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The Mayflies (Ephemeroptera) of Angola—new species and distribution records from previously unchartered waters, with a provisional species checklist

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Abstract

A preliminary assessment of Ephemeroptera species diversity in Angolan freshwater ecosystems is presented. The results are based on three surveys carried out between 2016 and 2018, supplemented by literature synthesis. The area studied includes headwater streams and tributaries feeding the Okavango Delta, namely the Cubango, Cuito and Cuanavale Rivers, which together produced 35 species, and those flowing into the Zambezi River system, the Cuembo, Cuando, Luanginga and Lungué-Bungo Rivers which together produced 29 species. Twenty-one species were identified from the Cubango River, a fast flowing, rocky substrate river, different in character to all the other rivers surveyed. The other rivers, which all flow over Kalahari sand substrate with dense rooted aquatic macrophytes, generally lacking rocky substrate, produced 33 species between them. Prior to this research, only one mayfly species had been described from Angola in 1959. During the 1990's, research on the Cunene and Kavango Rivers from the Namibian side produced the first lists of shared Angolan mayfly species, which have been included in this summary. This checklist of Angolan mayfly species, including the recent expeditions plus the earlier studies, gives a current total of 71 morphologically distinct mayfly species, many new to science. The work is currently on-going and additional species are likely to be identified.

Portuguese Abstract

É apresentada uma avaliação preliminar da diversidade de espécies de Ephemeroptera em ecossistemas de água doce angolanos. Os resultados são baseados em três pesquisas realizadas entre 2016 e 2018, complementadas pela síntese da literatura. A área estudada inclui riachos de cabeceira e afluentes que alimentam o Delta do Okavango, nomeadamente os rios Cubango, Cuito e Cuanavale, que juntos produziram 35 espécies, e os que fluem para o sistema do rio Zambeze, os rios Cuembo, Cuando, Luanginga e Lungué-Bungo que juntos produziu 29 espécies. Vinte e uma espécies foram identificadas a partir do rio Cubango, um rio de substrato rochoso de fluxo rápido, de caráter diferente de todos os outros rios pesquisados. Os outros rios, que fluem sobre o substrato de areia do Kalahari com macrófitas aquáticas de raízes densas, geralmente desprovidos de substrato rochoso, produziram 33 espécies entre eles. Antes desta pesquisa, apenas uma espécie de mosca d'água havia sido descrita de Angola em 1959. Durante a década de 1990, as pesquisas sobre os rios Cunene e Kavango, do lado da Namíbia, produziram as primeiras listas de espécies de efeméridas angolanas compartilhadas, que foram incluídas neste resumo. Esta lista de verificação das espécies angolanas da efémia, incluindo as recentes expedições mais os estudos anteriores, dá um total atual de 71 espécies de efeméridas morfologicamente distintas, muitas novas para a ciência. O trabalho está em andamento e espécies adicionais provavelmente serão identificadas.

Keywords: Africa, Okavango Wilderness Project, mayfly checklist, diversity, museum

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Introduction

Freshwater insects form a critically important component of any freshwater ecosystem, playing a vital role in nutrient cycling. They are widely used for biomonitoring of the ecological health of the freshwater ecosystems they inhabit (e.g. Dickens & Graham 2002). Different species are adapted to live under specific conditions, with the species composition of a freshwater population varying from region to region. Mayflies are well recognized as an important ecological indicator taxon. Their aquatic dwelling nymph is the dominant life stage, with a brief winged subadult (subimago) stage (unique to mayflies) preceding the short-lived sexually mature adult stage (Brittain & Sartori 2003). For proper species identifications and species descriptions, it is desirable to have both the nymph and adult specimens.

