The taxonomy and aspects of the ecology of the Ephemeroidea (Insecta: Ephemeroptera) of the Mooi River, KwaZulu-Natal Province, Republic of South Africa.

September 2004.

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DECLARATION

I hereby declare that this thesis, submitted to the University of KwaZulu-Natal, Pietermaritzburg for the degree of Masters of Science has not been submitted at any other university. The work described is entirely my own, except where indicated.

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ABSTRACT

The Ephemeroidea or burrowing mayflies are a superfamily of the Ephemeroptera (mayflies) with a worldwide distribution. Recent decades have seen a sharp decline in their abundance globally. Literature reviews of the past 20 years have shown this superfamily to be well represented on the Mooi River, KwaZulu–Natal — five species (*Eatonica schoutedeni, Ephemera mooiana, Afromera natalensis, Afroplocia sampsoni* and *Ephoron savignyi*) were recorded during the 20th century. However recent fieldwork failed to confirm this professed diversity, recording only two species (*Afromera natalensis* and *Ephoron savignyi*).

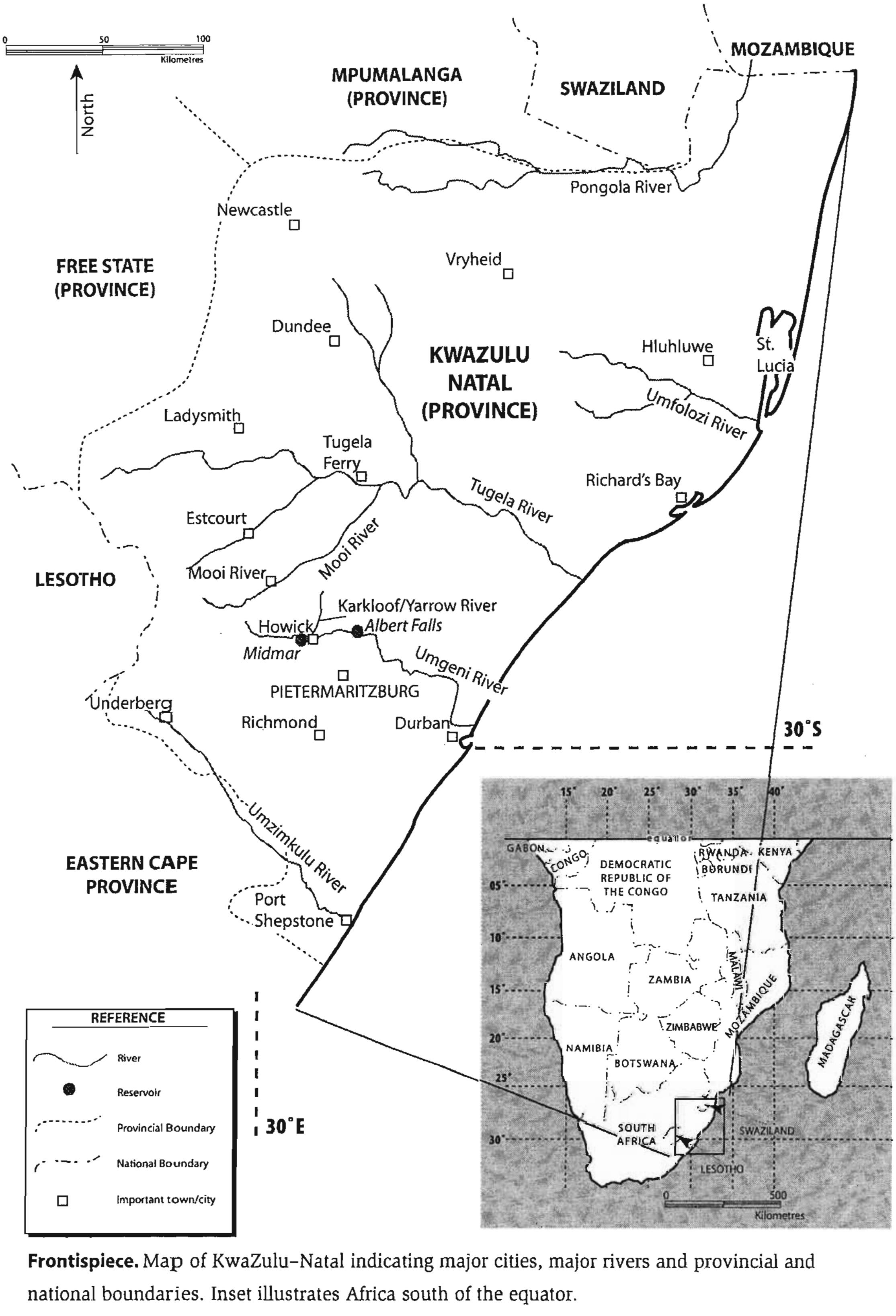
This work critically re-examined all of the literature relating to the Ephemeroidea of Africa (in the context of the five species recorded from KwaZulu-Natal) published in Africa and Europe (as well as many publications from the rest of the world) during the 19th and 20th century. It was found that a number of oversights were made in much of this literature that have become assimilated into the understanding of the taxonomy and ecology of this group. Amongst these, it was found that the synonymisation of three species of *Ephoron* (*=Polymitarcys—Polymitarcys savignyi, P. capensis* and *P. temerata*) in the 1920s was weakly justified.

To clarify problems in the published record relating to the five species recorded from KwaZulu-Natal, some of the most important museum holdings in Europe and South Africa were re-examined. Two previously unknown collections of *Ephemera* sp. were found in European museums. One of these collections was made in West Africa, undermining theories that *Ephemera* sp. are only found in cold waters. This research confirmed that the records for *Eatonica schoutedeni* in KwaZulu-Natal are probably spurious, the result of misidentification. This work presents a review of the publications relating to each of the species of the

Ephemeroidea recorded from KwaZulu-Natal. Lists of synonyms are provided. Descriptions from literature and museum specimens are given. The known distribution and biology of each is presented. The current status of the Ephemeroidea of KwaZulu-Natal are discussed and a new key to the species of KwaZulu-Natal is presented.

In order to assess the purported diversity of Ephemeroidea in the rivers of the KwaZulu-Natal midlands, extensive fieldwork was carried out the Mooi River and on other tributaries of the Tugela and Mgeni rivers from 1998 to 2000. This investigation failed to reveal four of the five species indicated in the literature. The sole species that was found, *Ephoron savignyi* was abundant in some areas of the Mooi and Karkloof Rivers. This apparent drop in diversity may be because the sampling effort carried out from 1998 to 2000 was too limited in time and space to gather specimens of all the species resident in the river, or because environmental changes in the region in the last 50 years have resulted in the extirpation of any or all of the remaining four species.

It is concluded that the records of *Eatonica schoutedeni* from KwaZulu-Natal are spurious; *Ephemera mooiana* is either not the only species in the genus *Ephemera* on the continent of Africa, or has a substantially wider distribution than previously thought; *Afromera natalensis* and *Afroplocia sampsoni* may be present on the rivers of KwaZulu-Natal but have not been found during this research; *Ephoron* spp. are abundant in KwaZulu-Natal, but further research is required to confirm that the species in South Africa are the same as those originally recorded from the type locality, Egypt.



Frontispiece. Map of KwaZulu-Natal indicating major cities, major rivers and provincial and national boundaries. Inset illustrates Africa south of the equator.

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PREFACE

This work is divided into four chapters. Chapter 1 provides the background to this work, outlines the aims of the project and provides an overall review of the ecology of the order Ephemeroptera. This chapter aims to introduce topics relevant to this study that are considered in later chapters and place them in the context of our current knowledge of the Ephemeroptera, and to allow readers who are not familiar with the order to comprehend most fully the three chapters that follow.

Chapter 2 presents the findings of a complete review of all the literature published in Africa and Europe in the 19th and 20th centuries relating to the superfamily Ephemeroidea of the Afrotropical region. Also in this section are the results of research carried out from 1998 to 2000 on major entomology collections in South Africa and Europe. Each of the South African species is discussed separately. Emphasis was placed on comparing the publications with each other and cross-checking as many of the original author's references and citations as possible in order to ascertain if and where errors may have occurred. Where feasible the original specimens discussed in these publications were studied. A series of maps illustrating the distribution of the relevant species on the continent of Africa and two chronology charts that summarise the findings of the review of 19th and 20th century literature follow. The chapter ends with a key to the Ephemeroidea of KwaZulu-Natal.

Chapter 3 presents the methods and results of fieldwork carried out during this study in KwaZulu-Natal to investigate the superfamily *in situ*. All field sites at which collections were made are described. This follows-on from the work of CRASS (1955) whose catalogue of fieldsites was invaluable in carrying out this work.

Chapter 4 presents the conclusions that can be drawn from Chapter 2 and Chapter 3.

Two appendices are provided. Appendix 1 reproduces the classification of McCAFFERTY (1991a) as this project applies the classification described therein. Appendix 2 reproduces the personal communications cited in Chapters one to four.

General taxonomic nomenclature is based on BLACKWELDER (1967) and the International Commission on Zoological Nomenclature, ICZN (1999). Style and format follows the recommendations of the Council for Biology Editors, CBE (2002).

1 INTRODUCTION;

WATER SUPPLY IN KWAZULU-NATAL, PROJECT AIMS AND THE ORDER EPHEMEROPTERA

1.1 WATER SUPPLY AND RARE INSECTS IN KWAZULU-NATAL

South Africa is a country of few natural lakes and highly variable precipitation levels. Therefore water supply usually has to be from man made reservoirs. The eastern province of KwaZulu-Natal is no exception. Since the 1970s two main impoundments of the Mgeni River, Albert Falls (Volume 290.7×10^6 m^3 — impounded 1976) and Midmar (Volume 177.8×10^6 m^3 — impounded 1964) have served the majority of urban residents and industries of the province with fresh water (UMGENI WATER 2003). However by the 1980s it was realised that these two reservoirs would probably not be of sufficient volume to supply, in particular, the growing industrial population of the city of Durban. For this reason, methods of supplementing this water supply were investigated. The proposal accepted as being most suitable by the Department of Water Affairs and Forestry (DWAF) involved the construction of a number of impoundments on the Mooi River, the details of these impoundments to be clarified by environmental impact assessments (EIA).

Literature reviews carried out as part of these EIAs in 1995 revealed that a high diversity of aquatic invertebrates had been reported from the Mooi River. In particular, it was shown that 50 species of mayfly (out of a total number of 100 recorded for the entire Republic of South Africa [BARBER-JAMES 1997]) had been recorded from the river since 1932 (DE MOOR 1995). Further to this it was found that one superfamily, the Ephemeroidea (generally known as the burrowing mayflies) was well represented on the river — six species are recorded from South Africa and five of these had been recorded on the Mooi River. Two of these five species, *Ephemera mooiana* MCCAFFERTY 1971 and *Afroplocia sampsoni* (BARNARD 1937) have very restricted known distributions — *Ephemera mooiana* on the Mooi and Karkloof Rivers in KwaZulu-Natal and *Afroplocia sampsoni* on the Mooi and UmZimkulu Rivers in KwaZulu-Natal and at Marendellas in Zimbabwe. Both species have been recorded on only a couple of occasions. In surveys of the Mooi River carried out since 1990 only the polymitarcyid *Ephoron savignyi* (PICTET 1843) and ephemerid *Afromera natalensis* (BARNARD 1932) have been found (DE MOOR 1995).

This research project was instigated in 1998 to investigate topics relating to the burrowing mayflies of the Mooi River prior to its impoundment.

1.2 THE AIMS OF THIS PROJECT

This project had three primary aims:

1.2.1. To assess what species of burrowing mayflies are present on the Mooi, Little Mooi and Karkloof rivers of KwaZulu-Natal province

Extensive sampling for mayflies has only been carried out on the Mooi River on two occasions; once in the 1950s (CRASS 1955) and once in the 1990s (DE MOOR 1995). The surveys carried out in the 1990s revealed that three species (*Afroplocia sampsoni, Ephemera mooiana* and *Eatonica schoutedeni* [NAVAS 1911]) had ostensibly disappeared since the survey of the 1950s. The loss of three species in such a short period of time would be of concern. The Ephemeroidea are generally regarded as pollution-intolerant (EDMUNDS 1973, USGS 1999). The fact that they are long-lived (up to four years as a nymph) and live within river or lake sediment may make them particularly susceptible to damage from pollutants such as heavy metals and insecticides, and their burrows to fertiliser-induced oxygen depletion. The apparent loss of burrowing species may therefore be indicative of a drop in water quality in the Mooi River catchment. Accordingly it was deemed urgently necessary to assess what species were present in the river. Of primary concern was the apparent loss of *Ephemera mooiana*. This species was the only known representative of the genus *Ephemera* recorded from the Afrotropical region, and was felt to be of great importance, both biogeographically and evolutionarily.

It was proposed to use a literature review to aid drawing up a short list of sites of primary importance i.e. those sites that had a previous sampling history. It was hoped that assessment of these sites would enable other similar sites in KwaZulu-Natal to be identified and investigated for the presence of Ephemeroidea.

1.2.2. To complete a taxonomic reassessment of South African Ephemeroidea

During an early stage of the literature review for this document it was realised that the historical records of South African Ephemeroidea were in a poor state. A large number of publications were prepared from 1900 to 1930, but little work has been carried out since then. The higher taxonomy of the Ephemeroidea has been extensively revised since 1955 (McCAFFERTY 1991a; see Appendix One for details of this revision). However publications by BARNARD (1932) and CRASS (1947, 1955) are still the only publications available that have large sections on South African Ephemeroidea. A comprehensive review that collates, synthesises and updates previous research would allow workers to carry out work with greater simplicity and confidence. This would be primarily achieved by means of a literature review. In order to supplement the literature review it was proposed to visit museums with holdings of Southern African Ephemeroidea. This would enable comparison between the published descriptions and the museum collections and further strengthen the revision.

This aim would be aided by the ongoing assessment of species on KwaZulu-Natal rivers (Section 1.2.1).

1.2.3. To determine whether the proposed impoundments would have a deleterious effect on the populations still present in the Mooi River

Whilst assessing what species were still resident in the catchment it was proposed to assess if the building of the intended impoundments might have negative (or positive) effects on burrowing mayfly species populations. Published accounts (CRASS 1947,

1955) suggested that populations of *Ephemera mooiana* were highly localised, patchy and that the total population was relatively low. It was feared that an impoundment could have serious consequences for this rare mayfly. Furthermore, burrowing mayflies are thought to be susceptible not just to pollution but also to changes in water temperature (EDMUNDS 1973), dissolved oxygen (EDMUNDS 1973, FREMLING 1967, FREMLING & SCHOENING 1973) and weather conditions during adult emergence (WHELAN 1980). Any or all of these potential effects could be exacerbated during and after the building of impoundments. However, it was also realised that dam-building may have positive effects for burrowing mayflies; for example by deposition of more sedimentary areas in the former streambed, or by oxygenating water downstream of the impoundment.

If the study were to find detrimental effects on the mayflies, mitigation measures were to be proposed in an effort to reduce such effects. Conversely if positive effects were possible, proposals to reinforce these positive effects should be made.

The proposal was to characterise the ecology of the burrowing mayflies *in situ* in the river during field studies. Possible sedimentary and oxygenation effects could be discussed with hydrologists and other experts assigned to the EIA teams.

A general knowledge of the ecology and biology of the order Ephemeroptera is essential to a good understanding of why this work was carried out and useful in understanding the terminology used in Chapter 2. The most relevant topics are discussed below.

1.3 THE MAYFLIES

The Mayflies are an order of insects, represented in South Africa by 100 known species in ten families (BARBER-JAMES 1997) (Figure 1). There are approximately 2000 species recorded worldwide (BRITTAIN 1982). The name 'mayfly' alludes to the fact that in Western Europe mayflies are usually first seen each year in the month of May, the beginning of the northern hemisphere summer. Their scientific name, Ephemeroptera, is derived from the Greek, '*Ephemeros*' meaning 'of short duration', a reference to the brief life of the adult flies. One of the common misconceptions about mayflies is that they are particularly short-lived. This is true insofar as the adults, the winged stage, may only live for a few hours. However the juvenile stage or 'nymph' may be relatively long-lived for an insect, in some instances living for four years before emerging from the water to pursue its brief adult life (GIBERSON & ROSENBERG 1994).

Eggs are usually laid directly after mating at the water surface. In many cases the eggs of mayflies are sticky or may have specialised attachment structures to attach to substrate. The period of development until the hatching of nymphs is highly variable between species, and may take most of a year.

The nymphs of all species of mayfly are completely aquatic, but occupy a wide diversity of aquatic habitats—including crawlers on vegetation, swimming forms, flattened nymphs that cling to rocks and burrowers in mud and vegetation. However the greatest species diversity is to be found in clear-water rocky-bottomed second and third order streams (EDMUNDS 1978). The duration of the nymphal life span may range from months to possibly four years in some lakes in northern Canada (GIBERSON & ROSENBERG 1994).

Between the nymph and adult life stage, mayflies go through a life stage unique in the insect world — the subimago. The subimago is sometimes described as a winged but sexually immature stage, but this is not always the case; frequently the females can (and for some species usually do) mate and oviposit as subimagoes.

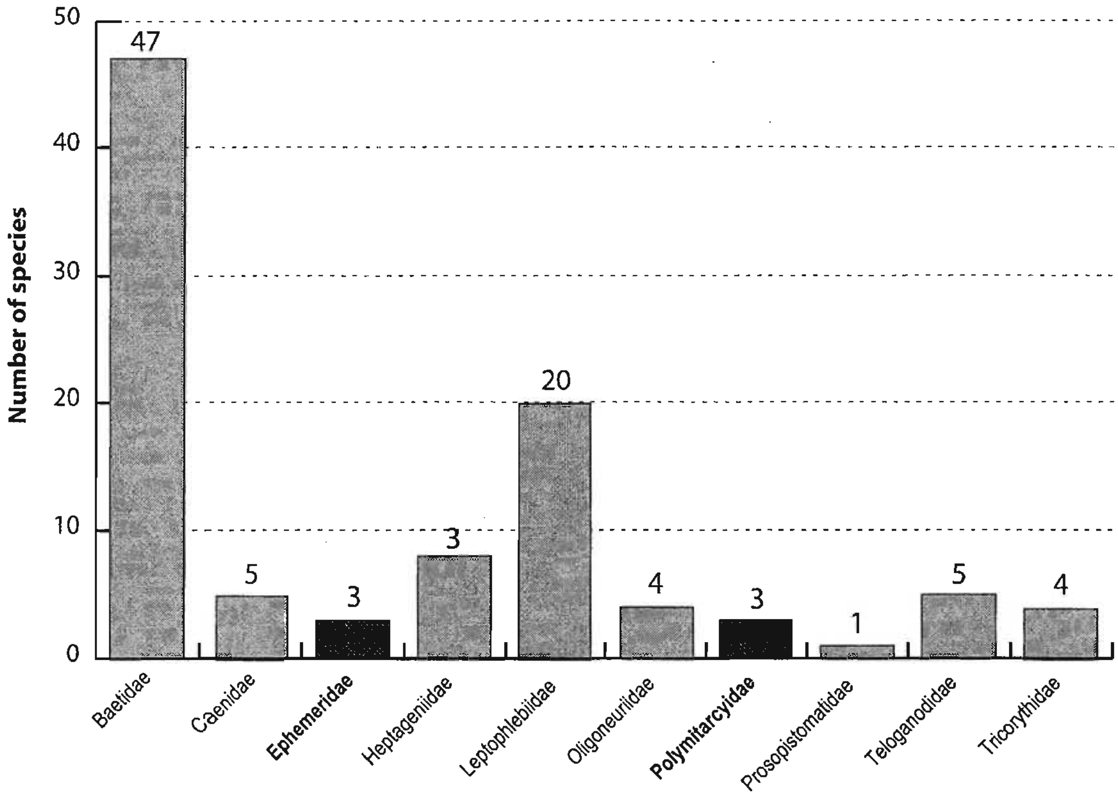


FIGURE 1: Chart outlining the number of species and their allocation to the different families in South Africa (arranged alphabetically, left to right). The columns representing the burrowing species are more darkly shaded. The number of species in each family recorded from South Africa is appended at the top of each column (data from Barber-James 1997).

1.3.1. Generalised anatomy and relevant terminology of the mayfly life stages

Terminology outlined in the section below is that which is specifically of interest or reference to mayflies. Many textbooks give outlines of general insect taxonomy (used here without explanations); in particular refer to De Villiers (1985) and (Chinery 1993).

1.3.1.1. The Adult

Mayfly adults range in size from 3 mm to greater than 30 mm. The most striking features are the two or four large triangular wings, the elongate ten-segmented abdomen and two or three cerci protruding from the hind abdominal segment. The wings tend to have numerous veins and cross veins (exceptions include the Caenidae and the Oligoneuriidae).

Head Four features are usually notable on the head of an adult mayfly. Firstly the antennae tend to be short and smooth. Secondly the mouthparts are non-functional, although the remnants of the nymphal mouthparts can usually be seen. Thirdly, as a general rule, the eyes of the males are larger, and frequently much larger, than those of the females. This condition is taken to extremes in the Baetidae and some Leptophlebiidae in which the upper portion of the eye is elevated onto a short stalk (so-called 'turbinate eyes'). The condition is partially explained by the fact that male mayflies generally approach the female from below, hence the upwardly directed eyes. Finally, the head bears three ocelli, usually placed in a triangular pattern just in front of the eyes in the centre of the head. The function of these ocelli is unclear. No work has been carried out on the ocelli of Ephemeroptera, but it seems likely from evidence for Orthoptera (Grasshoppers) and Odonata (Dragonflies) that they play a sensory role, helping to control pitch and roll while flying. They may also have a role in the perception of light intensity and hence determining the timing of emergence of the adult flies (extensive reviews of insect ocelli include those of GOODMAN [1970] and MIZUNAMI [1994]).

