus 1995; Mack 1998), a pattern that has also been found in PNG moths (Hebert 1980). In similar rainforest habitats of

South East Asia local endemism is very high (Orr 2003, 2004), and this might also be true for the studied area in PNG. Only seven of the 78 species recorded in the CMWMA were also found in a survey in the Lakekamu Basin, lowland PNG (Mack 1998).

Determining the sampling effort required for inventories of invertebrates in tropical environments is complicated. In most cases, sampling periods are too short to detect rare species that are only present in low abundances (Morse et al. 1988; Lawton et al. 1998; Godfray et al. 1999). Several methods exist to estimate total species richness from samples, and to account for different sampling periods in comparative studies (Heltshe & Forrester 1983; Palmer 1990; Colwell & Coddington 1994; Williams & Gaston 1995; Gotelli & Colwell 2001; Ugland et al. 2003; Colwell 2004). Most studies comparing natural with unnatural (i.e. logged) forest types use an equal sampling period in the two areas, or adjust the observed species richness by rarefaction methods (Williams & Gaston 1995; Willott et al. 2000; Cleary et al. 2004; Cleary et al. 2005). In this study I demonstrated that a much longer sampling period in the natural rainforest was required to reach a species accumulation curve with an asymptotic tendeny than in a modified forest landscape, probably as a result of many rare species being present in very low numbers (Morse et al. 1988; Godfray et al. 1999). Species accumulation curves are useful tools to standardize surveys with unequal sampling effort for comparative studies (Moreno & Halffter 2000; Willott 2001; Ugland et al. 2003). More research is required to assess the species richness of pristine and modified landscapes in order to evaluate the sampling period required for proper inventories in both landscape types.

Another factor complicating species inventories in aseasonal tropical habitats are unpredictable phenological differences in the presence or abundance of species. While such differences in seasonal environments can be accounted for in survey design or in data analysis (Thomas & Mallorie 1985), the lack of knowledge which taxons exhibit seasonal changes in presence or abundance in aseasonal environments hinders the application of such methods. In the CMWMA some odonates may undergo seasonal changes in abundance, whereas some are present throughout the year. In this study at least 11% of the species at CMBRS were present throughout the study period. Some initially abundant species almost disappeared later in the study period (e.g. *Huonia epinephela*). The total number of species recorded per sampling fortnight indicated seasonal changes in the presence or abundance of species. While small changes would be expected as a consequence of an observer becoming used to the environment and detecting more species as sampling time proceeds, the fact that only half the number of species was recorded at a later stage in the study period suggests that other factors might influence this statistic. Seasonality despite aseasonal environment is also assumed for birds in the CMWMA (A. Mack, pers. comm.). Hebert`s (1980) statement for moths, that due to the lack

of seasonality a short sampling period at any time of the year will produce the same species list, is therefore not applicable for odonates in CMWMA. For a complete inventory sampling should be carried out at least during a full year. This would also shed more light on the seasonal appearance of certain species.

This study, and the associated results of habitat associations (Oppel in prep.-a) and community similarity (Oppel in prep.-b), confirm findings of previous studies that deforestation and habitat disturbance may lead to lower species richness, and a shift towards more widespread generalists (Hill et al. 1995; Stewart & Samways 1998; Willott et al. 2000; Clausnitzer 2003; Cleary et al. 2005). Conservation of dragonflies in PNG is therefore linked to the widespread preservation of pristine forests, and deforestation will be a major threat as in many other tropical regions (Clausnitzer 2004; Dijkstra & Vick 2004; Orr 2004; Paulson 2004; Rowe 2004).

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## Zusammenfassung

Die Libellenfauna Papua Neu-Guineas (PNG) ist sehr artenreich, aber wenig ist bekannt über die Verbreitung und die Ökologie vieler Arten. In dieser vom IDF unterstützten Arbeit untersuchte ich im Jahr 2004 die Libellen zweier Standorte im größten Schutzgebiet PNGs, der Crater Mountain Wildlife Management Area. Ich sammelte und beobachtete Libellen an 112 Tagen in einem natürlichen Regenwald, und an 36 Tagen in einem traditionellen Dorf, welches durch Sekundärwald und Gärten charakterisiert ist.

Insgesamt wurden 78 Arten (60 Zygoptera, 18 Anisoptera) aus 13 Familien gefunden, darunter mindestens sechs derzeit noch unbeschriebene Arten. Der Primärwald war artenreicher (61 Arten) als das Dorf (37 Arten), und eine längere Dauer der Probennahme war dort nötig um ein etwa gleiches Niveau des Gesamtartenspektrums zu ermitteln. Ich erstellte Arten-Akkumulationskurven für beide Standorte und fand, dass zur Beschreibung der Libellenfauna 100 Tage im Primärwald, und 35 Tage im Dorf benötigt wurden. Mehr als zwei Drittel der Arten des Primärwaldes wurden in weniger als der Hälfte aller Untersuchungsabschnitte nachgewiesen, was auf die Seltenheit und saisonale Unstetigkeit vieler Arten hindeutet. Trotz asaisonaler Umweltbedingungen war das in einzelnen Untersuchungsabschnitten gefundene Artenspektrum saisonalen Schwankungen unterworfen.

Diese Arbeit impliziert dass natürliche Regenwälder für den Erhalt vieler Libellenarten in PNG dringend benötigt werden. Um dies in PNG durchzusetzen, muss die in den Regenwäldern lebende Bevölkerung aufgeklärt und in Schutzprogramme mit einbezogen werden. Die einheimische Bevölkerung im Untersuchungsgebiet war mit Libellen gut vertraut, allerdings spielen Libellen in kulturellen Riten keine Rolle. Mehr taxonomische als auch ökologische Forschungsarbeit ist notwendig um die hochdiverse Libellenfauna PNGs zu beschreiben und wirksame Schutzmassnahmen zur Erhaltung dieser Vielfalt ableiten zu können.