The mayflies of Angola remain largely under-explored and under-studied. The Portuguese colonialists had little interest in the freshwater insects of Angola, and what was collected was largely lost due to the 27 years of war that ravaged the country between 1975 and 2002, when museums were considered to be unimportant. The current studies, which are part of a larger program investigating the diversity of flora and fauna in parts of Angola, funded by National Geographic, herald the start of a new beginning of biodiversity recording in this region. Angola forms part of Central Africa, and as such, is clustered with Cameroon, Central African Republic, Chad, Democratic Republic of Congo (DRC), Equatorial Guinea, Gabon, Republic of Congo, Zambia and Malawi (along with Atlantic Ocean islands Annobón and Bioko, São Tomé and Príncipe) (Kirk-Spriggs 2017). Most of these countries are also in need of detailed species inventories to contribute to the understanding of the diversity and distributions of the freshwater insect species in Central Africa as a whole.

The National Geographic Okavango Wilderness Project (NGOWP) ran a number of expeditions between 2015 and 2018 to the largely untouched source lakes and upland rivers in Central Angola, which are near pristine and previously never surveyed. These lie within the miombo woodlands of the Angolan highlands. The headwater streams in this region, considered the "water tower" of Angola, are of fundamental importance in providing a continual water supply to rivers flowing into the Okavango Delta and Zambezi River basin. The former is a world renowned UNESCO (United Nations Educational, Scientific and Cultural Organization) natural heritage site and biodiversity hotspot (Ramsar News 2014), of great conservation importance. Yet these source lakes and rivers are themselves unique and in need of further study of their own biodiversity, with protection of the integrity and quality of these water resources. The rivers are embedded in ancient Kalahari sands, with dambo-like source lakes (Mackel 1985; Von der Heyden & New 2003). The headwater streams are rich in aquatic vegetation, flanked by dense water-logged grassland and sedge riparian vegetation, with underground geophytic forests along the margins, and miombo woodlands on the sandy ridges, typical vegetation of seasonally inundated plateau floodplains in Central Africa (Timberlake & Chidumayo 2011). This vegetation helps to retain the water in these wetlands during the dry season, releasing it slowly, leading to a constant year-round flow of water into the rivers. The slow release of water feeds the Okavango delta with precious water many months after the rainy season is over. The Angolan highland rivers are proving to be unique, both in terms of habitat, and the life within. Since this is largely uncharted territory from a biodiversity assessment perspective, all records present new distribution data even for the known Afrotropical species found in these waterbodies.

When trying to establish baseline biodiversity data for a region, the first place that one goes to see what is known about its fauna or flora is to its museums. Despite its history of civil war, Angola still has some records of aquatic insects in two of its three natural history museums, but much of this, including the Ephemeroptera, remains inaccessible and the condition of the specimens is uncertain. In his description of *Machadorythus* (Machadorythidae), Demoulin (1959) noted that he found this extraordinary mayfly amongst the abundant mayfly material in the Dundo Museum. This is a small museum in the extreme north east of Angola, situated only a few kilometers from the border with the DRC. Currently this museum is better known for its ethnographic collections than its insects, although there is still a historic insect collection. It is surprising that the taxonomy of Ephemeroptera was not covered during a period when the diamond mining company, Companhia de diamantes de Angola (DIAMANG), sponsored the publication of numerous volumes on the taxonomy and checklists of a variety of Angolan flora and fauna, 89 in all, between 1947 and 1977. An example of such a checklist is the chapter by Marlier (1966) on caddisflies (which dealt only with adults, no larval descriptions). As things stand, the only published record dealing with new mayfly species from Angola is Demoulin's (1959) description, meaning that only one species has, until now, been recorded in literature

from Angola. Research from the Namibian side on the Cunene and Kavango Rivers was carried out during the 1990's (Curtis 1991; de Moor *et al.* 2000), and as these rivers form a border with Angola for much of their length, their fauna can also be included in assessments for Angola. A relatively well-known insect collection in Angola is at the Agronomic Research Institute (IIA) in Huambo, where the collections survived the war. During the war, the plant collection was evacuated to Luanda, while the insects were safeguarded by former curator assistant, Mr. Francisco Elias. This collection has around 65 000 specimens, mostly relating to agriculture but with some aquatic insects, including mayflies (David Elizalde and Sara Fernandes Elizalde, pers comm). Their initial efforts to start digitizing these collections during 2018, funded by the Global Biodiversity Information Facility (GBIF), focused on the Odonata. The rest of the collection, including the mayfly collection, still needs to be studied, identified and the data transcribed from labels on pinned specimens, so it is currently unavailable to science. The small insect collection in the Natural History Museum in Luanda no longer exists due to the war. The new collections made during the NGOWP surveys therefore make a valuable contribution to the understanding of the diversity of aquatic insects in Angola.