Thorax The prothorax is generally reduced, the metathorax fused with the mesothorax to form the pterothorax to which the wings are attached. The mesothorax is particularly well developed, housing the muscles of the forewings.

The legs usually exhibit sexual dimorphism; males frequently have well developed fore-limbs (with which they grasp females during copulation) whereas the middle and hind limbs are much less developed.

Most mayflies possess two wings, but may possess four, as is the case in the Ephemeroidea (EDMUNDS 1978). The wings are generally triangular with numerous veins. Hindwings tend to be used for 'parachuting' flight (subsequent to the insect having actively flown upwards and making a controlled descent without beating its wings). Parachuting flight is usually only evident or aerodynamically efficient in relatively large–bodied forms. This may explain why families that are generally smaller, such as the Caenidae and Baetidae, have to a greater extent lost their hindwings (BRODSKY 1994).

The veins are categorised in a number of ways by researchers (Figure 2). Veins that are found on ridges on the wing are termed convex (indicated by a ' + ') and veins in furrows are termed concave (indicated by a '–'). Longitudinal veins generally arise at the wing base and run the length of the wing. Intercalaries are usually derived from one of these major longitudinal veins and run parallel to their partner veins (they usually situate in an opposite position to their partner vein i.e. where the longitudinal vein is concave, its intercalary will be convex). The third type of wing vein, the veinlet, originates at the wing margin and runs perpendicularly into a longitudinal vein or intercalary. Finally crossveins are those veins that connect major veins to each other, and hence usually run perpendicular to major veins (DE VILLIERS 1985). Usually the wings are held upright above the body (the subimagoes of some species hold the wings lateral to the body).

Reference to any of the works on mayflies written prior to 1950 will note the great importance attached by taxonomists to the wings of mayflies. Primarily this is due to the particularly delicate nature of preserved mayflies. The wings are generally more resistant to handling or preservation than any other feature of the insect — heads, legs and genitalia all become easily detached with time and body patterns rapidly fade (NEEDHAM, TRAVER & HSU 1935).

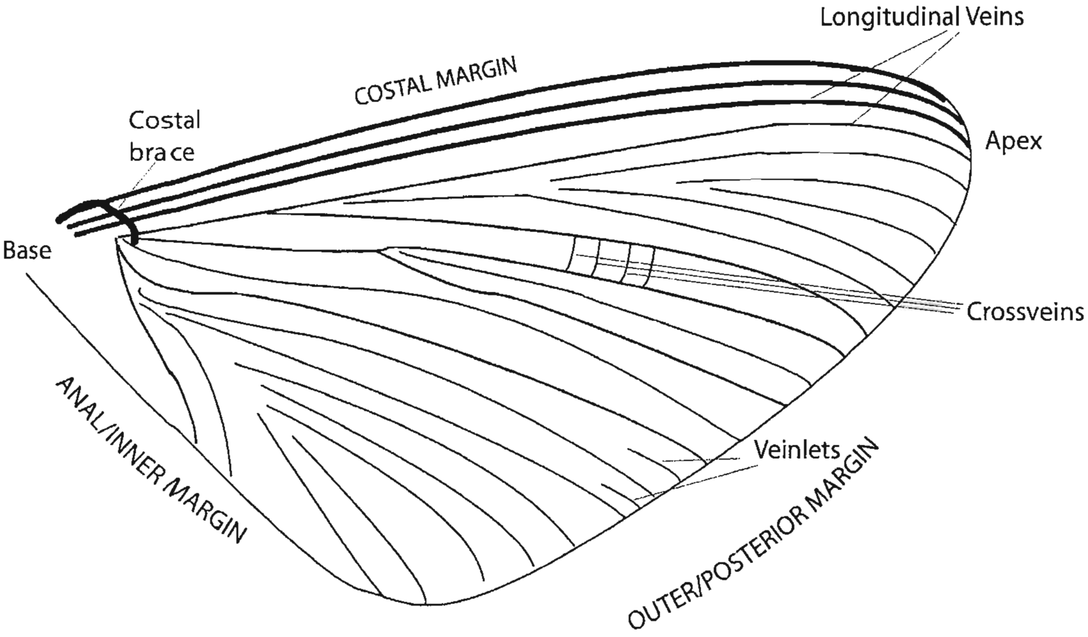
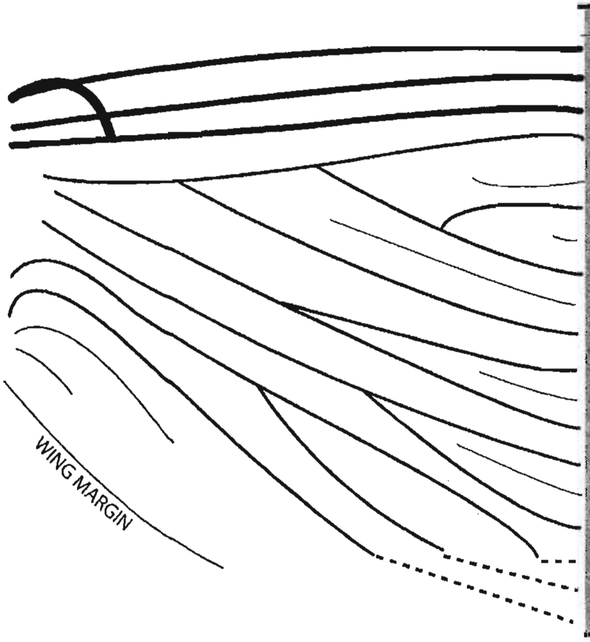


FIGURE 2: A summary of the terms used to describe insect wings. The diagram is based on a stylised mayfly wing and is not intended to represent any particular genus (adapted from CHOPRA 1927, NEEDHAM et al. 1935 and KIMMINS 1972).

While the pattern formed by the wing-veins is often used by taxonomists to distinguish between genera, there have been many changes in the notation used in wing descriptions, and for some time there was little agreement between workers as to which notation system to use (Figure 3). BARNARD (1932) expressed a preference for Tillyard's (1926) notation (cited in BARNARD 1932), but gave Comstock-Needham notation equivalents in his introduction 'as the Comstock-Needham notation is in use by many other authors'. That there was frequent debate about the developmental biology of the insect wing is evident from the lengthy discussions with detailed citations on the topic by CHOPRA (1927, pages 95 to 100), TILLYARD (1923) and NEEDHAM et al. (1935, pages 115 to 127).

In terms of the more recent major works, KIMMINS (1972) favoured the nomenclature suggested by NEEDHAM et al. (1935). GULLAN & CRANSTON (1994) suggest that the Kukalovà-Peck (1991) classification (cited in GULLAN & CRANSTON

1994) is a particularly well thought-out system for insects in general but note that, as many insect orders have an established venation nomenclature, workers are loathe to adopt new schemes. As most of the literature on South African mayflies was written prior to 1960, the nomenclature of NEEDHAM et al. (1935) is used in this text.



1935	1979	1926	1923	1912	1898	1883
C	C	C	C	C	C	1
Sc	Sc	Sc	Sc	Sc	Sc	2
R_1	R_1	R_1	R_1	R_1	R_1	3
R_2	R_2	R_2	$1R_{2a}$	M_1	R_2	4
—	—	—	—	—	R_3?	—
—	R_3		—	—	—	—
—	—	—	—	—	—	—
—	R_4	—	$5R_{2a}$	R_s	—	—
—	—	—	R_{2b}	—	R_4	—
R_3	R_5	M_{4+5}	R_3	M_2	R_5	5
R_4	Rs_1	MA_1	R_{4a}	M_3	M_1	6
—	—	—	R_{4b}	—	M_2	—
R_5	Rs_2	MA_2	R_5	M_4	M_3	—
M_1	MA	—	M_1	Cu_1	Cu_1	7
—	—	—	M_2	—	—	—
M_2	MP	M_{3+4}	M_{3+4}	Cu_2	Cu_2	—
Cu_1	CuA_1	Cu_1	Cu_1	1^{st} A	1^{st} A	8
Cu_2	CuA_2	Cu_2	Cu_2	2^{nd} A	2^{nd} A	9
1st A	CuP	1^{st} A	1^{st} A	3^{rd} A	3^{rd} A	—

FIGURE 3: Table and diagram summarising the major notations in general usage by mayfly taxonomists from 1888 to date. Abbreviations used: 1935 — NEEDHAM, TRAVER & HSU; 1979 — WOOTTON; 1926 — TILLYARD; 1923 — TILLYARD; 1912 — MORGAN; 1898 — COMSTOCK & NEEDHAM; 1888 — EATON. Wing vein abbreviations; C — Costal; Sc — Subcostal; R — Radius; Rs; — Radial Sector; M — Media; MA — Anterior Media; MP — Posterior Media; Cu — Cubitus; CuA — Anterior Cubitus; CuP — Posterior Cubitus; A — Anal. WOOTON'S (1979) terminology is not used in this text, but is in general use for other insect orders and is illustrated for comparison (adapted from NEEDHAM et al. 1935).

A number of folds are evident on the wing, both parallel to the longitudinal veins (longitudinal folds) and perpendicular to them (transverse folds). These folds that are sometimes observed in specimens (especially in wet-preserved specimens) serve to allow deformation of the wing in flight. In general these folds are of no taxonomic use (the nomenclature, aerodynamics and method of flight are covered extensively and at length by BRODSKY (1994), in particular pages 88 to 98 and 106 to 108).

Abdomen The abdomen is composed of ten segments, each segment composed of a dorsal half, the tergum (or tergite), and a ventral half, the sternum (or sternite), although the tergum occupies the dorsal surface and most of each of the lateral surfaces (lateral plates or pleura are reduced or absent in most of the order [RICHARDS & DAVIES 1977]). When numbering any given abdominal segment, the segments are counted, beginning with tenth segment, from posterior to anterior as the anterior segments are sometimes obscured by the metathorax.

The apex of the tenth segment gives rise to the cerci; two lateral cerci are always present; the median cercus may be reduced or absent. Sometimes this reduction or absence is a result of sexual dimorphism (male mayflies frequently only have lateral cerci, females having all three). These cerci may have a role in flight stability, aiding the insect in the control of pitch and yaw (the movement of the insect through its vertical axis) (ELLINGTON 1991).

The posterior portion of the female ninth sternite is developed into a plate usually protruding underneath and partially obscuring the tenth sternite. This sternite is therefore termed the subanal plate. In males the ninth sternite is termed the subgenital or styliger plate.

In the female two oviducts open by separate apertures between abdominal segments seven and eight. Internally the reproductive organs are relatively simple with no accessory glands associated with the ovaries or testes (RICHARDS & DAVIES 1977).

The male genitalia (Figure 4) are usually visible as a pair of forceps, with paired sclerotised penes dorsal to the subgenital plate. The morphology of the male genitalia is an important feature in distinguishing between many genera and species of mayfly, although in some cases, such as the polymitarcyid genus *Ephoron*, the male genitalia are somewhat homogenous and of no use in distinguishing between species (ISHIWATA 1996).

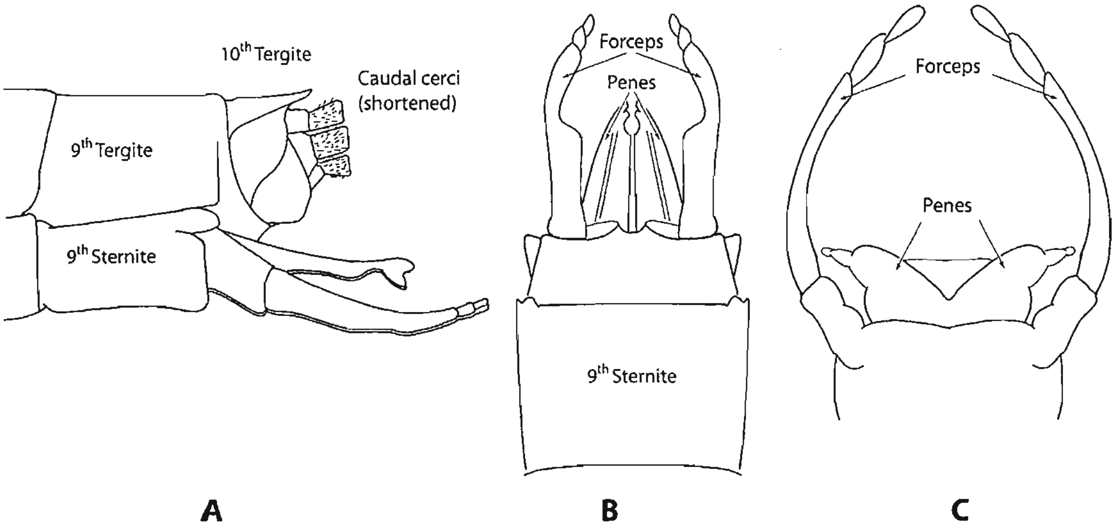


FIGURE 4: Representative ephemeropteran male genitalia. **A** depicts a lateral view of the terminal segments of *Atalophlebia* sp. (Leptophlebiidae) from Australia, **B** a ventral view of the same genus and **C** a ventral view of *Ephoron* sp. from the USA. **A** and **B** adapted from PETERS & CAMPBELL 1991, **C** adapted from NEEDHAM et al. 1935.

Internally the alimentary canal is reduced, and usually filled with air. It is generally held that the gut of the adult mayfly is completely non-functional, but this may not always be the case. HARKER (1999) suggests that the waves of contraction that are seen rippling down the gut of adult mayflies may play a role in distribution of haemolymph and metabolites around the body. Some authors have suggested a role in aiding flight (by changing the volume of air in the gut) — but this is strongly disputed by HARKER (1999) — and in the uptake of water. The rest of the abdominal cavity is usually taken up with reproductive organs.

1.3.1.2. The Subimago

In many cases the subimago of a species can be distinguished from the adult by the presence of a hairy skin (the subimagal cuticle) covering the entire surface of the insect. The wings of a subimago are generally dull and opaque whereas the wings of the imago are generally shiny and transparent. While early workers assumed that this hairy covering was the only difference between the adult and the subimago, this has since been shown not to be the case (Ide [1937] and Taylor & Richards [1963], both cited in EDMUNDS & MCCAFFERTY, [1988]). NEEDHAM et al. (1935) found that for *Isonychia bicolor* (Walker 1853)(Isonychiidae; a family not found in South Africa) the transition from subimago to imago resulted in a 21.5% decrease in weight. However only 1.5% of this weight loss was accounted for by the loss of the subimagal cuticle. They suggested that the removal of this cuticle facilitated the loss of water by evaporation, which accounted for the remainder.

The most comprehensive treatment of the subimago is by EDMUNDS & MCCAFFERTY (1988). They suggest that the hairy subimagal skin probably has a water repellent quality (similar to the hairy plastron used to trap air in some aquatic insects). They cite the example of subimagoes of *Dolania* sp. (Behningiidae) which are able to resume flight after coming into contact with water, but the adults (which lack the hairy covering) are unable to do so.

In many species of mayfly, the subimagal stage allows further structural development to take place. For example the forelegs of male *Ephoron leukon* Williamson 1802 and *Palingenia fuliginosa* (Georgi 1802) both lengthen more than 500% during the subimagal stage. However this is generally not regarded as true metamorphosis — rather, it is regarded as development — as the limbs metamorphose during the nymphal stage, but lengthen during the subimagal stage. Further evidence that the subimagal stage is more than just a hairy-cuticle covered true adult stage comes from EDMUNDS & MCCAFFERTY (1988). They found that males are unable to mate without progressing from the subimago to adult stages. The exact reasons for this inability are unknown. The females of many species of mayfly do not develop into imagoes, but mate as subimagoes.

1.3.1.3. The Nymph

All mayfly nymphs are aquatic and are found in virtually all aquatic environments. Nymphs are elongate and roughly cylindrical in shape. The overall body shape may vary depending on the habitat occupied by the animal. For example, the Heptageniidae, which are frequently found in fast flowing riffles of rivers, are usually dorso-ventrally flattened (in southern Africa). The exact benefit to the animal of this flattened condition is still questioned. It was initially thought that the dorso-ventrally flattened heptageniid *Ecdyonurus* sp. experienced reduced drag, therefore making it easier to cling to a substrate surface. However it is now realised that rather than experiencing reduced drag, these insects, due to their flattened, hydrofoil-like shape, may experience increased lift — something undesirable to riffle-dwelling insects. It is suggested that the flattened body is more useful in that it allows the insect to crawl under and around the rocks of riffles. Some species of *Baetis* also occupy torrential zones, but these are not dorso-ventrally flattened. Instead it seems that these relatively long-legged insects hold themselves away from the solid-fluid interface in an so as to avoid the major effects of drag and lift at the interface (VOGEL 1994).

Head The three major features of the head of adult mayflies as detailed above (short antennae, absence of functional mouthparts and sexual dimorphism of eye sizes) are not evident in mayfly nymphs (at least not until the final nymphal instar). Antennae are frequently elongate, mouthparts well developed and eyes are of equal size between the sexes, with no stalks visible in the juvenile males of Baetidae or Leptophlebiidae. Taxonomists frequently use mouthpart morphology in describing species.

Thorax Each of the three thoracic segments bears a pair of legs. Unlike the adults the legs are well developed and frequently modified for the habitat of the nymph in question; Oligoneuriidae have two rows of hairs present on the inner surface of each of the forelegs, which act as food filters (AGNEW 1980, MCCAFFERTY 1981); Ephemeridae and Polymitarcyidae have forelimbs modified for excavating burrows. In some genera the thorax is extended to form a shield extending part of the way along the abdomen (PETERS & CAMPBELL 1991).

Abdomen As in the adults two or three cerci extend from the tenth abdominal segment. The most noticeable feature of the ten-segmented abdomen is the presence of external abdominal gills that usually occur on segments one to seven (although they may be absent on any of these segments in any combination). Like most aquatic insects, mayflies have a gas-filled tracheal system for gas exchange (DALY, DOYEN & PURCELL 1998). While in most cases the abdominal gills are used solely for gas exchange, there are some complications and considerations.

In most species the gills beat rhythmically. This may form a current with which to aid gas exchange, may draw water over other respiratory tissues (such as the gills at the bases of the coxae in the American genus *Isonychia*), may draw fresh water into the burrows of burrow-dwelling species — such as the Ephemeroidea under consideration here — and draw water to feeding appendages in the case of burrowers and the Oligoneuriidae. These modified uses are demonstrated in an extreme manner by some Heptageniidae where some of the gills may be modified into a ventral attachment disc to keep the nymph attached to its favoured substrate (*Epeorus* sp., *Rhithrogena* sp. and the African genus *Dicercomyzon*). While the gills are responsible for an appreciable proportion of the total dissolved oxygen uptake of nymphs of *Litobrancha recurvata* (Morgan 1913) and *Ephemera vulgata* (Linnaeus 1758), they do not appear to play an important role in gaseous exchange (except in terms of physically ventilating the body surface) in *Baetis* spp. or *Cloeon* spp. Both these genera seem to derive most of their oxygen by diffusion via the body wall (WINGFIELD [1939], RICHARDS & DAVIES [1977]).

1.3.1.4. The Egg

Mayfly eggs vary in length from 150 µm to 1 mm in length (BRITTAIN 1982). The surface (chorion) of the egg may or may not be sculptured depending on the individual species in question. The chorion is made up of two layers, but there is no gas layer present (HINTON 1981). Figure 5 presents a selection of mayfly eggs. Adhesive structures are usually present, which are designed to attach the egg to the substrate to prevent them from being washed downstream in the case of stream dwellers or into unfavourably deep water in the case of lake dwellers. Where a large polar adhesive organ is present it is termed an epithema (Degrange [1960] cited in HINTON [1981]), although this terminological difference does not mean that the structure or function of the organ is any different to adhesive structures that may be found elsewhere (other than one of the poles) of the egg surface. Morphological features (primarily the structure of the micropyles) of the eggs of mayflies have been found to be effective for identifying some mayflies to generic or species level (KOSS 1968, 1973, HINTON 1981), but there has been little research on this topic in the last 20 years. The use of eggs for taxonomic purposes is most useful where female imagoes are collected without males (females of some genera are difficult to identify because of their lack of external genitalia) and when eggs can be obtained from late instar nymphs.

The Ephemeroptera follow a variety of egg-laying strategies. Eggs are usually scattered on the water surface—either singly or in batches. Some species however, crawl beneath the water surface to attach eggs to submerged vegetation. Most burrowing mayflies lay eggs at the water surface—in large batches in the case of *Ephoron* sp. or in small batches in the case of *Ephemera* sp. (NEEDHAM et al. 1935).

1.3.2. Features of the Biology of Mayflies

1.3.2.1. Food & Feeding

Considering there has been much work on the ecology of mayflies, it is perhaps surprising to discover that there has been little investigation of their food and feeding. Adult mayflies do not feed. It is generally felt that nymphs probably have quite a varied diet, with the majority being herbivores — KIMMINS (1972) suggests 'vegetative matter, filamentous algae, diatoms, fragments of plants'. Some nymphs such as *Dolania americana* Edmunds & Traver 1954 (Behningiidae) may be carnivorous, hunting for prey (chironomid larvae) in sand and fine gravel.