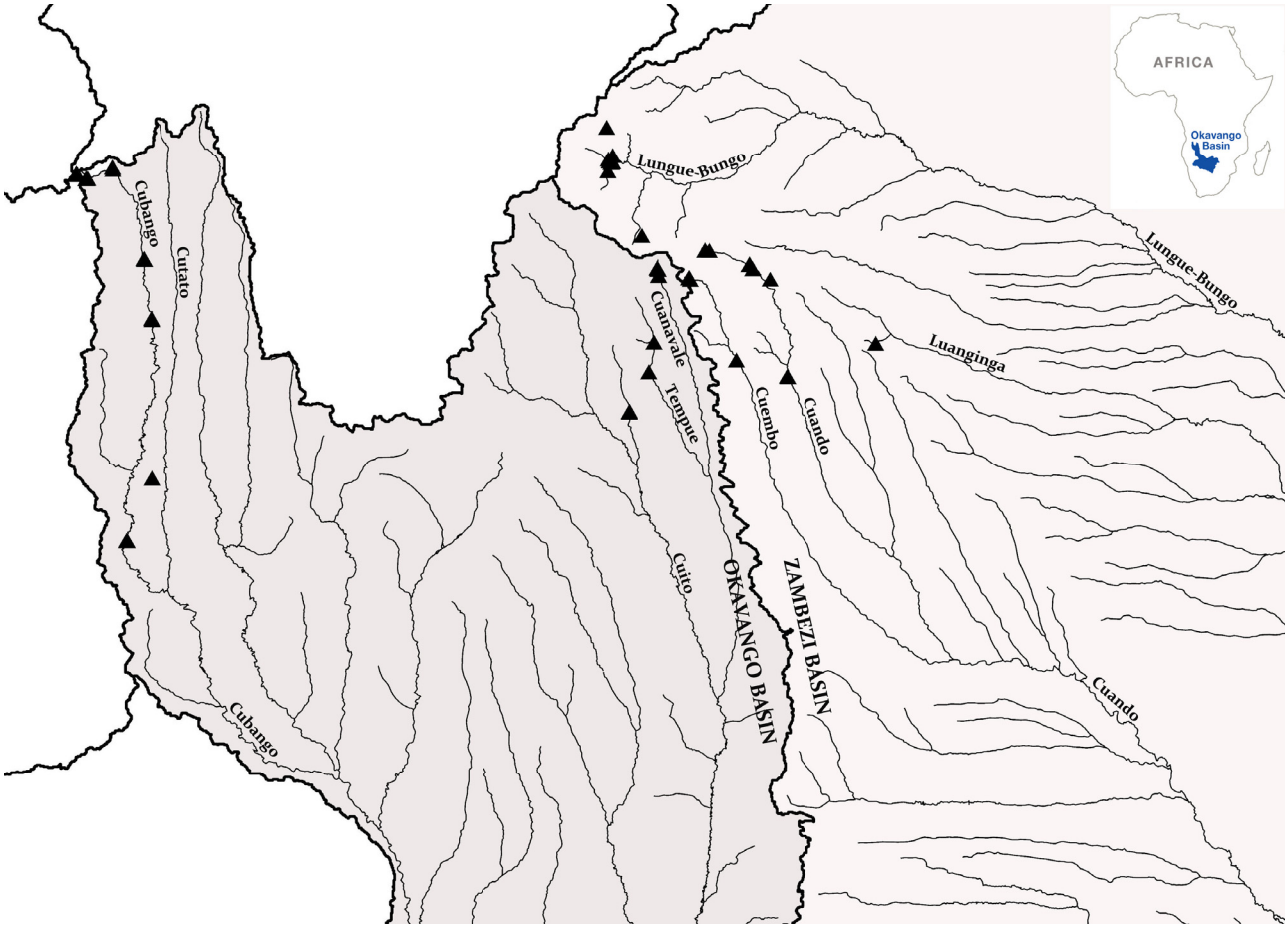

FIGURE 1. Collecting sites for all three field trips. Darker grey background shows rivers flowing into the Okavango Basin, paler grey shows those flowing into the Zambezi Basin. Map: Rainer von Brandis.