While filter-feeding is a well-documented occurrence in the Ephemeroptera, it is not the usual method of feeding for the order. However filter-feeding is particularly well-documented for members of the Ephemeroidea (WALLACE & MERRITT 1980). Functional feeding groups in aquatic insects have been extensively reviewed in CUMMINS & KLUG (1979) and COVICH, PALMER & CROWL (1999). The majority of mayflies can be classified as collectors (including filter feeders) or scrapers (BRITTAIN 1982). MCCAFFERTY & BAE (1992) note that *Anthopotamus* sp. (a member of the Potamanthidae from North America) nymphs have variously been classified as filter-feeders, periphyton grazers and detritivore collector/gatherers; they suggest that they are indeed filter-feeders.

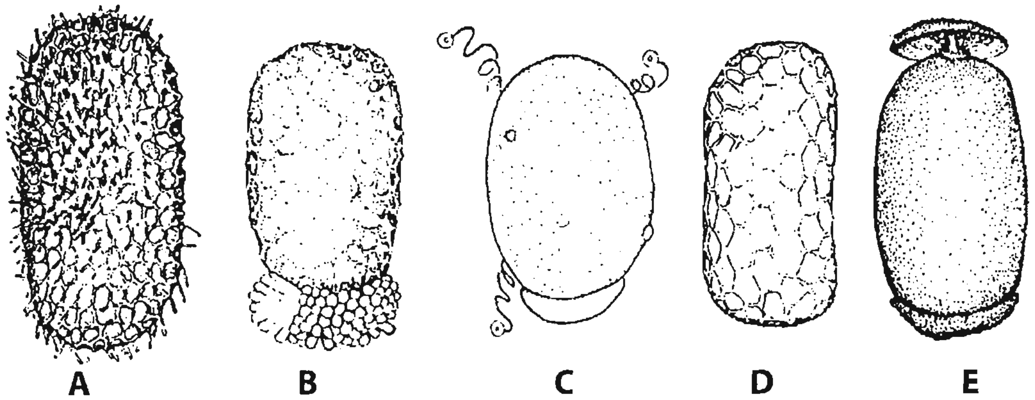


FIGURE 5: A selection of eggs of North American Mayflies, illustrating some of the variety of chorionic sculpturing found in the order as well as the variety in the morphology and number of polar organs — none in the Leptophlebiidae, one in the case of *Ephoron* spp., one or none in the Ephemerellidae and two in most *Caenis* spp. The eggs figured are **A**; *Leptophlebia johnsoni* McDunnough 1924 (Leptophlebiidae) **B**; *Ephoron album* (Say 1824) (Polymitarcyidae) **C**; *Ephemerella rotunda* Morgan 1911 (Ephemerellidae) **D**; *Eurylophella temporalis* (McDunnough 1924) (Ephemerellidae) and **E**; *Caenis hilaris* (Say 1839) (Caenidae). The eggs are not figured to scale. Adapted from NEEDHAM et al. 1935.

In many cases it has been found hard to classify the method used for feeding. For example BIDWELL (1978) determined that the nymphs of *Povilla adusta* (Navas 1911) in Nigeria do not feed before the third instar, subsisting instead on vitelline cells in the mid gut retained from the egg. PETR (1970) found *Povilla adusta* in Ghana to be primarily filter feeders when they are up to 4 mm in length. It is probable that once they grow beyond this size they supplement their diet by grazing at night on the filamentous algae around their burrows. PETR (1970) found fragments of wood in the alimentary canal of *Povilla adusta* but was unable to confirm whether or not they could digest it. BIDWELL (1978) also found that earlier instars fed mainly on planktonic algae, later instars feeding primarily, but not exclusively on periphyton. He found it probable that later instars fed on periphyton when it was available, but also supplemented their diet by crawling out of their burrows onto the substrate surface at night to feed on material attached to the substrate, or by filter-feeding from their burrows if necessary.

An important question raised by BRITTAIN (1982) which, to date has not been answered, is what proportion of the material that is ingested is actually digested? It has been found that much of the material that is taken into the alimentary canal leaves the animal undigested (BROWN 1960) and bacteria are poorly utilised as a food-source in mayflies (BAKER & BRADNAM 1976).

1.3.2.2. Mass emergence and population synchrony

Population synchrony refers to the tendency for adults of a given species to be emergent during a discrete period of time of the year and usually at certain times of day during that period of the year (SWEENEY & VANNOTE 1982). Emergence of large numbers of mayflies within short periods of time is a well-documented phenomenon. Emergences of *Ephoron shigae* (Takahashi 1924) (Polymitarcyidae) have caused traffic accidents in Japan (WATANABE, YOSHIKATA & MORI 1989) and Fremling 1968 (cited in THORNHILL & ALCOCK 1983) presents a photograph of a car on a bridge over the Mississippi axle-deep in adults of *Hexagenia bilineata* (Say 1824) (Ephemeridae). Both of these species fulfil the above criteria as a synchronised population. Two hypotheses have been proposed for the development of synchronised mass emergence in mayflies. The first is that population synchrony increases the probability of any given individual finding a mate (Corbet 1964 cited in SWEENEY & VANNOTE 1982). FRIESEN, FLANNAGAN & LAUFERSWEILER (1980) and SWEENEY & VANNOTE (1982) argue that while this hypothesis may in part drive population synchrony in mayflies, another factor, namely predator satiation also plays a major role. In a set of experiments over three years SWEENEY & VANNOTE (1982) found that for the North American tuskless burrower *Dolania americana* (Behningiidae) the percentage of adults preyed upon by aerial or aquatic predators was inversely related to the total number of adults available to the predators on any day.

1.3.2.3. Protandry

Protandry refers to emergence of males prior to the emergence of females. This phenomenon has been studied extensively in the case of butterflies by WIKLUND & FAGERSTRÖM (1977) and IWASA, ODENDAAL, MURPHY, EHRLICH & LAUNER. (1983). WIKLUND & FAGERSTRÖM (1977) maintain that this strategy should occur in species that maintain female monogamy; males would have to compete in order to mate with an individual female, therefore earlier emergence is more desirable. This theory is supported by THORNHILL & ALCOCK (1983), using observations on the lovebug fly *Plecia nearctica* Hardy 1940 and the digger bee *Centris pallida* Fox 1899. WATANABE, et al. (1989) investigated protandry in *Ephoron shigae* in Japan. While they were unable to determine if females were definitely monogamous, they concluded that the emergence pattern of *Ephoron shigae* probably fitted with the hypothesis of WIKLUND & FAGERSTRÖM (1977).

1.3.2.4. The thermal resistance of mayflies and effects of elevated temperature

Most Ephemeroptera evolved in temperate regions (EDMUNDS 1973). The changes that occur in water temperature throughout the year have an important influence on their lives; adult emergence can be advanced by a number of months in the laboratory when nymphs are subjected to a stable-flow/high-temperature regime purported to replicate that of a large river impoundment (this has been demonstrated extensively by a number of researchers in the laboratory; see LANGFORD [1975] for a comprehensive review). Elevated temperatures alone have generally been found to speed up development to final instar nymph (LANGFORD 1975, WRIGHT, MATTICE & BEAUCHAMP 1982, TOKESHI 1985, WATANABE, MORI & YOSHITAKA 1999) but some temperature regimes result in high mortality levels during the transition from nymph to subimago in *Hexagenia bilineata* under laboratory conditions (WRIGHT et al. 1982).

Speeded development may result in adult mayflies emerging at times of year when the environment may be unsuitable for mating or oviposition.

WHITNEY (1939) demonstrated that mayflies from slow or still waters have a much greater resistance to high temperatures than similar nymphs from swift waters. For example, *Rhithrogena semicolorata* (Curtis 1834) (from stones in swift water) suffered a mortality of 65% in 24 hours at 24°C whereas caenids (from choked streams) and *Cloeon dipterum* Linnaeus 1761(from ponds) suffered mortalities of only 2.5% or less.

Of particular importance may be the potential influence that heated water may have on the required cold period that results in a winter resting phase for the eggs of some species of Ephemeroptera, the diapause (EDMUNDS 1973). WATANABE, HATTA, HISAEDA, HOSHI, & ISHIWATA (1998) found that eggs of *Ephoron shigae* required a cold period of between 4 to 8°C after a 50-day period at 20°C in order to develop. In order for efficient hatching to occur however the eggs had to be returned to at least 8°C, preferably 15 to 20°C.

WATANABE et al. (1999) found that for *Ephoron shigae*, water temperature at certain times of year was essential for determining when adults emerge. For example the water temperature in July and August most strongly determined exactly the date of the peak emergence in the first three weeks of September (the findings rely on the determination of 'degree-days' whose application in mayflies is discussed thoroughly by TOKESHI 1985). According to the authors, these findings are now used to predict emergence on one river in order to assist traffic police officers alleviate the problems caused by the mass emergence of adults. WATANABE et al. (1998) confirmed that water temperature, in particular the limited range of environments exhibiting a water temperature low enough to initiate diapause, was a major limiting factor governing the geographical distribution of *Ephoron shigae* in Japan.

1.3.3. Mayflies and man

1.3.3.1. Problems associated with mayfly research

Taxonomy — the naming and classifying of life-forms — is an essential part of environmental science. In order to assess what impact a development may have on a life form (or groups of life-forms) it is essential to be able to attach a name and characteristics to that life form. This allows researchers keep track of organisms that they are working on and refer to other works on the same and related species.

The Ephemeroptera (Mayflies) are generally regarded as a taxonomically well-understood group of insects. They are a familiar sight to researchers working in freshwater, both rivers and lakes, in both their juvenile stages — when encountered in the water — and their adult stages — when they may be observed during their brief nuptial flight.

However while the taxonomy of the Ephemeroptera is well-understood in Western Europe and to a large extent in the USA and Canada, the same cannot be said for the rest of the world. It has frequently been found that the same genus may have been allocated different names, on a single continent (EDMUNDS 1973).

Furthermore — in general — there is a lack of correlation between life stages of Ephemeroptera. There have been a number of errors in major works whereby either adults and juveniles of different species have been wrongly associated with each other, or that a juvenile and adult of the same species have remained unassociated. For examples see EATON (1883), where two separate species were identified as the adult and nymphal form of *Jolia roeselli* Eaton 1883, CRASS (1947) where the nymph of *Ephemera mooiana* was misidentified as *Eatonica schoutedeni*, (discussed extensively in this thesis) and a number of similar examples from NEEDHAM et al. (1935).

1.3.3.2. The impact of man on mayflies and their habitats

Man's impact on this group of insects is poorly understood. Thermal pollution has become a greater concern since the 1950s, with large number of power stations being built alongside water bodies and ejecting heated waste water into lotic environments (WRIGHT et al. 1982).

Man-made impoundments have an exceptionally complex impact on a riverine habitat, both upstream and downstream of the impoundment itself. The most relevant topic from the point of view of burrowing mayflies is that of the consequences to the thermal regime of the river — as discussed in Section 1.3.2.4 mayflies, in general, are intolerant of raised water temperatures. From the aspect of the thermal structure of the water, the reservoir of water formed behind the impoundment should be equivalent to that of a natural lake of equivalent size — but with two major differences (THOMAS, MEYBECK & BEIM 1992). Firstly, after the dam is completed changes occur as the reservoir fills. Secondly, as a man-made structure for water supply, the water levels in the reservoir change according to demand as the water is abstracted (whether the water be used for electricity generation, agricultural supply or human drinking) rather than the more stable seasonal changes that typically occur in a natural lake. This has an impact both behind the dam and downstream of the impoundment. As this project concentrates on mayflies from lotic environments, what occurs to the fauna behind the impoundment as a consequence of water abstraction is largely irrelevant.

Downstream of the impoundment in the still-lotic environment the decisions made by the dam-builders have an important role to play — particularly the point where the water is withdrawn from the reservoir. Small impoundments typically allow excess water to flow over the top of the impoundment. Such water tends to be subjected to the influence of the sun and may become heated in sunny climates.

Larger impoundments may allow water to escape from any point from the base of the impoundment to the top. If released from the top of the reservoir, the water again tends to be heated water as in the case of a small impoundment. If released from anywhere else in the water column however the water temperature will be dependent on the physical characteristics of the reservoir behind it — if the release point is above the reservoir's thermocline, it may be regarded as unseasonally 'heated' and if released from below the thermocline, unseasonally 'cooled'. Modern environmental impact assessments are designed to take such considerations into account in the planning stages of dam building, but most of the research on these impacts has been carried out on fish (HORNE & GOLDMAN 1994).

One of the most noticeable features of mayfly life history in the past was the periodic huge emergences of mating swarms. Historically such emergences are well documented; by Swammerdam in the 18th century; for emergences in Prague in the 19th century (both cited in EDMUNDS 1973); and on the Great Lakes in the USA until the 1940s (USGS 1999). WILLIAMSON (1802), referring to *Ephoron leukon* in the USA in stated;

> 'These flies are so numerous that they appear some evenings like thick driven snow in a cloud that is hardly transparent'

(quoted from NEEDHAM et al. 1935). In many parts of the world these vast emergences are a thing of the past. In some cases natural catastrophe has been largely to blame for the decrease in numbers. For example storms in the 1970s devastated populations of the burrowing mayfly *Ephemera danica* in Ireland when the mating swarms were dispersed by high winds (WHELAN 1980). However it is likely that the decline in numbers of *Ephoron virgo* (described by Swammerdam in 1737 as *Palingenia virgo*) in mainland Europe and ephemerid burrowers on Lake Erie in the USA (besides numerous other examples) are the result of anthropogenic reductions in water quality resulting in lowering of levels of dissolved oxygen (EDMUNDS 1973, USGS 1999).

1.3.3.3. The use of the Ephemeroidea as water quality indicators

Freshwater biota have been used by environmental scientists as water quality indicators for a number of years. WOODIWISS (1964) proposed a system based on the diversity of a number of families of aquatic invertebrates in a given stretch of river. However due to the specific nature of this system (it was designed for use on the Trent River in central England) and the requirement to identify organisms to species level it was later superseded (see FRIEDERICH, CHAPMAN & BEIM (1992) for a summary of systems). The burrowing mayflies offer great potential to be used as water quality indicators. Most species are probably sensitive to pollution (USGS 1999). Their relatively large size and the distinctiveness of the group at Superfamily and Family level would be a boon to field scientists requiring easily recognisable species (certainly when compared to large families within the Ephemeroptera such as the Baetidae and Leptophlebiidae which require great time and skill to distinguish from each other, as well as access to a bewildering range of published papers).

1.4 THE SUPERFAMILY EPHEMEROIDEA—THE BURROWING MAYFLIES

1.4.1. Nymphs

Fossorial behaviour (the construction of burrows in aquatic substrate) is known from members of the infraorder Lanceolata that contains three superfamilies: the Leptophlebioidea, the Behningioidea and the Ephemeroidea. While there is evidence of burrowing behaviour from some members of the Leptophlebioidea (such as members of the Australian genus *Jappa*) the term 'burrowing mayflies' is generally only applied to members of the superfamily Ephemeroidea. According to EDMUNDS & MCCAFFERTY (1996), burrowing *sensu stricto* is applied to mayflies whose nymphs:

> '...demonstrate adaptations for excavating and residing more-or-less permanently within substrates that include coarse sand, silt, sand/marl, clay, mixed gravel, wood and freshwater sponges'.

This distinguishes 'true' burrowing mayflies — the Ephemeroidea — from other mayflies that show adaptations for living on, or partially to completely within sandy substrates (McCafferty 1991b). Such mayflies (for example members of the Acanthametropodidae — not found in South Africa) are termed 'psammophilous mayflies'. In South Africa there are no representatives of the Behningoidea and there is no evidence of burrowing behaviour in the Leptophlebioidea, and hence the term 'burrowing mayflies' is only applied to the Ephemeroidea.

Within these 'true' burrowing mayflies, the genera concerned can generally be split into two functional groups based on their ecology and behaviour.

U-shaped burrow dwellers The first group are those that construct a U-shaped burrow in relatively consolidated, relatively fine sediment (usually silt or clay — refer to Table 6 for definitions of sedimentary particle size ranges). This group is represented in South Africa by *Ephoron savignyi* (Polymitarcyidae), *Ephemera mooiana* (Ephemeridae) and probably by *Eatonica schoutedeni* (Ephemeridae) (Barnard 1932) and *Afromera natalensis* (Ephemeridae) (McCafferty & Gillies 1979). To date no ecological information regarding the nymphs of *Eatonica schoutedeni* or *Afromera natalensis* has been published.

Interstitial burrowers The second group are termed 'interstitial burrowers'. These dwell in coarse sand with mixed gravel and burrow in the interstices between substrate particles and existing crevices. The best-known representative of this behaviour is the carnivorous *Dolania americana* (Behningiidae) found in the southern USA, but the South African *Afroplocia sampsoni* (Polymitarcyidae) also probably fits into this category (Edmunds & McCafferty 1996). It must also be noted that these two functional groups serve as a general rule, but the former group (U-shaped tube burrowers) may be, and frequently are, found dwelling within interstices (Edmunds & McCafferty 1996).

Morphologically, the nymphs of members of the superfamily Ephemeroidea are distinguished from the other mayfly groups by the presence of paired, elongate gills, fringed with slender filaments on segments two to seven (McCAFFERTY 1975, 1981). In most cases the nymphs also have flattened forelimbs, which most likely are adapted for burrowing. The nymphs of most species possess modified mandibles (tusks) which protrude forward from the head and seem, in most cases, to be used for burrowing (Figure 6). There are exceptions however. *Afromera siamensis* McCAFFERTY & EDMUNDS 1973 (Ephemeridae) from Thailand and *Afromera evae* McCAFFERTY & GILLIES 1979 from The Gambia have severely atrophied tusks which, while present, are barely noticeable. *Ephemera (Aethephemera) nadinae* McCAFFERTY & EDMUNDS 1973 from South India has a reduced right hand tusk. These tusks are of relevance in taxonomic studies, particularly in identifying nymphs to family level; in members of the Polymitarcyidae the apices of the tusks curve downwards and towards each other, but in the Ephemeridae, the apices curve upwards and away from each other (Figure 6).

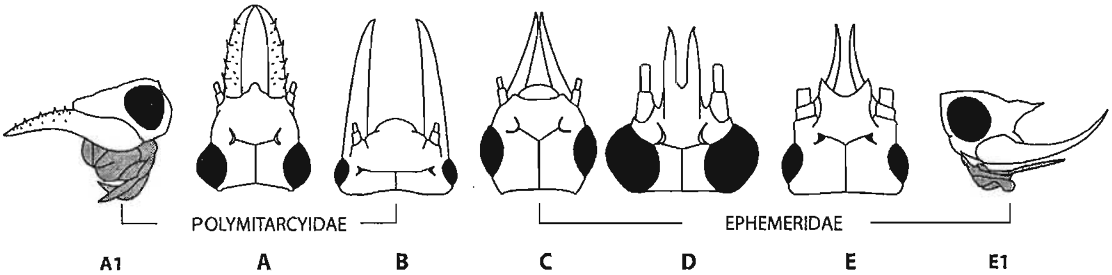


FIGURE 6: A to E; Stylised dorsal views of heads of the nymphs of the five genera of Ephemeroidea found in rivers in KwaZulu-Natal indicating the difference in head, frontal process and mandibular tusk morphology between the families and between the genera. The apices of the tusks of Polymitarcyidae curve downwards and towards each other, but upwards and away from each other in the Ephemeridae. Note that the mandibular tusks of *Afromera* sp. (D) are not visible in this view — looking down onto the dorsal surface of the head. In each case the antennae have been truncated for clarity. The genera illustrated are **A**; *Ephoron* sp., **B**; *Afroplocia* sp., **C**; *Eatonica* sp., **D**; *Afromera* sp. and **E**; *Ephemera* sp. Figures **A1** and **E1** present lateral views of *Ephoron* sp. and *Ephemera* sp. respectively to illustrate the differences between Polymitarcyidae and Ephemeridae when viewed from the side. The illustrations are not drawn to scale. Illustrations **A**, **B**, **D** and **E** are adapted from BAE & MCCAFFERTY (1995), **C** adapted from DEMOULIN (1968), **A1** and **E1** adapted from EDMUNDS (1978).

1.4.2. Adults

As adults, the different species of Ephemeroidea are morphologically quite similar. All of the South African Ephemeroidea are relatively large-bodied; all those recorded from KwaZulu-Natal are greater than 13 mm in length. One other common feature is that the veins M_2 and Cu_1 arch away from vein M_1 at their bases (Figure 7). The only other large-bodied Ephemeroptera commonly encountered in South Africa are the Oligoneuriidae and these are easily recognised as their wings have only 4 to 7 longitudinal veins (BARNARD 1932).