Study areas and methods

The NGOWP was founded in 2014 to study the diversity of flora and fauna associated with the rivers and adjacent catchments that feed into the biodiversity-rich Okavango Delta in Botswana. The Okavango Delta depends on water from the rivers in the Angolan highlands that feed into it, and the NGOWP is determined to protect the Delta by protecting these sources. Both the headwater streams feeding the Okavango system and those in the adjacent catchment which flow into to Zambezi River system were studied (Fig. 1). Those feeding the Okavango Delta include the Cubango, Cuito and Cuanavale Rivers and tributaries. The outflow of the Cuanavale Source Lake (Fig. 2) shows a typical view of the substrate, aquatic macrophytes and riparian

vegetation. Those rivers flowing into the Zambezi River system include the Cuembo, Cuando, Luanginga and Lungué-Bungo Rivers. Apart from the Cubango River, all of the rivers investigated flow over deep Kalahari sands, meaning that the substrate is sandy, predominantly without any rocks and stones.

Since 2015, several expeditions have been organised to this largely untouched region of source lakes, upland rivers, and miombo forests. The headwaters of these rivers lie at elevations between 1200 and 1500 masl. The Albany Museum joined three of the expeditions to assess the biodiversity of freshwater macroinvertebrates in this area, collecting at sites shown in Fig. 1. The first, the October–November 2016 Cuito-Cuando expedition, included the Cuito and Cuanavale Rivers and tributaries, which flow to the Okavango, and those flowing into the Zambezi River system. Specimens were collected from 23 sites across six river systems, Cuito (one site), Cuanavale (nine sites), Cuando (eight sites), Cuembo (three sites), Lungué-Bungo (one site) and Luanginga (one site). The Cubango River expedition followed in May 2017, with 23 sites along the upper Cubango River catchment, including mainstream river sites (Fig. 3), tributaries, isolated pools, wetlands and seeps. The Lungué-Bungo River (Fig. 4) and tributaries was the focus in April 2018, with 22 sites collected along the Lungué-Bungo, Comba and Cacau Rivers and the source lake, Lake Tchanssengwe (Fig. 5).

FIGURE 2. The outflow of Cuanavale Source Lake, showing a typical stretch of river flowing over Kalahari sand substrate, with aquatic macrophytes and riparian sedges and grasses. Photograph: Ina S. Ferreira.

The Cubango River (Fig. 3) is a fast flowing river characterized by rocky substrate of mainly bedrock and boulders, interspersed by rapids which can be up to 1 km long. Specialized aquatic macrophytes, (predominantly *Hydrostachys triaxialis* Engler & Gilg) cling to the rocks in fast flowing sections of this river. *Hydrostachys* is endemic to southern and central Africa and Madagascar. It requires fast flowing water and is considered to be threatened by habitat degradation, especially sedimentation and reduced water flow due to excessive abstraction in some regions (Sieben *et al.* 2006). According to Cusset (1973) who revised the genus,

H. triaxialis is found in the Cubango and the Cuanza Rivers in Angola, and in the Luanza River in the DRC (Luanza to Kabiashia, Kasenga district). Typically, this plant provides specialised habitat for mayflies. Unlike the Cubango River, the other headwater rivers all flow over deep Kalahari sands. These sandy bottom rivers may also be swift flowing, and even the smaller tributaries can be deep (too deep to stand in places). They are all surrounded by waterlogged grass and sedge vegetation, often with a variety of densely growing rooted aquatic macrophytes living under water, which provide habitat for the invertebrates.