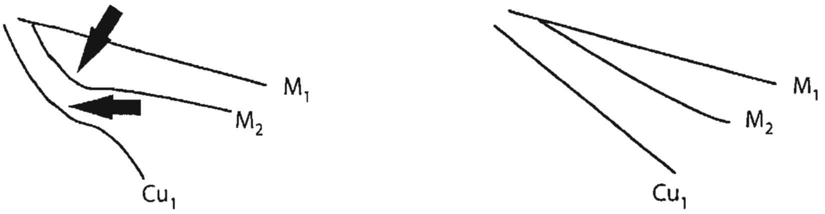


FIGURE 7: The characteristic wing-branching pattern found in members of the Ephemeroidea. In the Ephemeroidea (left-hand diagram) veins M$_2$ and Cu$_1$ arch away from vein M$_1$ at their bases as indicated by the arrows. This pattern does not occur in other taxa (right-hand diagram).

1.4.3. Species recorded from South Africa

Six species of Ephemeroidea are known from South Africa (Table 1), and five of these have been recorded from the rivers of KwaZulu-Natal. There are no records for *Povilla adusta* from KwaZulu-Natal rivers; *Povilla adusta* has however been recorded from two of the coastal lakes of KwaZulu-Natal; Lake Sibaya (Allanson, Bruton & Hart 1974 and Bhangazi South (Hart & Appleton 1997).

TABLE 1: The six species of burrowing mayfly recorded from South Africa to March 2000 and the authority of the adult stage of each species.

Family	**Species**	**Author**
Ephemeridae	*Afromera natalensis*	(Barnard 1932)
Ephemeridae	*Eatonica schoutedeni*	(Navas 1911)
Ephemeridae	*Ephemera mooiana*	McCafferty 1971
Polymitarcyidae	*Afroplocia sampsoni*	(Barnard 1937)
Polymitarcyidae	*Ephoron savignyi*	(Pictet 1843)
Polymitarcyidae	*Povilla adusta*	Navas 1911

2 THE BURROWING MAYFLIES OF KWAZULU–NATAL;

A SYNOPSIS AND ASSESSMENT OF 19TH & 20TH CENTURY RECORDS AND RESEARCH

2.1 INTRODUCTION

Since the first major publication of EATON (1883) detailing specimens of what have since become known as the Ephemeroidea, this relatively small group of insects has been the subject of many revisions in a wide variety of languages, by a great number of entomologists. It is only comparatively recently that greater stability has been introduced with the extensive reclassification of the group in a world-wide palaeontological and phylogenetic context (MCCAFFERTY 1991a; and refer to Appendix 1). From an Afrotropical viewpoint however, little published work has been carried out on this group in the last 20 years.

A major difficulty facing researchers working on this group is the problem with raising juveniles to adults and hence associating the nymph and adult stages, so allowing corresponding descriptions of both life-stages with certainty. To date no such association has been carried out for any of the South African representatives of this superfamily. The primary problem is the long-lived nature of the juveniles — nymphs can live for up to four years in cold climates before emerging as short-lived adults (GIBERSON & ROSENBERG 1994). There is no published data on the juvenile lifespan of Afrotropical taxa, but it is probably two years. It is therefore exceptionally difficult to rear juveniles in captivity.

The intention of this chapter is not to present new descriptions of the Ephemeroidea of KwaZulu-Natal; rather it is to collate and synthesise the existing literature. The chapter provides an introduction to each species based on information available in the literature. This is followed by a description of the principal morphological features of the adult, biology of the species and a listing of published synonyms. The specimens examined during this research are listed and the literature is then discussed in light of the museum investigation. Conclusions are presented in Section 2.11.

The information assembled in this chapter has been used in the preparation of a new key to the Ephemeroidea of KwaZulu-Natal province, presented here in Section 2.12.

2.2 EPHEMEROIDEA RECORDED FROM THE MOOI AND KARKLOOF RIVERS

Of the six species of burrowing mayfly recorded or reported from South Africa (Table 1) all except *Povilla adusta* have been recorded from the Mooi and Karkloof Rivers of KwaZulu-Natal. The section that follows is a systematic re-examination of all 19th and 20th century published literature on these five species (and relevant related species from other geographic areas). Particular attention has been made to compare these publications with each other and re-examine each critically so as to identify possible taxonomic misinterpretations and problems as they occurred and to trace these earlier misunderstandings to our current knowledge of this group. All this information is summarised in the six illustrations at the end of this section (Figure 15 to Figure 20). Figure 15 to Figure 18 show distribution maps of the Ephemeroidea in the Afrotropical region. Figure 19 and Figure 20 summarise the most relevant published findings of the 19th and 20th centuries in the form of flow charts (for the Ephemeridae and Polymitarcyidae respectively).

Classification follows that proposed for recent and fossil Ephemeroidea by McCafferty (1991a); refer to Appendix 1 for a summary of this revised classification.

2.2.1. Investigation of South African Ephemeroidea; methods & materials

Between July 1998 and August 2000 all holdings of Afrotropical Ephemeroidea held by Albany Museum Grahamstown, The University of Natal, Pietermarizburg, The Natural History Museum (London), The Royal Belgian Institute of Natural Sciences (Brussels) and the Museum for Central Africa, Tervuren (Brussels) were examined. The Natural History Museum was revisited in November 2003. It is believed that these museums hold all specimens of African Ephemeroidea housed in public collections in South Africa, Great Britain and Belgium.

In consultation with the curator of each collection, all available catalogues were inspected and all South African Ephemeroidea and related species extracted from the cabinets for inspection. All collections examined were relatively small and it was possible to examine every container in every holding. In order to check for Ephemeroidea that may have been misfiled or misidentified by earlier workers, all containers were inspected and any containing large-bodied Ephemeroptera were put aside for further examination. In this manner a number of previously misidentified Ephemeroidea were traced. Finally a brief inspection was made, where possible, of superficially similar-looking insect orders including Plecoptera. Some misclassified Ephemeroptera were found in this manner, but no Ephemeroidea. At the Museum for Central Africa, Tervuren, it was also possible to inspect the holdings of 'unidentified insects'. Some Ephemeroptera were present, but no Ephemeroidea found.

The exact methods by which specimens were examined varied depending on what facilities were provided by each of the museums visited. In general specimens were inspected under a dissecting microscope and reference made to the relevant literature. Notes and sketches were prepared. In November 2003 it was possible to photograph some specimens at the Natural History Museum.

All South African Ephemeroidea traced during these visits are detailed in this chapter, as well as some relevant related species. Where locality names have changed since the museum specimens were catalogued, or literature on a given species published, the modern locality name is appended, once, in square brackets after the locality (for example: Nyasaland [Malawi]). In all other cases the information has been reproduced here as it appears in the original literature, on the museum catalogue, or on the specimen label. Where such information originally appeared in a language other than English, an attempt has been made to translate such information.

Field sampling was carried out in KwaZulu-Natal province from June 1998 to April 2000. All sites investigated and sampling methods used are detailed in Section 3.3 and 3.4. Specimens were identified using a dissecting microscope and consultation of appropriate keys and literature.

Visualising the wing venation of these insects was found to be difficult, partially due to their slack nature when in liquid, partially as the venation is not particularly pronounced around the edges of the wing. A stain suggested by UPTON (1994) for staining moth wings was found to be useful. Wings were placed in 50% alcohol for a few hours and then stained overnight with a stain composed of 1g of acid fuchsin dissolved in 100 mL of 50% ethanol. Ten grams of chloral hydrate was dissolved (with agitation) in 5 mL of glacial acetic acid and added to the ethanol-fuchsin mixture. Excess stain was rinsed off in a couple of changes of 50% alcohol.

Figure 8 and Figure 9 illustrate wings untreated and treated with Upton's stain. The stain greatly aided the tracing of wing patterns in *Ephoron* sp. In particular the veinlets at the periphery of the wing, which are difficult to see in the majority of unstained specimens, are well stained. The stain was found to be easy to fabricate and stable over the few weeks it was tested. As can be seen, the images reproduce well in black and white and, if necessary, are easily traced with pen and ink.

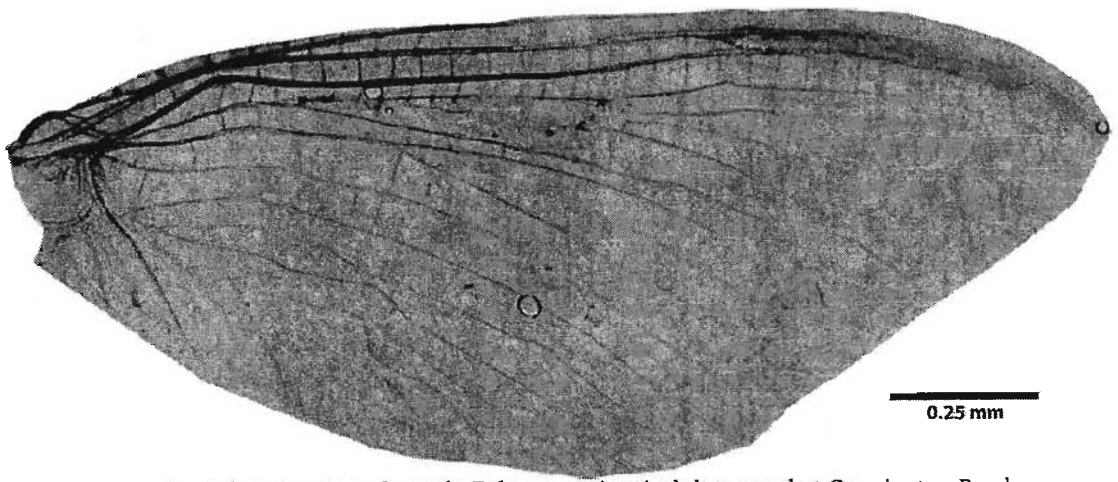


FIGURE 8: The right side wing of a male *Ephoron savignyi* adult trapped at Connington Road Bridge (CRB), KwaZulu-Natal, photographed with a Wild Photomicroscope onto black and white film. The background has been digitally removed. All detail at the wing periphery is lost and few crossveins and veinlets are visible. Some artefacts are visible—the result of bubbles trapped in the mounting medium.

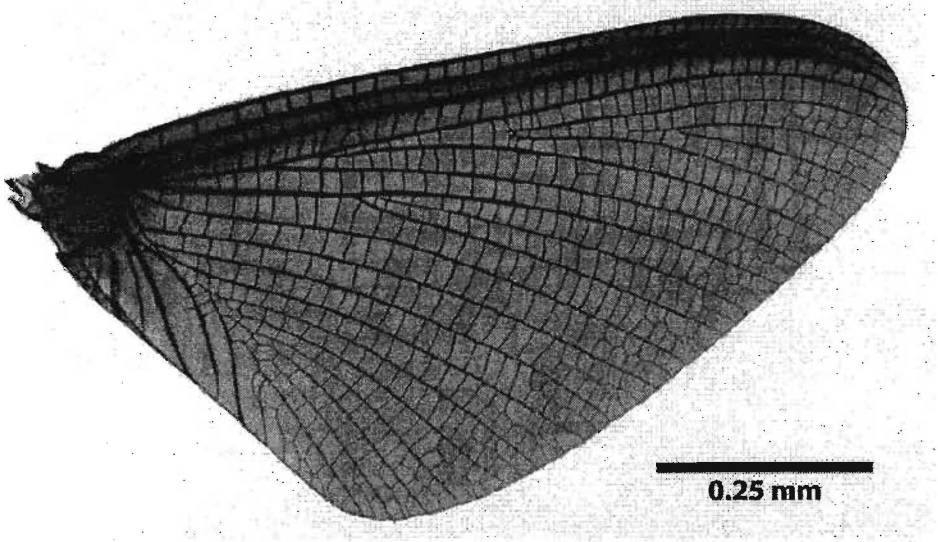


FIGURE 9: The right side wing of a male *Ephoron savignyi* adult trapped at Connington Road Bridge (CRB), KwaZulu-Natal, stained with Upton's stain and photographed under the same conditions as those of Figure 8. The use of Upton's stain greatly aided tracing wing patterns particularly around the periphery of the wing.

For the remainder of this chapter the titles of museums have been abbreviated. The abbreviations used are — AMG, Albany Museum, Grahamstown, South Africa; BMNH, Natural History Museum, London, England; RBI, Royal Belgian Institute of Natural Sciences, Brussels, Belgium; TER, Royal Museum for Central Africa, Tervuren, Belgium. As many of the genera discussed in this chapter begin with the same initial letter (*Eatonica, Ephemera, Ephoron* and *Afromera, Afroplocia* amongst others), genus names have only been abbreviated when necessitated due to lack of space.

All 'material examined' was preserved in alcohol or formaldehyde except where noted in the text.

2.3 GENERAL MORPHOLOGICAL FEATURES OF ADULT EPHEMERIDAE

In the Ephemeridae the first Anal (1st A) vein is simple (unforked) and attached to the hind margin of the wing by two or more veinlets. Wings may be patterned. Two or three cerci are present. The second and third legs are well developed (as compared with members of the Polymitarcyidae). The forceps of the male are three or four-jointed.

2.4 FAMILY: EPHEMERIDAE—SUBFAMILY: HEXAGENIINAE; *EATONICA SCHOUTEDENI* (NAVAS 1911);

***EATONICA SCHOUTEDENI;* PRIMARY LITERATURE AND MUSEUM HOLDINGS:**	
Adult description	NAVAS 1911a.
Nymph description	DEMOULIN 1968.
Type material	According to ALBA-TERCEDOR & PETERS (1985); housed at Museo de Zoologia del Ayuntamiento, Barcelona, Spain: one female adult (labelled as a *Ephemera schoutedeni* 'cotypus'), Belgian Congo, Kasai, 25 July 1906.

2.4.1. *Eatonica schoutedeni;* published synonyms and literature

Because of the large amount of literature published on this species the citation list below only includes those references deemed most relevant to this work; for a more complete list of citations refer to DEMOULIN (1970) and ELOUARD (1986a).

Ephemera Schoutedeni [sic] Navas 1911a; 1911b.

Hexagenia illustris Lestage 1931.

Hexagenia fulva Esben-Petersen 1913; Lestage 1931.

Eatonica schoutedeni Navas 1913 [cited in Alba-Tercedor & Peters 1985]; Lestage 1931; Barnard 1932, 1940; Demoulin 1968 (nymph).

Ephemera nimia Navás 1915.

Pentagenia schoutedeni Ulmer 1916.

Hexagenia retuculata [sic.] Navas 1929 [cited in Demoulin 1970].

Eatonica illustris Kimmins 1960 [cited in Demoulin 1970].

2.4.2. *Eatonica schoutedeni*; diagnosis

According to Demoulin (1970), the size of this species varies greatly throughout Africa — he mentions that specimens can have forewing lengths from 15 to 33 mm. Once male and female specimens are identified as Ephemeridae (see Section 2.3) they can be distinguished as *Eatonica* sp. using the sets of features listed in Table 2.

TABLE 2: Key features of adult specimens of *Eatonica schoutedeni* (adapted from Barnard 1932, McCafferty & Gillies 1979)

Male	Female
In hindwing, vein M_1 attached to vein M_2 basally but free from Cu_1	
foreleg $^{2}/_{3}$ to $^{3}/_{4}$ as long as body	
tarsus $1^{2}/_{3}$ as long as tibia	tarsus shorter than or equal in length to tibia
forceps 3-jointed, penis bilobed	
	prothorax longer than broad
2 cerci (median cercus is rudimentary)	3 cerci—mid cercus is more slender and shorter than the others

2.4.3. *Eatonica schoutedeni*; material examined

1 nymph, Chad, Lake Chad, Îlots Bancs, 16 Mar. 1965, C. Dejoux (RBI); 4 nymphs, Chad, L. Chad, Bol. 3 Jul. 1967, C. Dejoux (RBI); 1 nymph, Chad, Mani, banks of the Chari, 12 Jun. 1965, C. Dejoux (RBI); 2 nymphs, Chad, Mani, Chari, 10 Sep. 1965, C. Dejoux (RBI); 1 nymph, Chad, Mani, Chari, 10 Sep. 1965, C. Dejoux (RBI); 66 female

adults, 1 male adult, Ethiopia, Ghibe R., 215 km from Addis, 13 to 14 May 1961 (at light), A. Tjonnenland (BMNH); 2 female adults, Ethiopia, Gojeb River, 10 Apr. 1961, G. Hodera (BMNH); 1 nymph, [Democratic Republic of the Congo], River Zizi, Bilomba, 24 May 1950, G. Marlier (RBI); 1 nymph, [Democratic Republic of the Congo?] Eiv Suhoho [sic], 1950, G. Marlier (RBI); 13 male adults, Guinea, Niandau Bambuya, 25 Oct. 1984, labelled *Eatonica* sp., no collector information (BMNH); 6 female adults, Guinea/Ivory Coast border, Fere Dougouba 13 Jul. 1979, P. Reiter (BMNH); 1 female adult, Belgian Congo [Democratic Republic of the Congo], Tahopo-Lindi watershed, NE Stanleyville [Kisangani], Apr. 1921, T.A. Barns (pinned specimen) (BMNH); 2 female adults, Belgian Congo, Ituri Forest, 3800 ft., 08 Apr. 1930, no collector information (pinned specimens) (BMNH); 1 female adult, Belgian Congo, Elisabethville [Lubumbashi], 22/27 Nov. 1939, C Seydel (pinned specimens) (BMNH); 1 female adult, Belgian Congo, Elisabethville, 16 Dec. 1939, C Seydel (pinned specimen) (BMNH); 1 female adult, Belgian Congo, Elisabethville, 22 Dec. 1939, C Seydel (pinned specimen) (BMNH); 7 female adults, Uganda, Masaka, Kiwala Hotel, 31 Aug. 1954, P.S. Corbet, EAFRO Collection (BMNH); 26 female adults, 1 male adult, Uganda, L. Victoria, Old Bukakawa, 12 to 13 Jul. 1950, R. Hartland-Rowe (BMNH); 1 male adult, Uganda, L. Victoria, Old Butakata, 13 Dec. 50, R.H.L. [R. Hartland-Rowe] (BMNH); 10 female adults, Uganda, L. Victoria, Kagera Bay, 12 May 1954, N.E. Hickin (BMNH); 1 male subimago, Tanzania, Njombe, 27 Mar. 1963, labelled *Eatonica* sp., no collector information (BMNH); 32 female adults, Nyasaland [Malawi], L. Nyasa [Lake Malawi], Chipoka II. Jan., Aug. & Dec. 1946, R. Hartland-Rowe (BMNH); 2 female adults, Nyasaland, L. Nyasa Chipoka, 6 Aug. 1952, L. Berner (BMNH); 4 male adults, Nyasaland, Ntundu, 9 Aug. 1952, L. Berner (BMNH); 1 female adult, South Africa, Pretoria, Transvaal, 30 Mar. 1907, no collector information (pinned specimen) (BMNH); 1 female adult, South Africa, Bloksberg, Johannesburg, 1907, C.H. Pead (pinned specimen) (BMNH).

2.4.4. *Eatonica schoutedeni;* taxonomic discussion

NAVAS (1911a) first described the adult of *Eatonica schoutedeni*. The nymph was described by DEMOULIN (1968) — this replaced a previous nymph which had been classified as *Eatonica schoutedeni* by CRASS (1947). Crass' nymph was later reclassified by MCCAFFERTY (1971) as *Ephemera mooiana* (see Section 2.5).

A second continental African species of *Eatonica*, *Eatonica crassi*, was described by MCCAFFERTY (1971). This is known only from the adult stage. In this case the specimens were from Sudan, Tanzania [cited as Tanganyika] and Malawi [cited as Nyasaland]. The two species can be distinguished from one another on the basis of male genitalia and abdominal tergite patterns (See Figure 10). *Eatonica crassi* has a distinctive W-shaped pattern on abdominal tergites eight and nine. *Eatonica schoutedeni* has sharp lateral projections at the apices of the penes (MCCAFFERTY 1971, ELOUARD 1986a).

Two more species of *Eatonica* are described from the Afrotropical Region. *Eatonica josettae* was described from Madagascar by DEMOULIN (1969) and is thought to be endemic to that island (ELOUARD 1986a). *Eatonica patriciae* (ELOUARD 1986a) is described from West Africa. The females of this species have similar abdominal tergite patterns to *Eatonica crassi*, but are easily distinguished from that species by their noticeably greater length and the fact that the males have a unique body pattern. ELOUARD (1986a) found sympatric populations of *Eatonica crassi* and *Eatonica patriciae* in rivers in Guinea.

TABLE 3: Summary of important information relating to continental Afrotropical species of *Eatonica*.

	E. schoutedeni	***E. crassi***	***E. patriciae***
Authority	Navas (1911a)	McCafferty 1971	Elouard 1986
Distribution	Central & southern Africa (Demoulin 1970)	Malawi & Tanzania, Guinea (McCafferty 1971, Elouard 1986a)	West Africa (Elouard 1986a)
Important morphological features of the male	'Parallel' lines on tergites 8 and 9, short lateral projections at apices of penes (see Figure 10)	W-shaped pattern on tergites 8 and 9	Body pattern described by Elouard (1986a)
Important morphological features of the female	'Parallel' lines on tergites 8 and 9	W-shaped pattern on tergites 8 and 9	Body pattern as *E. crassi*, but body greater in length

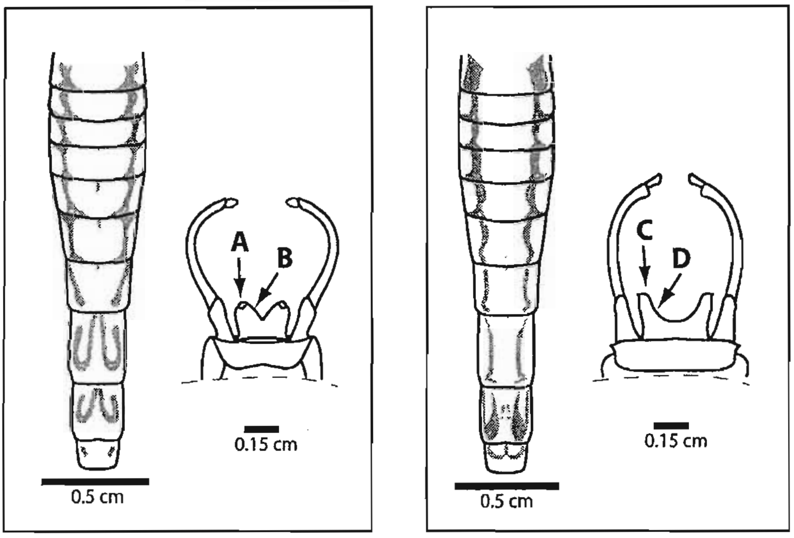


FIGURE 10: The abdominal tergite pattern and male genitalia of two species of *Eatonica*; *E. crassi* (left) and *E. schoutedeni* (right). The most apparent difference between these two species is the W-shaped markings on the eighth and ninth abdominal tergites of *E. crassi*. These species do not exhibit any obvious differences in the tergite patterns between males and females. Differences are also evident in the male genitalia. The penes of *E. schoutedeni* bear a sharp lateral projection at each apex (C) that are absent in *E. crassi* (A). The penes of *E. crassi* are separated by a V-shaped notch (B); those of *E. schoutedeni* a wide U-shaped notch (D). *E. crassi* adapted from McCafferty (1971) and Ulmer (1916), *E. schoutedeni* adapted from McCafferty (1971). Scales shown here are approximate.

While this species is abundant in museum collections, its taxonomy and biology are poorly-documented. Considering the abundance of adults in museum collections it is surprising that so few nymphs are available in collections. Nothing has ever been published about the biology of the nymphs of *Eatonica* sp.

The nymphs in the RBI collection are only identified to the level of genus. The body markings are badly faded in most cases, but in the case of one of the Chad specimens a trace of the pattern indicated by McCAFFERTY (1971) for *Eatonica crassi* is visible (illustrated here in Figure 10). ELOUARD (1986a) notes that the body pattern of *Eatonica crassi* is similar to that for female *Eatonica patriciae*. However in the case of this nymph from Chad, forceps are visible underneath the nymphal skin, indicating that this nymph is male. It is likely, therefore, that this is a specimen of *Eatonica crassi*. This is an indication that *Eatonica crassi* may be more widespread than was at first thought. If McCAFFERTY (1971) is correct in his assertion that the body pattern of *Eatonica crassi* differs from *Eatonica schoutedeni* in the W-shaped markings on the eighth and ninth tergites (Figure 10), then the majority of the adults in the BMNH are in fact be *Eatonica crassi* rather than *Eatonica schoutedeni*. Of the 178 specimens examined in that collection, only five clearly exhibit the body pattern of *Eatonica schoutedeni*, (i.e. without W-shaped markings on the abdomen; one of these specimens is reproduced here in Figure 11, C). The other 173 specimens either clearly had *Eatonica crassi*-like body markings (Figure 11, D), or markings which, due to damage, were difficult to judge, but bore a closer resemblance to *Eatonica crassi* than to *Eatonica schoutedeni*. As noted by McCAFFERTY (1971), those with the W-shaped body pattern had penes separated by a V-shaped notch — in the case of some individuals deeper than that figured by McCAFFERTY (1971; page 59 fig 1C; adapted here as Figure 10, [B]). The body pattern figured by ULMER (1916) for *Eatonica schoutedeni* strongly resembles that of *Eatonica crassi* as figured by McCAFFERTY

(1971) —showing a W-shaped pattern on the eighth and ninth tergites — it appears likely therefore that some specimens identified by Ulmer as *Eatonica schoutedeni* may in fact be *Eatonica crassi.*

Only two specimens from the Republic of South Africa were catalogued (or found in the collections) in any of the museums visited. Both specimens, from Gauteng are in the BMNH collection and in poor condition. The better-preserved specimen is shown in Figure 11 (B). Both specimens are in such a poor state of preservation that it was not possible to determine if the specimen had markings of *Eatonica schoutedeni* or *Eatonica crassi.* The second specimen (not shown here) has had the abdomen glued back on and the pattern is destroyed.

ALBA-TERCEDOR & PETERS (1985) list a 'cotypus' for *Eatonica schoutedeni* in the Museo de Zoologia del Ayuntamiento in Barcelona. This is not wholly compatible with NAVAS' (1911a) type description. In his description, Navas refers to a female adult taken at Lukombe (probably in the Democratic Republic of the Congo).

It would seem that many of the citations referring to *Eatonica schoutedeni* in South Africa actually refer to CRASS' 1947 record for the nymph now known as *Ephemera mooiana.* The only records that it has so far been impossible to confirm or deny are those of BARNARD (1932, page 210) listed as Zululand; Durban; S. Rhodesia [Zimbabwe]; Sabi, Transvaal; Pietermaritzburg (it is uncertain whether the record listed in BARNARD 1940 [p. 619] — Nelspruit, Transvaal [November], H.K. Munro — refers to the 1932 record or is a new record). These specimens are not catalogued in any of the museums investigated and have not been located.

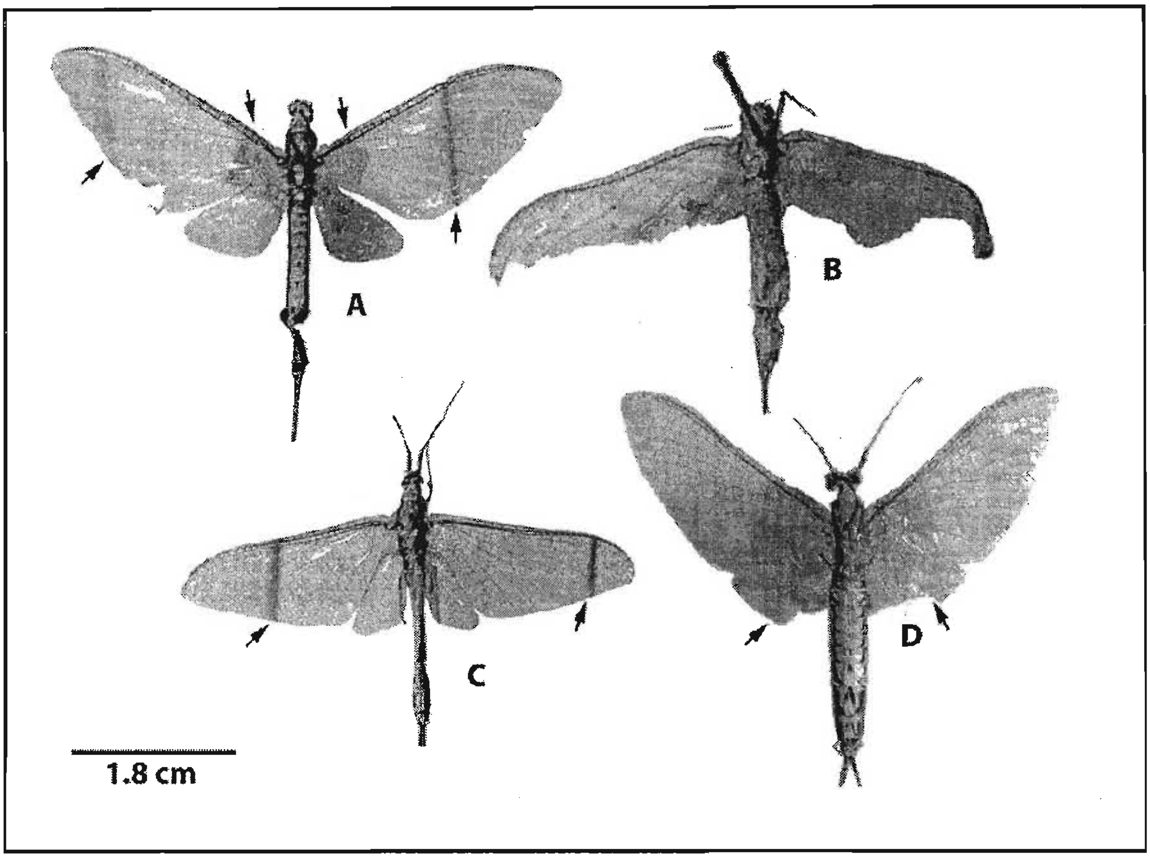


FIGURE 11: Pinned specimens of *Eatonica* sp. from the BMNH. Specimens are; **A** *Eatonica* sp. (female) from Tahopo-Lindi watershed, Belgian Congo 1921; **B** *Eatonica* sp. (female) from Johannesburg, South Africa 1907; **C** *Eatonica schoutedeni* (female) from Stanleyville, Belgian Congo 1939; **D** *Eatonica crassi* (male) from Ghibe R., Ethiopia 1961. The pattern of abdominal tergite 8 is of fundamental importance in identifying specimens of *Eatonica* sp. The tergite pattern of specimen **A** is damaged. The pattern of specimen **B** has faded and is not traceable with a dissecting microscope. Segment 8 is clearly visible on specimens **C** and **D**. Specimen **C** displays the characteristic abdominal pattern of *E. schoutedeni*. Specimen **D** displays the W-shaped pattern exhibited by males and females of *E. crassi*. Arrows indicate artefacts in the photographs—the wings of all these specimens are unpatterned. Photographs taken November 2003 and reproduced here with permission of the curator of the collection.

2.4.5. *Eatonica schoutedeni;* biology

Little is known of the biology of this species or genus other than the fact that the nymphs are presumed to burrow in aquatic substrates. It is distributed through Togo, Ethiopia and Cameroon (DEMOULIN 1970). A distribution map of *Eatonica* sp. in Africa is illustrated in Figure 16.

2.5 FAMILY: EPHEMERIDAE—SUBFAMILY: EPHEMERINAE; *EPHEMERA MOOIANA* MCCAFFERTY 1971

As discussed in Section 2.4.4, the nymph originally described by CRASS (1947) as that of *Eatonica schoutedeni* has since then been tentatively redescribed as the nymph of *Ephemera mooiana* (MCCAFFERTY 1971). For the remainder of this document all references by CRASS (1947) to *Eatonica schoutedeni* are therefore accepted to refer to *Ephemera mooiana*.

PRIMARY LITERATURE AND MUSEUM HOLDINGS:

Adult description	MCCAFFERTY 1971.
Nymph description	CRASS 1947 (labelled as *Eatonica schoutedeni*).
Type material	Male holotype; Mooi River, South Africa; South African Museum, Cape Town, South Africa (currently on loan to AMG).

2.5.1. *Ephemera mooiana;* published synonyms and literature

Eatonica schoutedeni CRASS 1947; 1955.

Ephemera mooiana MCCAFFERTY 1971; MCCAFFERTY & GILLIES 1979.

Afromera natalensis DEMOULIN 1968.

2.5.2. *Ephemera mooiana;* diagnosis

Ephemera mooiana is the only member of the genus *Ephemera* recorded from the continent of Africa. However it is closely related to and bears strong morphological resemblance to members of the genus *Afromera* (MCCAFFERTY & GILLIES 1979). Due to this, care is required in its identification. Once a specimen is identified as one of the Ephemeridae (see Section 2.3) the most important genus-level morphological features to check are in the forewing. In the forewing of *Ephemera* sp., vein M_2 is attached to

Cu_1 as shown in Figure 12; in *Afromera* M_2 is attached to M_1 (see Section 2.6 for a full discussion of *Afromera natalensis*).

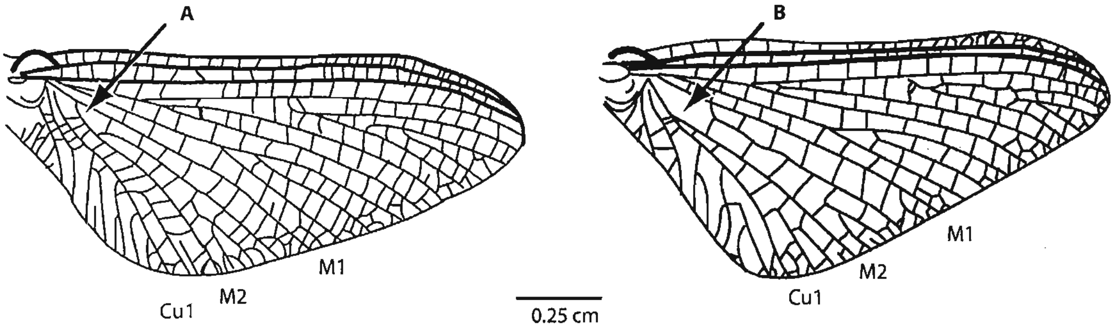


FIGURE 12: The forewings of *Afromera* sp. (left) and *Ephemera* sp. (right). In members of *Afromera*, vein M_2 is attached to M_1 as indicated by arrow 'A'. In *Ephemera* sp. vein M_2 is attached to Cu_1, as indicated by arrow 'B'. *Ephemera* sp. illustration is adapted from McCAFFERTY & GILLIES (1979). *Afromera* sp. illustration is adapted from McCAFFERTY & EDMUNDS (1973). Scale indicated is approximate.

2.5.3. *Ephemera mooiana;* type material examined,

1 adult, South Africa, male holotype, Natal, Mooi River, Sect. 45; R.S. Crass (AMG).

2.5.4. *Ephemera mooiana;* other material examined

1 nymph, Guinea, (Catalogue number 18), small stream on road to Mamou from Dalaba, 21 Jan. 1957, Mission Bertrand (RBI); 1 nymph, Guinea, (Catalogue number 24), waterfall on the Téné, near to the IFAC station, 27 Jan. 1957 Mission Bertrand (RBI); 4 nymphs, Guinea, Téné at Diaguissa (Catalogue number 23), 24/26 Jan. 1957, Mission Bertrand (RBI); 1 nymph, Guinea (Catalogue number 26), small stream in the Jardin Chevalier, 12 Feb. 1957 Mission Bertrand (RBI); 1 nymph, Guinea, (Catalogue number 82), Ziéla, 20/29 Mar. 1957, Mission Bertrand (RBI); 1 nymph, Guinea (Catalogue number 82b), Niomouya, Mission Bertrand (RBI); 2 nymphs, Guinea (Catalogue number 83b) Gouan 1200 metres, Mission Bertrand, (RBI); 1 nymph, Guinea (Catalogue number 99 OT), stream on the route to Tonkoui [Ivory Coast], 07 Apr. 1957, Mission Bertrand (RBI). 4 nymphs, South Africa, Natal, Mooi River, Sect.

45, R.S. Crass (AMG); 4 nymphs, South Africa, Natal, Mooi River, [R.S. Crass?] (BMNH);

2.5.5. *Ephemera mooiana;* taxonomic discussion

LESTAGE (1931) considered that there was only one species of ephemerid mayfly on the continent of Africa, *Eatonica schoutedeni*, and he synonymised six species (*Eatonica schoutedeni* Navas, *Hexagenia illustris* Eaton, *Hexagenia fulva* Esben-Petersen, *Ephemera nimia* Navas, *Pentagenia schoutedeni* Navas and *Hexagenia reticulata* Navas) with *Eatonica schoutedeni*.

DEMOULIN (1968) reported that the nymph ascribed to *Eatonica schoutedeni* by CRASS 1947 (as illustrated in CRASS [1947], page 51) was '*Afromera*, without doubt, *Afromera natalensis*...', so contradicting Crass' assertion that he bred nymphs prior to 1947 to adulthood and they corresponded with the adults of *Eatonica schoutedeni*. There is no evidence that Demoulin examined Crass' specimens. Demoulin did not publish any formal reclassification of Crass' material.

The adult and nymphal material lodged by Crass in the South African Museum, Cape Town, were re-examined by MCCAFFERTY (1971). The male imago was described as a new species, *Ephemera mooiana*, and, as the nymphs came from the same general area as this adult, they were associated with it and are assumed to be the nymphs of it.

In June 2000, on my suggestion, four nymphs labelled as *Eatonica schoutedeni* in the BMNH collection were relabelled as *Ephemera mooiana*. The four nymphs — two mature nymphs and two early instar nymphs — had been lodged as nymphs of *Eatonica schoutedeni*. This reclassification is justified as they do not match the currently recognised published description of *Eatonica schoutedeni* (DEMOULIN 1968), but do match CRASS' (1947) drawing and MCCAFFERTY'S (1971) description of

Ephemera mooiana, and have similar collection data (Mooi River, Natal 1946). Similar nymphs have been found in the RBI collection

When Crass found *Ephemera*-like nymphs in KwaZulu-Natal in the 1940s his choice of described ephemerid species was limited to *Eatonica schoutedeni* (which despite the fact that it was supposedly found throughout Africa and of impressive size had never been assigned a nymph) and *Ephemera natalensis* (now *Afromera natalensis*; see Section 2.6). BARNARD 1932 had described *Ephemera natalensis* from the Pietermaritzburg region and a forewing and male genitalia were figured (alongside figures of the fore and hind wing of *Eatonica schoutedeni* from Zululand). It is notable that BARNARD (1932) stated

> 'The nymph [of *Eatonica schoutedeni*] is unknown, but may be expected to resemble that of *Ephemera*...'.

CRASS (1947) succeeded in keeping the *Ephemera*-like nymphs he found in captivity and managed to rear a number of them to adulthood. It may be that the similarity in the body pattern between the adults he raised and that of *Eatonica schoutedeni* (see Figure 13), plus the large size of the nymphs (*Ephemera mooiana* nymphs are up to 29 mm, *Eatonica schoutedeni* adults up to 33 mm and *Afromera natalensis* adults up to 15 mm) led Crass to propose them as the nymphs of *Eatonica schoutedeni*, rather than nymphs of *Afromera natalensis* or of a new, undescribed species.

DEMOULIN'S (1968) description of the nymph of *Eatonica schoutedeni* meant that the taxonomic status of CRASS' (1947) nymphs needed to be reassessed. Inspection of adults that Crass had apparently lodged at the same time as these nymphs and labelled as *Eatonica schoutedeni* revealed a hitherto unknown species of *Ephemera* sp., *Ephemera mooiana* (MCCAFFERTY 1971) (unlike *Eatonica* sp. these specimens had 4-segmented forceps; see Figure 10 and Figure 13 for illustrations of *Eatonica* sp. and *Ephemera* sp. genitalia respectively). As these nymphs were found to be morphologically similar to other *Ephemera* sp. nymphs (and they were lodged at the same time as the *Ephemera mooiana* adults) they were designated as the nymphs of the new species.

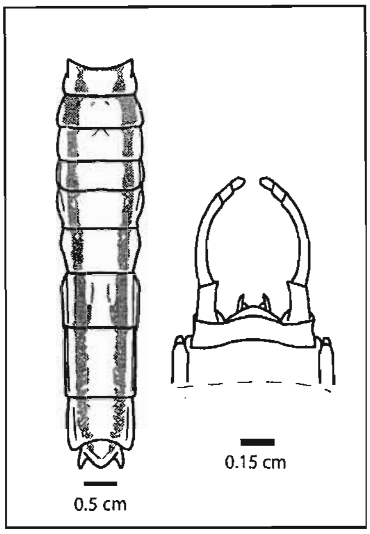


FIGURE 13: The abdominal tergite pattern and male genitalia of *Ephemera mooiana*. Note that the abdominal tergite pattern is superficially similar to *Eatonica schoutedeni* (see Figure 10), but the forceps are 4-segmented, rather than 3-segmented as found in *Eatonica* sp. Adapted from McCafferty 1971. Scales indicated are approximate.

The discovery that these specimens were, in fact a species of *Ephemera*, led to quite a degree of interest in the taxon, primarily as it was the only known species of this genus on the continent of Africa and that it had such an apparently narrow range. However extensive sampling by a number of workers (including Crass himself as recently as 1996) between 1960 and 2000 failed to turn up a single nymph or adult of the species.

There was speculation regarding why this genus had such an apparently narrow range in Africa, especially when contrasted with the seemingly closely-related genus *Afromera*. It has been suggested (MCCAFFERTY & GILLIES 1979) that *Ephemera* sp. are cool-water forms that burrow in substrates which contain a proportion of sand whereas *Afromera* sp. are adapted to perennially warmer waters with a preference for burrowing in silty substrates. If this were proven to be the case it would explain the absence of *Ephemera* sp. from further north in Africa. It would also go some way to confirming that these are indeed two separate genera and not a consequence of over enthusiastic genus splitting by taxonomists. This hypothesis is not necessarily disproved by the apparent overlap of these two species on the Mooi River, South Africa. There is a sharp drop in altitude downstream of the town of Mooi River. It is possible that the waters downstream of the town of Mooi River are, due to the lower altitude, sufficiently warm enough to harbour a population of *Afromera natalensis.* Upstream of Mooi River town may be of a high enough altitude to allow cold-loving *Ephemera mooiana* populations (see section on *Afromera natalensis* below for further discussion on the topic).