FIGURE 3. Section of Cubango River, showing a typical rapid over rocky substrate. Photograph: Ina S. Ferreira.

Collecting methods for the insects' aquatic stages, which live on substrates in the rivers and lakes, included use of a standard net used for SASS (South African Scoring System) biomonitoring in South Africa, known as a SASS net (mesh size 1 mm) (Chutter 1994, 1998). The SASS protocol was not followed since sampling was not quantitative and time restricted, as in SASS, but rather with the aim to maximize diversity assessment. In some cases, a smaller hand-net (mesh size 0.25 mm) was used. Nets were pulled through submerged aquatic vegetation, and stones, when available, were disturbed to release the clinging insect larvae. This was complimented by general hand-picking off stones where present, submerged logs and plant stems, as well as from the submerged poles of wooden bridges. As many aquatic biotopes as possible were sampled at each site. The flying adult stages were mostly collected using light traps. Tray light-traps were set up at dusk and left overnight at all possible sites, to collect the adult stages of many aquatic insects, important for species identification. These traps consisted of a white tray, partially filled with water, with a drop of detergent to break the surface tension so any insect landing in the tray could not escape; specimens were collected the next morning, gently rinsed to get rid of any detergent, and bottled. Sheet light-traps at selected sites were manned from dusk until darkness had fallen, allowing more targeted collecting of selected species and better quality specimen preservation, also better for future DNA extraction. A malaise-trap was used to collect flying insects along the banks of the Lungué-Bungo River, left up for one week during the April 2018 trip. General collecting of flying adult insects was carried out using sweep nets among the riparian vegetation along the banks of the rivers and lakes.

FIGURE 4. The Lungué-Bungo River, a fast flowing, often deep river with sandy substrate. Photograph: Helen M. Barber-James.

All specimens were preserved in 80% ethanol, labelled and given an Albany Museum CAW (Central African Waters) field catalogue number. Samples were sorted in the Albany Museum after the fieldtrips, further catalogued and identified to the lowest taxonomic rank possible for each group, for incorporation into the Albany Museum's Department of Freshwater Invertebrate collection. Some of the adults were associated with the aquatic stages in the laboratory, linked by the fact that they were collected at the same site, although further linking of life stages needs to be the done using DNA barcoding.

Prior to the present surveys, earlier surveys were done on the Cunene and Kavango Rivers from the Namibian side (Curtis 1991; de Moor *et al.* 2000), which are relevant to the species checklist presented here.

Results

Table 1 summarises the number of families, genera and species known and those thought to be new to science. A checklist of currently recognised Angolan mayfly species is presented in Table 2. Before the recent surveys, only *Machadorythus maculatus* Demoulin, 1959 was known from Angola. Investigations during the 1990's on the Cunene River from the Namibian side (Curtis 1991; de Moor *et al.* 2000), produced 39 mayfly species, including several unrecognised or undescribed species, which are included in this checklist. Curtis (1991) also reported a small list from the Kavango River, which is the Namibian name for the lower Cubango River when it borders with Namibia, adding two species to the list for the Cubango River (Table 2). This research and literature synthesis indicates that at least 71 mayfly species, including currently unknown species, occur in Angola.

TABLE 1. Summary of Ephemeroptera diversity in terms of families, genera and species in Angola. Compiled from the three recent surveys as well as records from the Cunene River from de Moor *et al*. (2000) and Curtis (1991).

Families	No of genera	Known species	Unknown species	Total no of species
Baetidae	19	24	12	36
Caenidae	1	5	3	8
Dicercomyzidae	1	2	0	2
Ephemerythidae	1	1	0	1
Euthyplociidae	1	0	1	1
Heptageniidae	2	5	1	6
Leptophlebiidae	5	2	3	5
Machadorythidae	1	1	0	1
Oligoneuriidae	1	1	1	2
Polymitarcyidae	2	2	1	3
Prosopistomatidae	1	0	1	1
Tricorythidae	1	4	1	5
Total	**36**	**47**	**24**	**71**

FIGURE 5. Lake Tchanssengwe, the source lake feeding the Lungué-Bungo River. Photograph: Helen M. Barber-James.

TABLE 2. List of mayfly species recorded in rivers in Angola, showing species found for each expedition, as well as a summary of previously recorded species from the Cunene River. X indicates records from the three NGOWP expeditions, * indicates records from previous studies (Curtis 1991, de Moor *et al.* 2000).

	River systems					
	Okavango catchment		Zambezi catchment		Cunene catchment	
Taxa recorded	Cuito, Cuanavale, (Oct-Nov 2016)	Cubango (May 2017) / Kavango (Curtis 1991)	Cuando Cuembo Luanginga (Oct-Nov 2016)	Lungué-Bungo, (April 2018)	Cunene (Curtis 1991, de Moor *et al.* 2000)	Total species summary
Baetidae						
Acanthiops sp. 1					*	x
Acanthiops sp. 2				x		x
Afroptilum sudafricanum Lestage, 1924					*	x
Baetis magae (Barnard, 1932)					*	x
Bugilliesia sp.	x			x		x
Centroptiloides bifasciata (Esben-Petersen, 1913)		x			*	x
Cheleocloeon excisum (Barnard, 1932)	x		x	x	*	x
Cheleocloeon sp. 1	x	x	x	x	*	x
Cheleocloeon sp. 2	x		x			x
Cloeon areolatum Navás 1930	x		x	x		x
Cloeon perkinsi Barnard 1932	x		x	x		x
Cloeon rhodesiae Barnard 1932	x		x	x	*	x
Cloeon smaeleni Lestage 1924			x			x
Cloeon sp. 1			x	x		x
Crassabwa flava (Crass, 1947)					*	x
Crassabwa sp. 1			x	x		x
Crassolus inzingae (Crass, 1947)					*	x

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TABLE 2. (Continued)

	River systems					
	Okavango catchment		Zambezi catchment		Cunene catchment	
Taxa recorded	Cuito, Cuanavale, (Oct-Nov 2016)	Cubango (May 2017) / Kavango (Curtis 1991)	Cuando Cuembo Luanginga (Oct-Nov 2016)	Lungué-Bungo, (April 2018)	Cunene (Curtis 1991, de Moor *et al.* 2000)	Total species summary
Dabulamanzia fica Lugo-Ortiz & McCafferty, 1996					*	x
Dabulamanzia media (Crass, 1947)					*	x
Delouardus sp. 1				x		x
Dicentroptilum papillosum Wuillot, 1994		x			*	x
Labiobaetis glaucus (Agnew, 1961)					*	x
Labiobaetis kalengoensis (Kopelke, 1980)					*	x
Labiobaetis piscis Lugo-Ortiz & McCafferty, 1997	x	x	x	x	*	x
Labiobaetis vinosum (Barnard, 1932)	x	x	x		*	x
Labiobaetis sp. 1	x	x		x		x
Labiobaetis sp. 2			x			x
Labiobaetis sp. 3			x			x
Nigrobaetis bethuneae Lugo-Ortiz & de Moor, 2000					*	x
Potamocloeon dentatum (Kimmins, 1956)					*	x
Procloeon africanum (Esben-Petersen, 1913)	x				*	x
Pseudopannota camerunense (Ulmer, 1920)	x	x		x		x

...*Continued on next page*

TABLE 2. (Continued)

	River systems					
	Okavango catchment		Zambezi catchment		Cunene catchment	
Taxa recorded	Cuito, Cuanavale, (Oct-Nov 2016)	Cubango (May 2017) / Kavango (Curtis 1991)	Cuando Cuembo Luanginga (Oct-Nov 2016)	Lungué-Bungo, (April 2018)	Cunene (Curtis 1991, de Moor *et al.* 2000)	Total species summary
Pseudopannota bertrandi (Demoulin, 1961)					*	x
Pseudopannota sp. 1	x		x	x		x
Susua niandanensis (Wuillot, 1993)					*	x
Gen nov sp. 1	x					x
Caenidae						
Caenis anteculana Malzacher, 1990					*	x
Caenis cibaria Eaton, 1879		x				
Caenis douglasi Malzacher, 1993					*	x
C. elouardi Malzacher, 1990	x					
Caenis jinjana Kimmins, 1956					*	x
Caenis spp. ≥ 3	x	x		x	*	xxx
Dicercomyzidae						
Dicercomyzon costale Kimmins 1957	x		x	x		x
Dicercomyzon femorale Demoulin, 1954		x				x
Ephemerythidae						
Ephemerythus niger Gillies 1960	x	x	x			x