In July 2000 a number of previously unrecorded specimens were uncovered in RBI. These included a number of nymphs labelled '*Afromera* sp.'. DEMOULIN 1968 maintained that the nymphs described by CRASS (1947) were those of *Afromera* — this is perhaps a surprising assertion as the adults of *Afromera natalensis* reach a maximum length of about 15 mm (DEMOULIN 1955) whereas Crass' nymphs and those labelled by Demoulin as *Afromera* sp. were substantially longer, up to 30 mm. It is not unreasonable to assume that Demoulin labelled these specimens in the RBI himself and proposed them to be representatives of the same species figured by CRASS (1947). The staff in RBI suggested that Demoulin was the last person to work extensively on this collection, so it is unlikely that anybody else would have labelled these specimens. These specimens are similar to those figured by CRASS (1947) (with selected features figured in MCCAFFERTY [1971]). These specimens were taken in Guinea, in the region of the Fouta Djallon plateau according to the catalogue. As a tropical country, Guinea would not be expected to have an endemic *Ephemera* sp. population — current evidence suggests that tropical waters would be too warm for *Ephemera* sp. to tolerate (MCCAFFERTY & GILLIES 1979). One possible explanation is that these nymphs were restricted to a cold-water streams in Guinea. While the coastal capital city Conakry has an annual temperature range between 22°C in winter and a maximum of over 30°C (PEARCE & SMITH, 1993) and much of the rest of the country is subjected to even higher temperatures, parts of the inland plateau are regarded as temperate (BEN YAHMED 2000).

The existence of the Guinean nymphs leads to one of two possible conclusions. First that there are two individual populations of *Ephemera* sp. in Africa, one, an as yet undescribed species in Guinea and another, *Ephemera mooiana* in South Africa. Second that *Ephemera* sp. are found throughout Africa, at least from KwaZulu-Natal to Guinea in cooler regions and highland plateaux.

The second proposal is the more credible. The scarcity of specimens of ephemerid nymphs from outside the Republic of South Africa (particularly nymphs of *Eatonica schoutedeni* — as adults of *Eatonica schoutedeni* are said to be abundant in this region, it would be expected that more museum specimens would be available if sampling had been carried out) would suggest little collecting has been done in that region. It may be that if any adults of *Ephemera mooiana* (or any other *Ephemera* sp.) have been found that they have been misidentified as *Eatonica* sp. or *Afromera* sp. This would not be surprising as there has been little work on the Ephemeroidea of central Africa since 1965, six years before MCCAFFERTY'S (1971) publication on *Ephemera mooiana*.

2.5.6. *Ephemera mooiana;* biology

CRASS stated (1955 & pers. comm. 1998) that the nymphs of *Ephemera mooiana* were fairly abundant in a 'certain type of clayey substrate' on the Karkloof and Mooi Rivers. Of particular note was the fact that they constructed a rather distinctive burrow — one that he described as having a turret around the openings. He also remarked that the burrows were frequently found at the base of clay riverbanks where *Cyperus* sp. grew. *Ephemera mooiana* is only recorded from the Mooi River at

S 29°21′43.0′′, E 30°16′38.2′′ and the Karkloof River at S 29°23′27.8′′, E 29°52′28.8′′ (both KwaZulu-Natal, Republic of South Africa).

According to CRASS (1947) *Ephemera mooiana* nymphs live for some time (unspecified) in captivity, 'even in jars'. Subimagoes 'apparently' hatch during the day and the adults swarm at dusk.

CRASS (1955) observed adults rising from rivers from 10 am until nearly sunset, transformation from subimago to imago taking from 22 to 48 hours (no dates given for these observations). He notes that in October nymphs had not begun to emerge, whereas by February many had emerged.

The nymph reaches a maximum length of 28 mm (CRASS 1955).

2.6 FAMILY: EPHEMERIDAE—SUBFAMILY: EPHEMERINAE; *AFROMERA NATALENSIS* (BARNARD 1932)

PRIMARY LITERATURE AND MUSEUM HOLDINGS:

Adult description	BARNARD 1932 (labelled as *Ephemera natalensis*).
Nymph description	Undescribed.
Type material	No specimens or records in any museum visited; originally described from Pietermaritzburg (BARNARD 1932)

2.6.1. *Afromera natalensis*; published synonyms and literature

Ephemera natalensis BARNARD 1932; LESTAGE 1945.

Ephemera (Ephemera) natalensis MCCAFFERTY & EDMUNDS 1973.

Afromera natalensis DEMOULIN 1955; DEMOULIN 1968; MCCAFFERTY & GILLIES 1979; ELOUARD 1986b.

2.6.2. *Afromera natalensis;* diagnosis

Afromera sp. and *Ephemera* sp. are closely related and morphologically similar. The primary means of distinguishing between the genera is to inspect whether vein M_2 connects to Cu_1 or M_1, as discussed in Section 2.5.2 (also refer to Figure 12). In general *Afromera* sp. are smaller, with a forewing less than 15 mm in length, compared to a forewing greater than 16 mm in length which is generally encountered in *Ephemera* sp. In *Afromera* sp. the bases of the forceps project beyond the median posterior margin of subgenital plate; in *Ephemera* sp. the forceps only project slightly beyond the median posterior margin of the subgenital plate (McCAFFERTY & GILLIES 1979).

2.6.3. *Afromera natalensis;* material examined

1 adult, Uganda, Masaka, Busungwe Bay 12 Apr. 1955, P.S. Corbet (BMNH); 1 adult, Nyasaland [Malawi], L. Nyasa [L. Malawi], Chipoka, Jan., Aug. & Dec. 1946, R.H. Lowe (BMNH); 1 adult, Nyasaland [Malawi], L. Nyasa [L. Malawi], Chipoka, 6 Aug. 1952, L. Berner (BMNH); 5 adults, Nyasaland [Malawi], Ntundu, 10 Aug. 1952, L. Berner (BMNH); 6 adults, Nyasaland [Malawi], Ntundu, 11 Aug. 1952, L. Berner (BMNH); 5 adults, Nyasaland [Malawi], Ntundu, 12 Aug. 1952, L. Berner (BMNH).

2.6.4. *Afromera natalensis;* taxonomic discussion

BARNARD (1932) first described the adults of *Afromera natalensis* as *Ephemera natalensis*. The genus *Afromera* was first erected by DEMOULIN (1955) for an *Ephemera*-like species, *Afromera congolana*. At the same time he placed *Ephemera natalensis* within the new genus.

The nymph of *Afromera natalensis* has not been described. DEMOULIN (1968) asserted that the nymph currently recognised as *Ephemera mooiana* was the nymph of *Afromera natalensis*. However the nymphs of other species of *Afromera* have been described; *Afromera evae* from The Gambia and *Afromera siamensis* McCAFFERTY &

EDMUNDS, 1973 from Thailand. The tusks that are so prominent in *Ephemera* are small to the point of being indiscernible from the dorsal side in *Afromera evae* nymphs. It is maintained by MCCAFFERTY & GILLIES (1979) that *Afromera* most likely derived from an *Ephemera* ancestor.

The genus *Afromera* was briefly dismantled. As part of an extensive review of the genus *Ephemera*, MCCAFFERTY & EDMUNDS (1973) created a number of new subgenera. Among these was a subgenus from South East Asia, *Ephemera (Dicrephemera)*. This subgenus contained only one member at the time, *Ephemera (Dicrephemera) siamensis* from Thailand and was diagnosed largely on the basis of nymphal characters. Like *Ephemera* nymphs, this species had an elongate bifid frontal process, but unlike *Ephemera* sp. nymphs the mandibular tusks were much reduced. The adults (which had been raised from nymphs in the laboratory) were found to be difficult to separate from true *Ephemera* sp. adults. At the same time they synonymised the genus *Afromera* with their new subgenus *Ephemera (Ephemera)* (reverting *Afromera natalensis* back to *Ephemera natalensis* in the process). They felt that this was justified as the characters proposed as diagnostic of the genus *Afromera* by DEMOULIN (1955) — male foreleg tarsi, posterior margin of the subgenital plate and the wing venation — were variable.

However the discovery of a new *Ephemera*-like species from The Gambia prompted MCCAFFERTY & GILLIES (1979) to reconsider the designation of subgenera to the *Ephemera* genus. In this case both adults and nymphs were available and it was found that the adults of the new species, *Afromera evae*, had *Afromera*-like characters, whereas its nymphs had *Ephemera (Dicrephemera)* like characters. They decided that *Ephemera (Dicrephemera)* sp. and *Afromera* sp. were one and the same and so re-established the genus *Afromera* to accommodate all the species. The genus *Ephemera* still contains two subgenera; *Ephemera (Ephemera)*, into which *Ephemera* *mooiana* is classified, and *Ephemera* (*Aethephemera*) which is not recorded from Africa.

The genus *Afromera* was first erected by DEMOULIN (1955) on the basis of an adult male from Elisabethville (now Lubumbashi, Democratic Republic of the Congo). This was the first description of a species of ephemerid mayfly from Africa that took LESTAGE'S comments from 1923, 1931 and 1945 — his assertion that *Eatonica schoutedeni* was the only ephemerid on the continent of Africa — into account in its diagnosis. LESTAGE (1945) had recognised that *Ephemera natalensis* was not a member of the genus *Ephemera*, but also maintained that it was not a member of the genus *Eatonica*. KIMMINS (1956) added the species *Afromera aequatorialis* from Uganda to the genus.

Adults of *Afromera natalensis* have been recorded from the Mooi River most recently by Dr. WP McCafferty (Purdue University, Indiana, pers. comm.) in 1991 and Dr. Ferdy de Moor, (AMG) in 1995 (unpublished data — Albany Museum collection catalogue number MOI55).

2.6.5. *Afromera natalensis;* biology

DEMOULIN (1970) lists the distribution of *Afromera natalensis* as Uganda and Nyasaland [Malawi]. A distribution map of *Afromera* sp. in Africa is illustrated in Figure 18. The biology of the nymph is unknown; *Afromera evae* is the sole species of *Afromera* from Africa for which a nymph has been described (MCCAFFERTY & GILLIES 1979). The description was made from 3 exuviae and a sole nymph caught in drift nets, so the authors made no attempt to describe the biology of the species.

2.7 FAMILY EPHEMERIDAE: THE HABITAT REQUIREMENTS OF AFRICAN EPHEMERINAE

At first, the placement of two species as similar as *Afromera natalensis* and *Ephemera mooiana* is perplexing. Their (adult) morphological similarity is illustrated by the fact that experienced entomologists such as Barnard, Crass, Demoulin, McCafferty and Edmunds all had difficulty in classifying the two species. The discovery of nymphs of *Afromera evae* in the Gambia was the first convincing evidence that the two species did indeed belong to different genera as Demoulin had first suspected. Given the apparent morphological similarity between the species, the differences in habitat preference between the two species could form a basis for their allocation to separate genera.

McCAFFERTY & GILLIES (1979) proposed two factors — that *Afromera* sp. were warm water-loving species which dwelt in silty substrates whereas *Ephemera* sp. preferred cooler waters and coarser, more conglomerated substrates. This proposal made some sense in light of the fact that most species of *Afromera* were found near the Equator. Indeed populations of *Afromera natalensis* were found by KIMMINS (1956) in Lake Malawi, and more recently discovered species such as *Afromera gilliesi* Elouard 1986 and *Afromera troubati* Elouard 1986 have been found in areas closer to the equator in West Africa (ELOUARD 1986b).

No specific reference has been made to the habitat requirements of *Afromera natalensis*. Neither was the potentially puzzling fact that *Afromera natalensis* and *Ephemera mooiana* were found in the same river, the Mooi River in KwaZulu-Natal. However the Mooi River does drop significantly in altitude downstream of the town of Mooi River, and this may allow enough of a climate change for the river to reach an average temperature sufficiently high to support a population of *Afromera natalensis*.

EASTHAM (1939) suggested that the composition of a river substrate may have an important role to play in the suitability of a site to *Ephemera* sp. in Britain. Percival & Whitehead (1926, cited in EASTHAM 1939) found that nymphs of *Ephemera danica* were most commonly found in substrates containing 65% coarse sand, 2%

fine sand and 1 % silt, fine silt and clay. EASTHAM (1939) suggested that this may be because of the sensitivity of the gills of this species. He found that the gills became easily entangled by small amounts of debris and that the nymph combed the gills out with the last pair of legs with great precision. Mainly-sand substrates have also been suggested as the preferred habitats of *Afroplocia sampsoni* (EDMUNDS & MCCAFFERTY 1996).

During extensive fieldwork on the Mooi and Karkloof rivers (and some of their tributaries) during the period June 1998 to April 2000, no representatives of either *Ephemera mooiana* or *Afroplocia sampsoni* were found. If *Ephemera mooiana* nymphs require a large proportion of coarse sand in order to find a suitable burrow site, then the lack of success in finding samples of *Ephemera mooiana* (or *Afroplocia sampsoni*) during this work is not particularly surprising — substrates with a high proportion of sand were only found on two occasions. Both sandy substrates were in the form of sand-bars in mid-river and were almost certainly of a shifting nature and not what would be thought suitable for sustaining a population of a large mayfly.

2.8 GENERAL MORPHOLOGICAL FEATURES OF ADULT POLYMITARCYIDAE

Two features distinguish the Polymitarcyidae from other South African Ephemeroidea. The most obvious feature of members of the Polymitarcyidae is that the wings of the adults are translucent (sometimes described as 'milky' or 'cloudy'). This feature is especially obvious when the wings of specimens are compared to the wings of members of the Ephemeridae, all of which have clear wings (frequently referred to as 'hyaline'). Secondly, at least the middle and hind legs are poorly developed (male *Ephoron savignyi* have long forelegs).

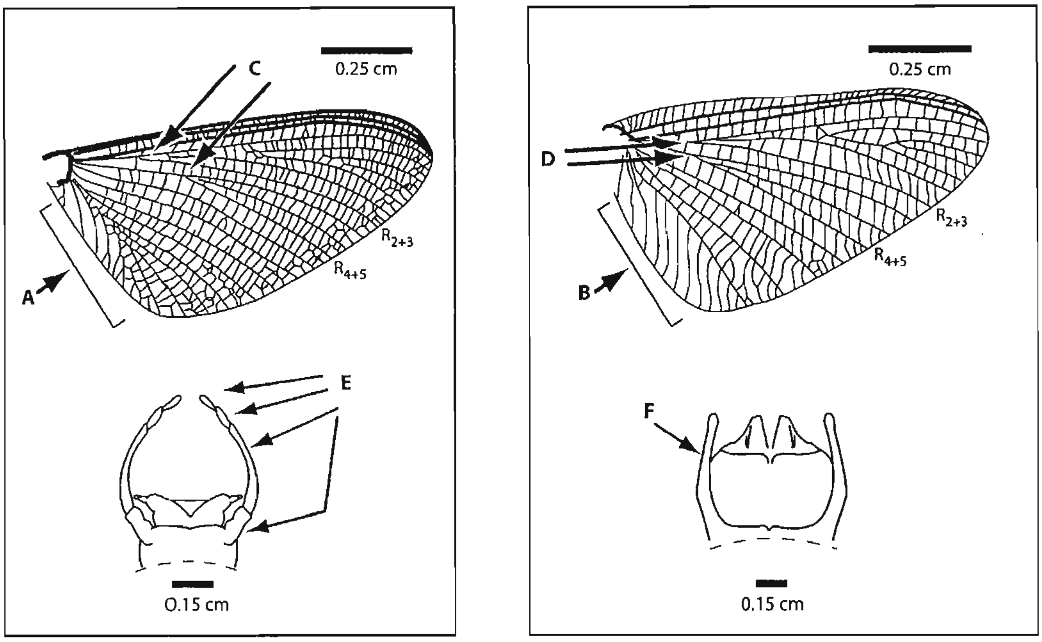


FIGURE 14: Diagnostic characters of the Polymitarcyidae of KwaZulu-Natal—the forewing and genitalia of *Ephoron* sp. (left); the forewing and genitalia of *Afroplocia* sp. (right). In *Afroplocia* sp. the anal area of the forewing has nine parallel cross veins (B); these are absent in *Ephoron* sp. (A). In *Ephoron* sp. the forks of R4 + 5 and R2 + 3 are at approximately the same level in forewing (C); in *Afroplocia* sp. R4 + 5 is distal to the fork of R2 + 3 (D). Male *Ephoron* sp. have 4-jointed genitalia (E); *Afroplocia* sp. have 1-jointed genitalia (F). *Ephoron* sp. wing adapted from Barnard 1932 and *Ephoron* sp. genitals adapted from Needham et al. 1935 *Afroplocia* sp wing and genitals adapted from Gillies (1980). Scales indicated are approximate.

2.9 FAMILY: POLYMITARCYIDAE—SUBFAMILY: EXEUTHYPLOCIINAE; *AFROPLOCIA SAMPSONI* (BARNARD 1937)

PRIMARY LITERATURE AND MUSEUM HOLDINGS:

Adult description	Barnard 1937 (labelled as *Exeuthyplocia sampsoni*).
Nymph description	Barnard 1940 (labelled as *Exeuthyplocia sampsoni*).
Type material	No specimens or records in any museum visited; originally described from the Umzimkulu, Yarrow and Mooi Rivers, KwaZulu-Natal (Barnard 1940).

2.9.1. *Afroplocia sampsoni*; published synonyms and literature

Exeuthyplocia sampsoni Barnard 1937; Barnard 1940; Crass 1947.
Afroplocia sampsoni Lestage 1939; Gillies 1980; Edmunds & McCafferty 1996.

2.9.2. *Afroplocia sampsoni*; diagnosis

Afroplocia sampsoni shares many of the morphological characteristics of the other Polymitarcyidae, in particular members of the genus *Exeuthyplocia*. The main features distinguishing adult Afroplociinae from adult Exeuthyplociinae are presented in Table 4. Body length is 13 to 15 mm.

TABLE 4: Key features used to distinguish *Afroplocia sampsoni* from members of the genus *Exeuthyplocia* (adapted from Barnard 1940 and Gillies 1981).

	Afroplocia sampsoni	***Exeuthyplocia* spp.**
Legs	legs of males and females poorly developed	forelegs of males long; mid and hind legs (and forelegs of females) poorly developed
Cerci	cerci covered in setae in males	cerci without setae in males
	cerci in females long (20 to 25mm)	cerci in females short (5mm approx.)
Wing	approximately 9 sigmoidal parallel veins in anal area of wing	3 to 5 sigmoidal parallel veins in anal area of wing
Body	body length 13 to 15mm	body length 6 to 7 mm
Genitalia	forceps consist of a single joint	
	penes consist of two 'leaf-shaped lobes with a process in between'	penes undescribed

2.9.3. *Afroplocia sampsoni*; material examined

1 adult, South Africa, Hmzimkulu [sic] River, Natal, South Africa, 1911 (BMNH).

2.9.4. *Afroplocia sampsoni*; taxonomic discussion

Barnard (1937) first described the adult of the species as *Exeuthyplocia sampsoni*. Barnard (1940) described the nymph from a nymphal exuvium retrieved from the Umzimkulu River, KwaZulu-Natal.

It is unknown what became of this exuvium and no preserved specimens of the nymphs are on record in the museums visited (although Gillies [1980] mentions having examined the exuvium at the BMNH). A single adult specimen is lodged in the

BMNH from the Hmzimkulu [sic] River, Natal, 1911. The specimen is in a poor condition, undoubtedly due to its age.

LESTAGE (1939) removed this species from the genus *Exeuthyplocia* and erected a new monospecific genus *Afroplocia* within the Polymitarcyidae to accommodate it. DEMOULIN (1952) created the subfamily Euthyplociinae on the basis of adult characters, and Edmunds & Traver (1954, cited in GILLIES 1980) elevated this subfamily to the family Euthyplociidae. However, GILLIES (1980) erected the subfamily Exeuthyplociinae (within the Euthyplociidae) on the basis of nymphal characters for the genera *Exeuthyplocia* and *Afroplocia.* MCCAFFERTY (1991a) later abolished the family Euthyplociidae, instead placing *Exeuthyplocia* and *Afroplocia* within the Polymitarcyidae, where they had originally been placed by LESTAGE (1939) on creation of the genus *Afroplocia* (other euthyplociids such as *Campylocia* and *Proboscidoplocia* were placed in the subfamily Euthyplociinae).

GILLIES (1980) described the nymphs of an *Exeuthyplocia* species (species unspecified, but probably those of *Exeuthyplocia minima* [Ulmer 1916]) from the River Gambia in West Africa. He found that they closely matched the nymph described for *Afroplocia sampsoni* by BARNARD (1940), but differed in the shape of the gill on Abdominal Segment 1 and the structure and length of gills on Abdominal Segments 2 to 7.

According to BARNARD (1937) the adult has similar wing venation to *Ephoron savignyi*, and like *Ephoron savignyi* lays two masses of greenish eggs. However, unlike *Ephoron savignyi* there is no sexual dimorphism exhibited in the forelimbs of the adults.

Whether or not the nymphs of *Afroplocia sampsoni* actually burrow in substrates throughout their life is still a contentious issue. CRASS (1955) states that *Afroplocia* nymphs dig into deposits but do not form a burrow, remaining only partially buried and are found in sand and silt on the bottom of pools. In his surveys which he lists in 1955, CRASS only makes mention of *Afroplocia sampsoni* once, taken in 'additional collecting' on the Mooi River (at station 'M 2', Crass' reference to the stretch of river downstream of the confluence of the Mooi River and the Reekie Lynn stream, a small stream that joins the Mooi River downstream of Kamberg Nature Reserve. Refer to Section 3.3.2.2 for a full description of this sampling site). When Crass refers to 'additional collecting' it is usually in reference to burrowing nymphs that were taken individually rather than in a kick sample. It may also be that he is referring to adults sampled on the wing or nymphal exuviae floating on the surface of the water.