...*Continued on next page*

TABLE 2. (Continued)

Taxa recorded	River systems: Okavango catchment: Cuito, Cuanavale, (Oct-Nov 2016)	Okavango catchment: Cubango (May 2017) / Kavango (Curtis 1991)	Zambezi catchment: Cuando Cuembo Luanginga (Oct-Nov 2016)	Zambezi catchment: Lungué-Bungo, (April 2018)	Cunene catchment: Cunene (Curtis 1991, de Moor *et al.* 2000)	Total species summary
Euthyplociidae						
Afroplocia sp. 1		x				x
Heptageniidae						
Afronurus peringueyi (Esben-Petersen, 1913)		x			*	x
Afronurus ugandanus Kimmins 1956					*	x
Afronurus sp. 1		x				x
Notonurus bequaerti (Navás, 1930)			x			x
Notonurus njalensis (Kimmins, 1937)					*	x
Notonurus tortinervis (Navás, 1930)					*	x
Leptophlebiidae						
Adenophlebiodes decoratus (Navás 1931)	x	x	x	x		x
Hyalophlebia sp.					*	x
Choroterpes sp.		*				x
Euthraulus sp.		x	x		*	x
Thraulus torrentis Gillies 1964	x			x		x

...*Continued on next page*

TABLE 2. (Continued)

	River systems					
	Okavango catchment		Zambezi catchment		Cunene catchment	
Taxa recorded	Cuito, Cuanavale, (Oct-Nov 2016)	Cubango (May 2017) / Kavango (Curtis 1991)	Cuando Cuembo Luanginga (Oct-Nov 2016)	Lungué-Bungo, (April 2018)	Cunene (Curtis 1991, de Moor *et al.* 2000)	Total species summary
Machadorythidae						
Machadorythus maculatus Demoulin, 1959		x			*	x
Oligoneuriidae						
Elassoneuria grandis Gillies, 1974					*	x
Elassoneuria trimeniana (McLachlan, 1868)		x		x		x
Polymitarcyidae						
Ephoron savignyi (Pictet, 1843)					*	x
Ephoron sp. ♀	x					x
Povilla adusta Navás, 1912		*				x
Prosopistomatidae						
Prosopistoma sp. 1					*	x
Tricorythidae						
Tricorythus discolor (Burmeister, 1839)					*	x
Tricorythus reticulatus Barnard, 1932					*	x
Tricorythus tinctus Kimmins, 1960	x	x			*	x
Tricorythus furicfer Kluge, 2016			x	x		x
Tricorythus sp. 1					*	x
TOTALS	22	21	20	20	39	71