GILLIES (1980) was of the opinion that *Afroplocia sampsoni* and the closely related *Exeuthyplocia minima* from West Africa were burrowing forms, primarily as they both have flattened fore tibia, a feature that is generally (but not exclusively) restricted to burrowing forms. AGNEW (1985) presents *Afroplocia* as a member of the family Euthyplociidae, stating that they are not burrowers but use their tusks for filtering food (AGNEW [1985] asserts that three species of euthyplociid have been recorded from KwaZulu-Natal; he gives no reference for this statement and no other reference to these two extra species has since been found. It may be that he is referring to *Exeuthyplocia minima*, the West African species and various species of *Proboscidoplocia*, a genus large-bodied mayfly [of the subfamily Euthyplociidae] endemic to Madagascar [MCCAFFERTY 1991a, ELOUARD & SARTORI 1997]). EDMUNDS & MCCAFFERTY (1996) state that there have been no observations of burrowing for *Afroplocia sampsoni*.

The most recent revision of the phylogeny of the Ephemeroptera (MCCAFFERTY 1991a) places the subfamily Exeuthyplociinae within the Polymitarcyidae, a family made up entirely of burrowing forms. EDMUNDS & MCCAFFERTY (1996) found two nymphs of *Afroplocia sampsoni* from silt/sand/cobble on the Mooi River. However it was felt that these nymphs may not necessarily have been kicked directly from that substrate, but rather may have been disturbed elsewhere and drifted into the sample, so no assumptions regarding burrowing habits were drawn from that sample (Dr WP McCafferty, Purdue University, Indiana 2000 pers. comm.).

2.9.5. *Afroplocia sampsoni*; biology

CRASS (1955) states that the adults of *Afroplocia sampsoni* emerge just before dusk, transforming from subimago to adult within a few minutes of emergence. Specimens from KwaZulu-Natal have only ever been caught in late October and early November on the Umzimkulu, Yarrow and Mooi Rivers (CRASS 1947, 1955; BARNARD 1937, 1940; DEMOULIN 1970).

Outside of KwaZulu-Natal *Afroplocia sampsoni* specimens have only been found in Marendellas (then, in 1960, Southern Rhodesia, now Zimbabwe). A distribution map of *Afroplocia* sp. and other Exeuthyplociinae in Africa is illustrated in Figure 17.

2.10 FAMILY: POLYMITARCYIDAE—SUBFAMILY: POLYMITARCYINAE; *EPHORON SAVIGNYI* (PICTET 1843)

PRIMARY LITERATURE AND MUSEUM HOLDINGS:

Adult description	Pictet 1843 (First illustration in Eaton 1871 — *Polymitarcys savignyi* from the Nile, Egypt). South African specimens; Eaton 1883, Plate VI; 10b, Barnard 1932 (labelled as *Polymitarcys savignyi*).
Nymph description	Crass 1947 (labelled as *Polymitarcys savignyi*).
Type material	Two females (both labelled 'holotypes') and one male (also labelled 'holotype'), TER (dried specimens). Originally labelled as *Polymitarcys temerata*. Fetish Rock [Angola], 24 Feb. 1911, Burgeon.

2.10.1. *Ephoron savignyi*; published synonyms and literature

Palingenia savignyi Pictet 1843.

Polymitarcys savignyi [sic] Eaton 1871.

Polymitarcys savignyi Eaton 1883; Ulmer 1916; Barnard 1932; Crass 1947 (nymph).

Polymitarcys capensis Esben-Petersen 1913.

Polymitarcys temerata Navas 1915.

Ephoron savignyi Spieth 1940.

2.10.2. *Ephoron savignyi*; diagnosis

The middle and hind legs are poorly developed. In the males the forelimbs are long (the forelegs are poorly developed in the female). Males have two long cerci, females three cerci, which are shorter than those found in the male. The wings have particularly intricate venation with many more cross veins than are found in any other species of South African Ephemerid. Forceps are 4-jointed.

2.10.3. *Ephoron savignyi*; type material examined

2 female adults, [Angola] each labelled 'holotype', Fetish Rock, 24 Feb. 1911, Burgeon (dried specimens) (TER); 1 male adult, [Angola] labelled 'holotype', Fetish Rock 24 Feb. 1911, Burgeon (dried specimen) (TER).

2.10.4. *Ephoron savignyi*; other material examined

1 female adult, Abyssinia [Ethiopia], Lagalafto Ravine between Hawash River and L. Zwai, ca. 6000 ft [above sea level], 31 Oct. 1926, H. Scott (BMNH); 10 female subimagoes, Ethiopia, Gojeb River, 10 Apr. 1961, G. Hodera (BMNH); 13 female subimagoes, Ethiopia, Ghide R. 215 km from Addis Ababa, 13 to 14 May 1961 (at light), A. Tjonnenland (BMNH); 1 female adult, [Democratic Republic of the Congo] River Biakobe, Butembo, 12 Feb. 1950, G. Marlier (RBI); 1 female adult, [Democratic Republic of the Congo] Kwamoth, 1 Feb. 1906, Waelbroeck; (dried specimen) (TER); 1 female adult, [Democratic Republic of the Congo] Stanley Falls [Kisangani], 1 Feb. 1905 Waelbroeck; (dried specimen) (TER); 1 female adult, Uganda, Isundibugyo (NW slope of the Ruwenzori Mts.) Toto [?] district, Alt. 3000´, 06 Apr. 1962, T.R. Williams (BMNH); 1 female adult, [Rwanda?] Kivu [lake?], Lozo Valley Aug. 1937, J. Ghesquière; (dried specimen) (TER); 1 female adult, Tanganyika [Tanzania], Moba, 780 metres Oct./Nov. 1953, H. Bomans; (dried specimen) (TER); 280 female adults, South Africa, KwaZulu-Natal, Edgehill Farm (S29°14´56.2´´ E29°57´57.1´´), Mooi River, 23 Dec. 1999 to 10 Apr. 2000, Conor Cahill (AMG); 90 nymphs, South Africa, KwaZulu-Natal, Connington Road Bridge (S29°22´38.0´´ E 29°55´30.5´´), near Rosetta, Jul. 1998 to April 2000, Conor Cahill (AMG); 36 nymphs, South Africa, KwaZulu-Natal, Edgehill Farm, Mooi River, Oct. 1999 to Apr. 2000, Conor Cahill (AMG).

2.10.5. *Ephoron savignyi;* taxonomic discussion

Pictet (1843) briefly refers — in an appendix to his section on *Palingenia* — to an African polymitarcyid from Egypt that he named *Palingenia savignyi*. Eaton's two primary publications (1871, 1883) both contain material regarding this specimen in the text and both give similar information — that of 1871 is in Latin. The 1871 publication presents figures of the male genitalia and transfers the species from *Palingenia* to *Polymitarcys*. Eaton (1883) provides an illustration of the wing of a 'S. African sp.' [sic] (plate VI; 10b), but not of *Polymitarcys savignyi*. No reference is made to the 'S. African sp.' at any point in the text so it is unknown whether Eaton regarded it and *Polymitarcys savignyi* as the same or different species.

Two further species of *Polymitarcys* from Africa were described — *Polymitarcys capensis* from Zululand [northern KwaZulu-Natal Province], South Africa by Esben-Petersen (1913) and *Polymitarcys temerata* from Angola by Navas (1916). No drawings were provided in either case and the species were distinguished from *Polymitarcys savignyi* on the basis of abdominal body pattern and colour.

Lestage synonymised *Polymitarcys temerata* with *Polymitarcys savignyi* in 1918, and with *Polymitarcys capensis* prior to his 1924 publication.

McDunnough (1926) synonymised the genus *Polymitarcys* with *Ephoron* (cited in Needham et al. 1935). This does not seem to have been applied in common usage in the literature relating to the South African fauna until 1960 (Oliff 1960).

The first illustration of an adult wing that can be positively identified as *Ephoron* (= *Polymitarcys*) *savignyi* is provided in Barnard (1932) (sections of the wings of a number of specimens from museums around Europe were illustrated by Ulmer 1916). The nymph was first described and illustrated by Crass (1947).

Specimens of the genus *Ephoron* have always proven somewhat difficult to identify. Adults in particular have provided the greatest difficulty. A primary problem with the genus is that the morphology of the male genitalia is homogenous throughout the genus and is of no use in distinguishing between species. Concurrently there has been a lack of consistency regarding the classification of this species *Ephoron savignyi*. Firstly no clear description (with illustrations) of the species has ever been published — rather the description of the species has evolved over time and through many authors. Secondly the synonymisation of *Polymitarcys savignyi* with other African species of *Polymitarcys* has been carried out haphazardly. Thirdly the designation of the holotype of this species has been carried out incorrectly (at least under the modern nomenclatural codes) and in a manner that may cause confusion to taxonomists (see Section 2.10.5.3).

2.10.5.1. Original descriptions of **Ephoron savignyi**

PICTET'S (1843) original description was brief and unillustrated. It was not until EATON'S (1871, 1883) descriptions that the species was more thoroughly described and some parts illustrated (1871 — it should be stressed that there is no illustration of this species in EATON 1883; ESBEN-PETERSEN [1913] was aware that the illustration on plate VI does not show *Ephoron savignyi*, but an unnamed 'S. African sp.'. It would seem that Lestage was aware of this in 1918 [LESTAGE 1918] but then seems to have disregarded this fact in his 1924 paper and assumed Eaton's 'S. African sp.' to be *Ephoron savignyi*).

ULMER (1916) does not appear to have set out to redescribe *Ephoron savignyi*, although he does give a brief description (p. 4). The primary aim of his publication rather, seems to have been to note the high degree of variability in the number of intercalaries in the anal sector of the wing (the area of wing between the Cubitus and the Anal veins). In this publication ULMER (1916) briefly refers to NAVAS' (1915) *Polymitarcys temerata* (p. 6) noting that it corresponds with his 'Figure 3' (p. 5 ULMER 1916). He does not specifically state that the two are synonyms.

The first illustration showing an entire wing positively identified as *Ephoron savignyi* is by BARNARD (1932) who was referring to specimens taken in South Africa (although the specimens are referred to in terms of the museums where the specimens were held, not where the specimens were trapped. These specimens are not on record with the South African Museum and are presumed lost). As he refers to both LESTAGE'S papers (1918 and 1924) he may have taken his synonymies from those papers. Unfortunately he gives no description of the specimens he examined in the text, so it is impossible to confirm whether these truly are specimens of *Ephoron savignyi*.

In his description of the nymph of *Polymitarcys savignyi*, CRASS (1947) states that the nymph 'probably represents the nymph of *Polymitarcys savignyi*' as it closely resembles the nymph of *Polymitarcys virgo*. No other reasons are given (unlike many other nymphs that Crass identified, these specimens were not bred to adulthood or associated with adults trapped in the same locality).

***2.10.5.2. Synonymisation of* Polymitarcys temerata *and* P. capensis *with* P. savignyi**

For his 1918 publication, LESTAGE compared the specimens of *Polymitarcys temerata* identified by NAVAS (1915) (those taken in 1911 in Angola by Burgeon) with specimens of *Polymitarcys savignyi* probably also identified by Navas (those taken in 1905/1906 by Waelbroek). LESTAGE (1918) concluded that all of these specimens corresponded exactly with the description of ULMER (1916), from the point of view of venation (albeit both authors agreed that the venation of the species is highly variable) and coloration; therefore *Polymitarcys temerata* was designated as a junior synonym of *Polymitarcys savignyi*.

The status of *Polymitarcys capensis* is less certain. LESTAGE (1918) presents *Polymitarcys capensis* as a separate species to *Polymitarcys savignyi* and comments briefly on it. Six specimens are noted in the text (one male, five females). According to ESBEN–PETERSEN (1913) these specimens were lodged at the South African Museum. This would probably have prevented Lestage from seeing the specimens themselves in order to reassess them. However at no point does LESTAGE (1918, 1924) maintain that he has inspected the specimens. In his text LESTAGE (1918) refers to having corresponded with ESBEN–PETERSEN (p. 69) (his 'excellent colleague' 1924) and that Esben–Petersen believed that *Polymitarcys capensis* corresponded with the drawing of the forewing of the 'S. African sp.' (p. 79) figured by EATON (1883). The next reference to *Polymitarcys capensis* in any text is in LESTAGE (1924) when it is listed among the synonyms of *Polymitarcys savignyi*. All later texts only refer to *Polymitarcys capensis* as a junior synonym of *Polymitarcys savignyi* (DEMOULIN'S [1970] comprehensive checklist and bibliography makes no reference to any publications that relate to *Polymitarcys savignyi* published between 1918 and 1924).

LESTAGE (1918) refers to ULMER'S (1916) paper as a 'redescription' of *Polymitarcys savignyi*. If this is true, then it is a wholly inadequate redescription, with scant text description and illustrations showing only a section of wing in each case. Also the text refers to specimens from a great range of localities — Cameroon, Togo, Democratic Republic of the Congo and Sudan (as well as locality names with no country specified). Lestage seems to use this paper as the initial basis for his synonymisation of *Polymitarcys temerata* with *Polymitarcys savignyi*. Lestage did refer to specimens used by Navas in his description of *Polymitarcys temerata*. However his primary justification in synonymising the two species was that the *Polymitarcys temerata* specimens (from Angola) match specimens that Navas had earlier identified as *Polymitarcys savignyi* (from Stanley Falls, Democratic Republic of the Congo). The synonymisation was therefore carried out on the basis of a comparison with Navas' own work from approximately the same region (Stanley Falls is within 400 km of

Fetish Rock), rather than referring back to the original descriptions of Eaton or Pictet or type (or even non-type) specimens from Egypt.

2.10.5.3. **Polymitarcys temerata** ***specimens as holotypes of*** **Ephoron savignyi**

The designation of 'holotypes' of *Polymitarcys savignyi* by LESTAGE (1924) is completely invalid under modern nomenclatural rules. By definition there can only be a sole holotype of any species. Three are present in the TER collection. However, none of these specimens are suitable to be designated as any form of type specimen. In the case of the designation of neotypes — which these specimens would be — the International Commission on Zoological Nomenclature code (ICZN 1999) states that the specimen should be from as '...nearly as practicable the original type locality...' (Article 75.3.6). The original type locality of *Ephoron savignyi* is Egypt, so these specimens therefore should not be regarded as the neotypes of *Ephoron savignyi.*

2.10.5.4. ***Current status of*** **Ephoron savignyi**

None of the 13 species of *Ephoron* described to date can be identified on the basis of wing venation. The reason is clear — a comparison of available descriptions (EATON 1883, CHOPRA 1927, BARNARD 1932, NEEDHAM et al. 1935, SHIOYAMA 1978 and ISHIWATA 1996) reveals the similarity in wing pattern of the 13 species.

As far as *Ephoron savignyi* is concerned ULMER (1916) was the first researcher to publish a note on the high level of variability in the wing venation of the species. He noted that in the samples available to him (from Egypt, Sudan, Togo and the Belgian Congo) the number of veins in the anal area of the wing varied between four and nine. Unfortunately ULMER (1916) did not give exact localities for his specimens. At best he specified the country from which the specimen had been taken — usually he only provided the name of the museum that housed the specimen(s). He did note that Egypt provided the specimens with both the highest number of 'anal' veins (nine veins) and the lowest number (four veins), while only six veins had been noted for specimens from 'the West' (presumably Cameroon and Togo). However ULMER'S (1916) reckoning of what was to be judged as a 'long vein in the anal area' was highly subjective — in ULMER'S (1916) Figure 3 it looks as if what he has labelled as Cu_2 may in fact be the A_1 vein (he was using the COMSTOCK & NEEDHAM 1898 notation according to NEEDHAM et al. 1935). If this is the case then this specimen has at least seven 'anal veins', not six as he states. However as he provides only a sector of the wing it is impossible to confirm whether or not this is the case. Further to this, from the diagrams provided it is hard to determine how many 'long anal veins' are present.

Nevertheless there is variation in the wings figured by ULMER, especially the two extremes of the Egyptian specimens which he suggests have four and nine anal veins respectively (Figures 2 and 6 in ULMER 1916). As ULMER (1916) originally suggested, if the intermediate condition (between four anal veins and nine anal veins exclusive) had not been noticed, he would have presented the nine-veined condition as a new species.

LESTAGE (1918) strongly supported the views of Ulmer, and seems to have regarded the paper by ULMER (1916) as a redescription of *Polymitarcys savignyi*. A short description is given of the species but too brief and lacking in illustrations and critical analysis to be regarded as a redescription. He probably used this paper as the basis for his incorporation of *Polymitarcys temerata* and *Polymitarcys capensis* into *Polymitarcys savignyi*.

When ULMER'S (1916) hypothesis is applied to wings of *Ephoron savignyi* from South Africa, variability does seem to be present. Seven such veins can be seen in BARNARD'S (1932) illustration of the wing of *Ephoron savignyi* from South Africa — BARNARD (1940) notes that there is an error in this figure; the vein labelled as Cu_2 is in fact only a branch of Cu_1; the correct Cu_2 is that labelled 1A — (although the forks of the veins are not as clear as those figured in ULMER [1916]), while EATON (1883) figures six anal veins for his 'S. African sp.' (which apparently corresponds with ESBEN-PETERSEN'S *Polymitarcys capensis*). More recent samples (collected during this study) exhibit up to eight anal veins. It may be that there is no satisfactory answer to this question due to the intricate connections between these veins in the section of the wing in *Ephoron* sp. and it may not be possible to count them objectively. It is obvious, therefore, that wing venation is not a satisfactory method with which to describe the species of this genus, at least as far as those on the continent of Africa is concerned. This is unfortunate, as the taxonomy of this genus has been heavily based on wing venation, in particular, the synonymisation of *Polymitarcys temerata* (NAVAS 1916) and *Polymitarcys capensis* (ESBEN-PETERSEN 1913), with *Polymitarcys savignyi*.

2.10.5.5. Potential methods for classifying African* Ephoron *sp.

As discussed in the paragraphs on *Ephoron savignyi* above, the current system used to identify members of the species (namely wing venation alone) is unsatisfactory. Three other methods have been in general use for separating closely related species of insects:

2.10.5.5.1. Morphometrics

As mayflies are comparatively soft-bodied insects, their bodies are prone to distortion after death. Both alcohol and drying have potential to shrink the body tissues. Measurement of harder body parts such as limbs or wings might be used as a basis for measurements. However body size may also be influenced by environmental factors such as water temperature (Dr. Ferdy de Moor, AMG pers. comm. 2000). Higher water temperatures may allow for more rapid growth and hence lesser (or greater) body size in the resulting imagoes. Therefore body size must be used with caution in taxonomic studies. Average body dimension measurements are also highly dependent on sample size as small sample sizes will give statistically less reliable average size values.

As far as *Ephoron savignyi* is concerned little size data exist. Of that which does, most authors (EATON 1883, ESBEN-PETERSEN 1913, NAVAS 1916) indicate no sample size, nor the length of time since the sample was first preserved. It is likely that EATON'S 1871 and 1883 samples of African polymitarcyids were at least 40 years old as he notes they were donated to him by M. Pictet, presumably either F.J. Pictet, the original author, or one of his relatives. The potential for physical distortion in these specimens would have been high if they were indeed that old. Another factor, which is relatively peculiar to the polymitarcyids, is that the female contracts the abdomen transversally in order to eject the two egg packets. During the current study only a fraction of all female adults preserved retained their eggs and hence their true body length. Most of those adults viewed in museum collections had not retained their eggs and so would be of little use in morphometric studies.

2.10.5.5.2. Ultrastructure of the chorion of the egg

Egg surface structures of *Ephoron* sp. have been illustrated by a number of authors (CHOPRA 1927, LESTAGE 1918), but it is only since the invention of the electron microscope and the comparatively recent understanding of the taxonomic uses to which a knowledge of the surface ultrastructure of the chorion of the egg can be put (HINTON 1981, KOSS 1968, 1973) that it has been possible to achieve accurate images of the surface structure or desirable to do so.

2.10.5.5.3. Nymph morphology

Diagnosis of nymphs may prove to be a more reliable method for separating African *Ephoron* species than the use of adults. *Ephoron album* and *Ephoron leukon* (both found in the USA) are most easily separated as nymphs. In Japan, recent studies have found examination of nymphs to be the most reliable method for separating the three species of *Ephoron* present there (ISHIWATA 1996). The original description of the nymph of *Ephoron savignyi* (CRASS 1947) is however not especially detailed. In particular no reference was made to its striking body pattern other than

> 'the abdomen shows indications of a fuscous [brownish-grey] pattern, which is obscured by a deposit of sediment'.

However it may be that nymphs of this genus have only rarely been found in Africa and even more rarely lodged in museums. Of the museums visited during the course of this study, only AMG (which holds nymphs from the Republic of South Africa only) and the RBI (two individuals, River Bikaboe, Butembo, Country Unknown) have holdings of nymphs of *Ephoron savignyi.* Those of the RBI are in a poor condition, to the extent that they are impossible to identify with certainty as representatives of the genus. It therefore seems possible that nymphs have never been recognised outside of South Africa.

None of these questions regarding the taxonomy, morphology or biogeography of this species can be answered until fresh specimens from throughout the continent of Africa become available for study.