Discussion

The Cubango River habitat is very different to the other rivers surveyed during the National Geographic expeditions, with more conventional rocky-river biotopes available to provide biotope diversity to harbour mayfly nymphs and other aquatic insects. Twenty-one species were found in the Cubango River, 10 of which are common between the Cubango and Cunene Rivers, which is also a rocky substrate river. The Cunene River has 39 species recorded (Table 2), nearly double the number collected from the Cubango River. This may be because the Cunene River has been more intensively and repeatedly surveyed, with repeated surveys done in November (summer) when species diversity was likely to be highest, while the Cubango was sampled once in May (early winter). When the Cubango River reaches the border with Namibia, it becomes known as the Kavango River, forming a section of the border between Angola and Namibia, with the Cuito River joining it on its journey to the Okavango swamps. In addition to the species included in Table 2, Curtis (1991) also reported Baetidae, Caenidae and Heptageniidae from the Kavango River, but only occurrence at family level, so an accurate estimate of species diversity is not currently possible for this part of the system. Burrowing mayfly species, which were rare, prefer muddy banks or fine gravel substrates depending on species. Immature nymphs of one species (*Afroplocia* sp.) were collected in the Cubango River. These mayflies are understudied and seldom found, so this is a significant finding. *Afroplocia sampsoni* (Barnard, 1937) is currently the only known species, described from rivers in KwaZulu-Natal (South Africa) as adults. Barnard (1940) assigned a nymph from an empty nymphal exuvium which was floating on the water surface of the Umzimkulu River, but until this expedition, no whole nymphs of this genus had been collected. The nymphs collected in the Cubango River are therefore a significant new distribution record of a genus not collected since 1940, and it would be valuable to find their adults to complete the identification and see whether it is the same species or an unknown one. The other burrowing species found was the adult of a much more common genus, *Ephoron*, collected from the Cuanavale River Source Lake. Curtis (1991) reported *Povilla adusta* from the Kavango River.

In the sandy bottomed rivers, including both those feeding the Okavango Delta and the Zambezi River system, mayfly nymphs were found mainly on marginal and aquatic vegetation or, if present, on stones. Sand was not a favoured biotope except by *Cheleocloeon* which was represented by several species including two unknown; typically, such psammophilous mayflies tend to have long claws, which help them to scurry over the sand substrate. The sandy bottomed rivers share ten species with the Cubango River. They are more similar to each other than to the Cubango River, irrespective of the catchment they are flowing in, with the rivers feeding the Okavango Delta sharing 18 species with those feeding into the Zambezi system. Since they are very similar in ecotype, one may have expected an even higher overlap of similar species. Seasonal differences due to different sampling times will almost certainly have resulted in some differences in the species compliment currently recorded. The first survey of the Okavango catchment rivers was in October–November 2016 (summer), while the Zambezi catchment rivers were sampled in both October–November 2016 and April 2018 (autumn). The sandy substrate Okavango Delta feeding rivers (excluding the Cubango River), produced 22 species, while those feeding the Zambezi system had 29 species identified. These sandy bottomed rivers collectively produced 33 distinct species including at least 16 species potentially unknown to science, with a few others that could not be clearly placed. One particularly unexpected find was a Baetidae species resembling *Delouardus* from the Lungué-Bungo River. This is a genus only known so far from Madagascar (Lugo-Ortiz & McCafferty 1999). Further research is needed to confirm this identification, and the unknown adults of both this and the Madagascan species are needed for comparison. New records have been established for West African Caenidae, and several unknown Caenidae species are currently being studied further.

The work is currently ongoing and additional species are likely to be identified. The resulting species list is therefore still tentative with much work needed to link nymphs and adults, either by rearing mature nymphs or by DNA barcoding nymphs and adults to confirm the actual number of new species, as currently some are represented by adults only and others by nymphs only. Curtis (1991) suggests that the Cunene River may represent the southernmost limit of the Angolan fauna. Further surveys to include increased seasonal species variation to accommodate the varying life histories of different mayfly species, and collections across other parts of Angola as well as from under-collected regions in neighbouring countries is needed to get a better estimate of species diversity and distribution in Central Africa. Old records and specimens of mayflies in Angolan museums need to be accessed. Museums in Angola need to be funded and have staff trained to build

up these resources in this biologically diverse country, so that new material can be added to their collections.

Conclusions

This work provides baseline data of mayfly diversity in Angola. As this is largely uncharted territory, it provides new distribution records for many known Afrotropical mayfly species. It has also uncovered at least 24 unrecognised species across all sites, many of which are clearly undescribed species. Some of these are likely to be endemic species due to the unique habitats found in this region and the isolation of these streams. Further detailed research, also extending into adjacent countries to determine the extent of occurrence of species, would be valuable. In addition to DNA barcoding to link different life stages, genetic studies are needed in due course to get to get a better understanding of the phylogenetic relationships between different species. This could also give insight into the evolutionary history of Ephemeroptera in relation to African landscape evolution in Central Africa.

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