2.10.6. *Ephoron savignyi;* biology

Members of the genus *Ephoron* are found world-wide — thirteen species are described (ISHIWATA 1996). The nymphs are usually found in burrows in semi-consolidated silt and clay, but are also known from a range of coarser substrate types where they probably adopt a lifestyle of living in crevices and under stones (MCCAFFERTY 1979). It is probable that nymphs are not found in unconsolidated silt or shifting sediments.

The adults are short-lived and well-known from some parts of the world due to their mass-emergent behaviour and relatively large body size (WATANABE & ISHIWATA 1997).

Ephoron savignyi is the only known member of the genus found south of the Tropic of Cancer on the continent of Africa — *Ephoron virgo*, a predominantly European species is found in Tunisia and Morocco (BOUMAIZA & THOMAS 1986, GAGNEUR & THOMAS 1988).

Crass (1947) found specimens of *Ephoron savignyi* 'among vegetable [sic] detritus and grass roots' on the Yarrow stream (a tributary of the Karkloof River), KwaZulu-Natal. Crass found exuviae on the water near Rosetta on 05 October 1944.

During the study adults were attracted to light traps from late December 1999 until mid-April 2000. Emergence was usually observed to commence after sunset, but before dark. Males appeared to emerge first, with some males seen at dusk, but few females were seen until they were attracted to the lights about 20 minutes later. The largest numbers were attracted to lights in the second and third weeks of January 2000.

DEMOULIN (1970) observed that the adult is well known and found in Egypt, Abyssinia [Ethiopia], Cameroon, Togo, Belgian Congo [Democratic Republic of the Congo], The Zambezi, The Congo River, Swaziland and Natal. A distribution map of *Eatonica* spp. in Africa is illustrated in Figure 15.

2.11 CONCLUSIONS

The single biggest obstacle to gaining an understanding of the status of these insects in a South African context is the dearth of samples and reliable collection data from throughout the continent of Africa. The samples retained in the few museums visited during this work spanned the 20th century and were in various states of preservation. The samples that are physically most intact are in general of such an age as to be of little use as their colours and patterns have all but faded away. Many other samples are no longer available — those of EATON have decayed with time and it must be assumed that those that formed the basis of ULMER'S work (1916) have also been destroyed. Without such samples it is impossible to identify any samples with certainty or draw conclusions regarding their taxonomy. In such cases it is usual practice to obtain samples from the original species localities, but this will be difficult to achieve satisfactorily for the few species discussed here — not only are the specimens difficult to obtain due to their seasonal nature, but the areas involved are vast (from Egypt to South Africa and west to Guinea) and frequently original locality information is scant — that for *Ephoron savignyi* is 'Egypt'. In other regions land use changes have been immense — when Waelbroek trapped specimens of *Ephoron savignyi* at Stanley Falls in 1905 there was a small settlement in the area. This area is now Kisangani, home to half a million people.

These concerns aside, the following conclusions can be drawn about the species reported from South Africa.

Eatonica schoutedeni

Only two specimens from South Africa are available in the museums visited during the course of this study. The specimens are, however, in poor condition and it is impossible to confirm whether they are truly *Eatonica schoutedeni*. Future workers should be aware that *Eatonica crassi* may be much more widespread than indicated in most of the available literature and its presence in South Africa should not be ruled out.

Ephemera mooiana

Ephemera mooiana has not been recorded in South Africa since 1947. The specimens housed by the South African Museum are the only specimens identified with certainty. It must be remembered that *Ephemera mooiana* was described from the male adult and the nymphs described by CRASS (1947) are only associated with it — their official designation as the nymphs of *Ephemera mooiana* is held back pending the discovery of new specimens. Those nymphs held by the BMNH too have only been tentatively identified pending future confirmation.

The current status of this species is impossible to determine due to lack of specimens. It seems likely that this species may have a greater range than previously thought due to the discovery of *Ephemera mooiana*-like nymphs from Guinea, but again solid conclusions cannot be made without new collections.

Afromera natalensis

This species is rare but has been recorded on a relatively regular basis in the past 50 years, most recently individuals were trapped in 1991 and 1995 on the Mooi River, KwaZulu-Natal. Collection of nymphs would be of great interest as the sibling species of *Afromera natalensis* are found throughout Africa but remain poorly understood taxonomically and biologically.

Afroplocia sampsoni

Little is known of this rare species or the related *Exeuthyplocia minima*. Any published descriptions have been limited to a small number of preserved adults and a sole nymphal exuvium. The discovery of any new specimens would be of great value in understanding the taxonomy of the species and its ecological requirements.

Ephoron savignyi

The extent of this species' range through Africa must be reassessed — the presumption that it is found throughout the continent was arrived at in the 1920's and there is no certainty as to why this species was synonymised with *Polymitarcys capensis*. Due to this uncertainty and the gradual nature of the description of the species (from fragmentary descriptions in PICTET [1843] and EATON [1871 & 1883] to more comprehensive descriptions by ULMER [1916] and LESTAGE [1918, 1924, 1931, 1939 & 1945]) this species should be reassessed taxonomically on a pan-African basis. Particular attention should be paid to nymphal and egg morphology as it is these attributes that have proven most useful in characterising the other species of *Ephoron* in other parts of the world (in particular the USA and Japan, but also India).

A complete redescription of all life stages of the species based on specimens from Egypt would be most useful in this regard.

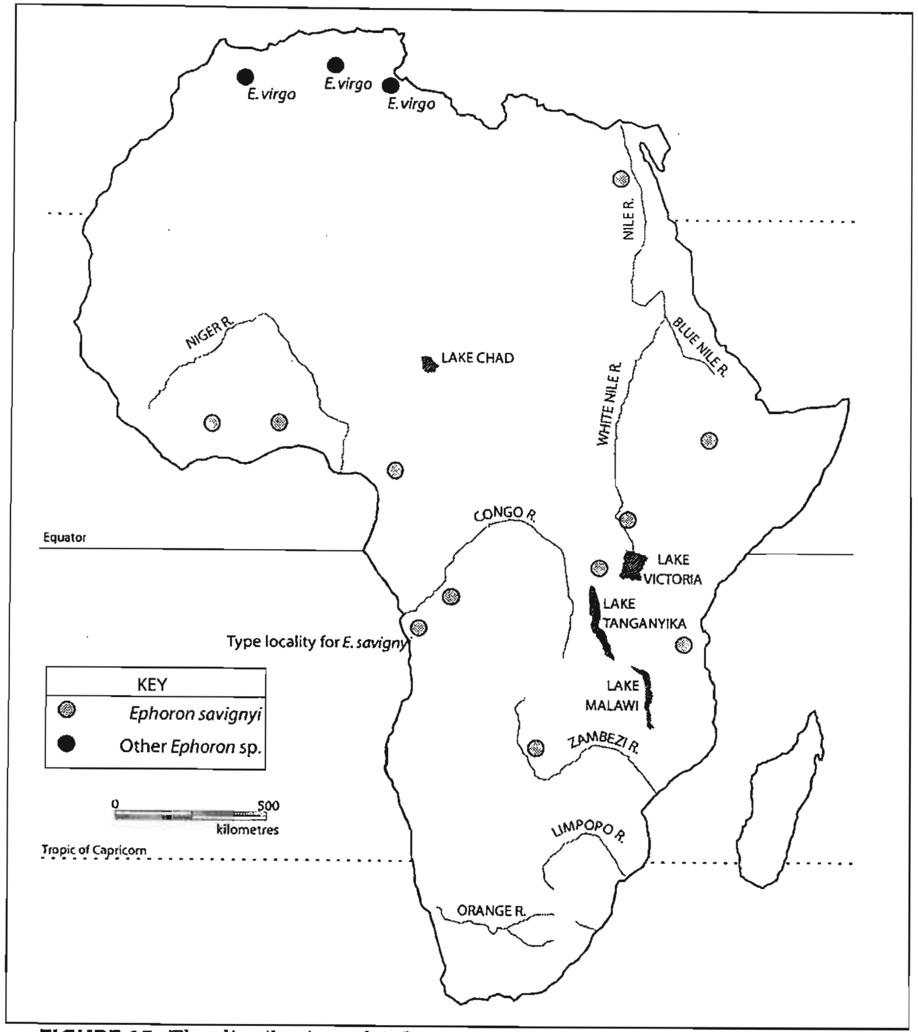


FIGURE 15: The distribution of *Ephoron savignyi* and related species in Africa (excluding Republic of South Africa).

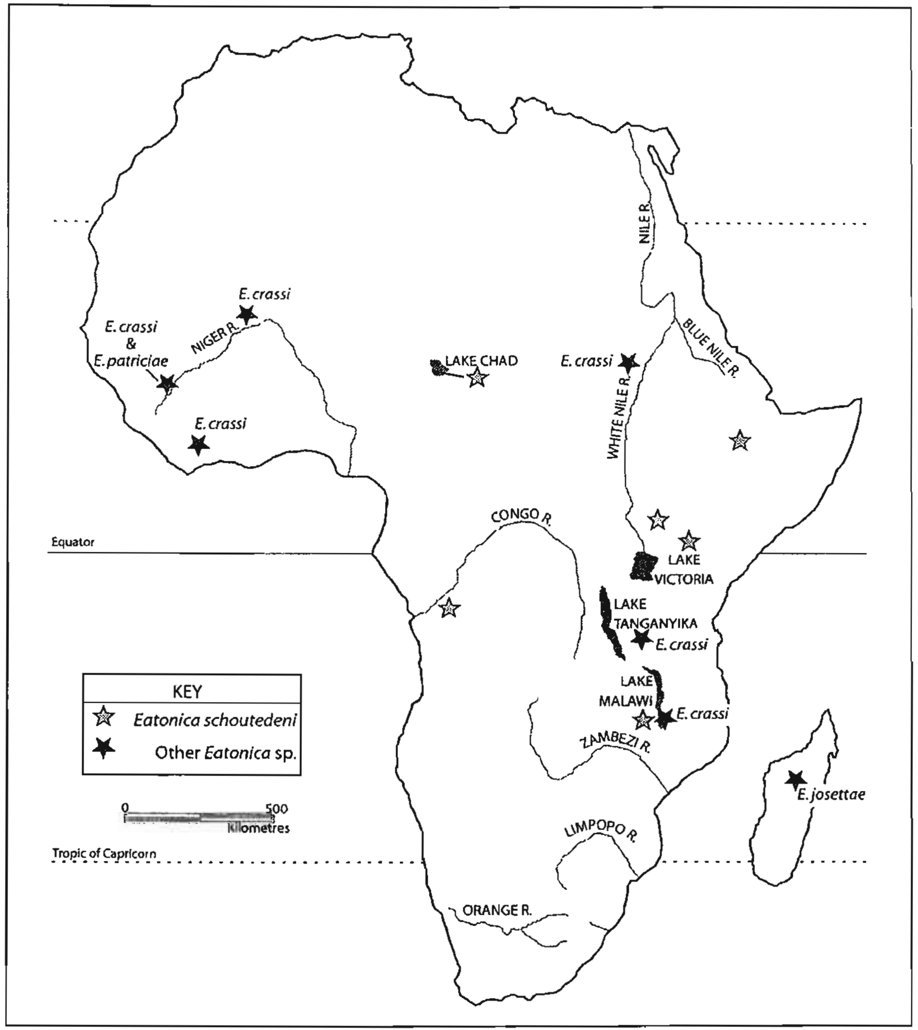


FIGURE 16: The distribution of *Eatonica schoutedeni* and related species in Africa (excluding Republic of South Africa).

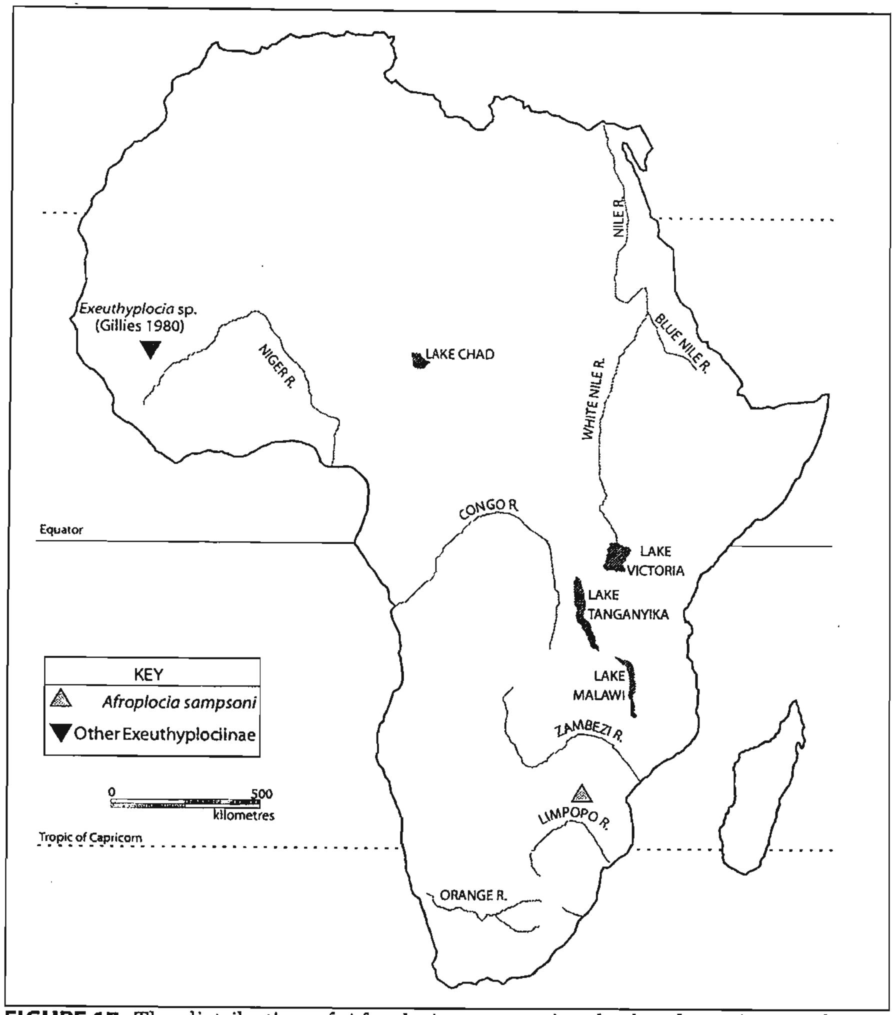


FIGURE 17: The distribution of *Afroplocia sampsoni* and related species in Africa (excluding Republic of South Africa).

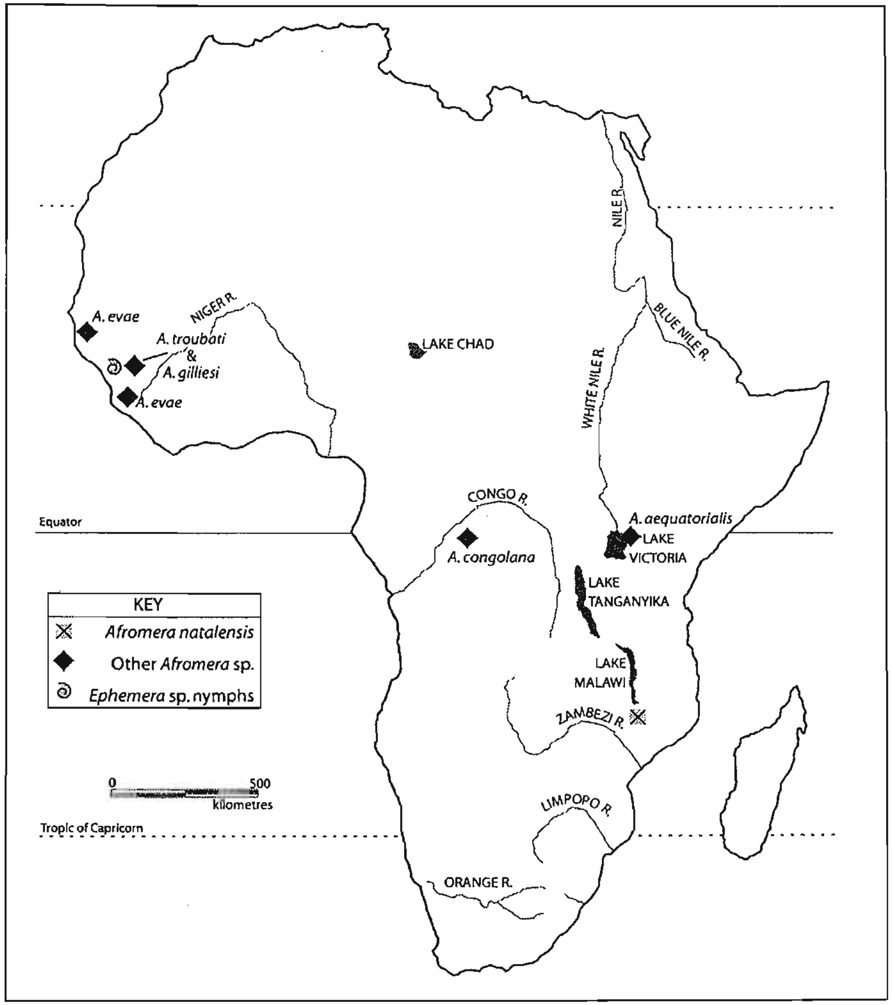


FIGURE 18: The distribution of members of the subfamily Ephemerinae and related species in Africa (excluding Republic of South Africa).

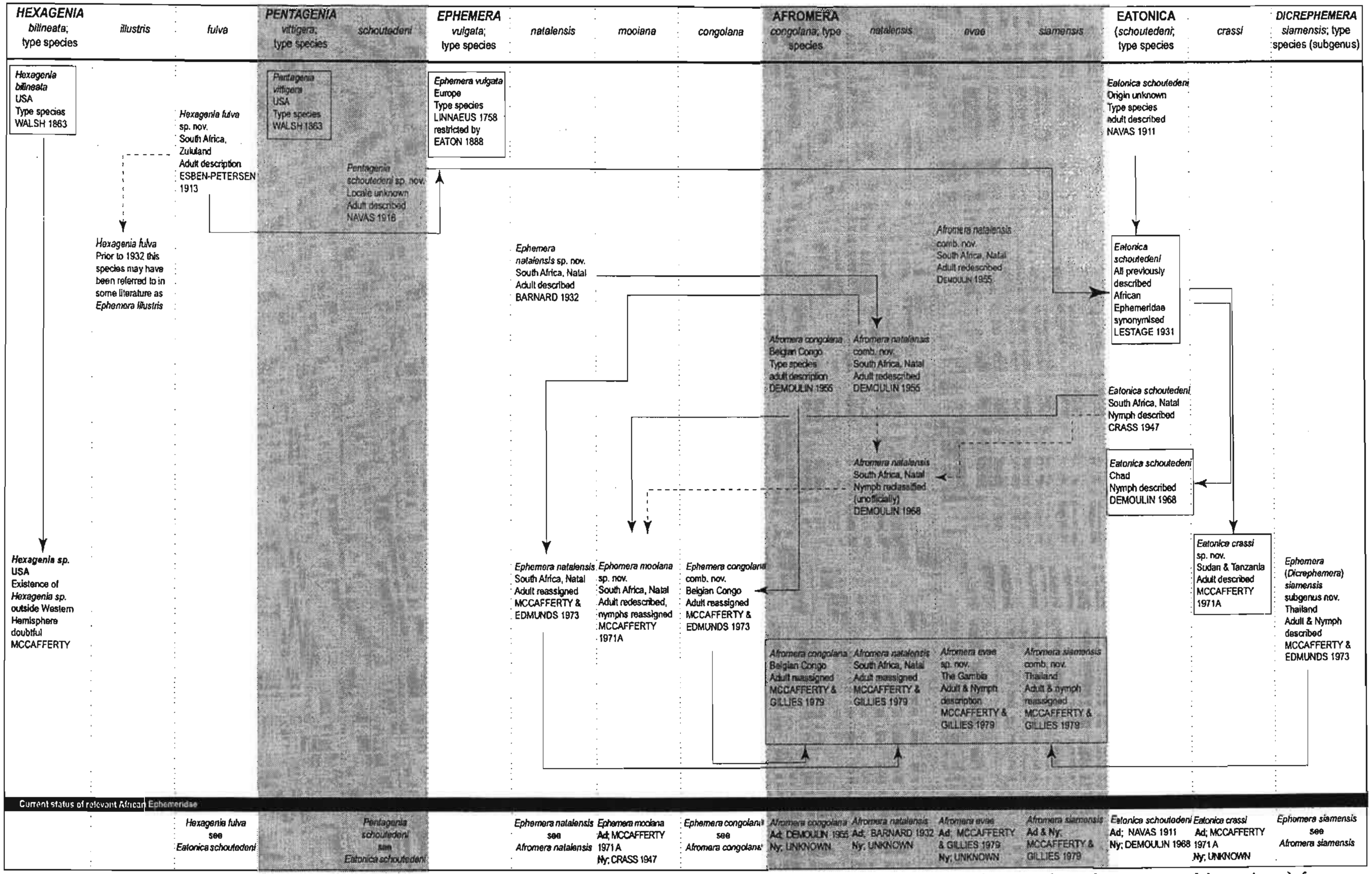


FIGURE 19: Chronology chart illustrating the fate of rejected synonyms of the Ephemeridae of Africa (and relevant changes for other geographic regions) from 1863 to 2001. Accepted synonyms (November 2002) are boxed. Abbreviations used; **'Ad'**; adult, **'Ny'**; Nymph.

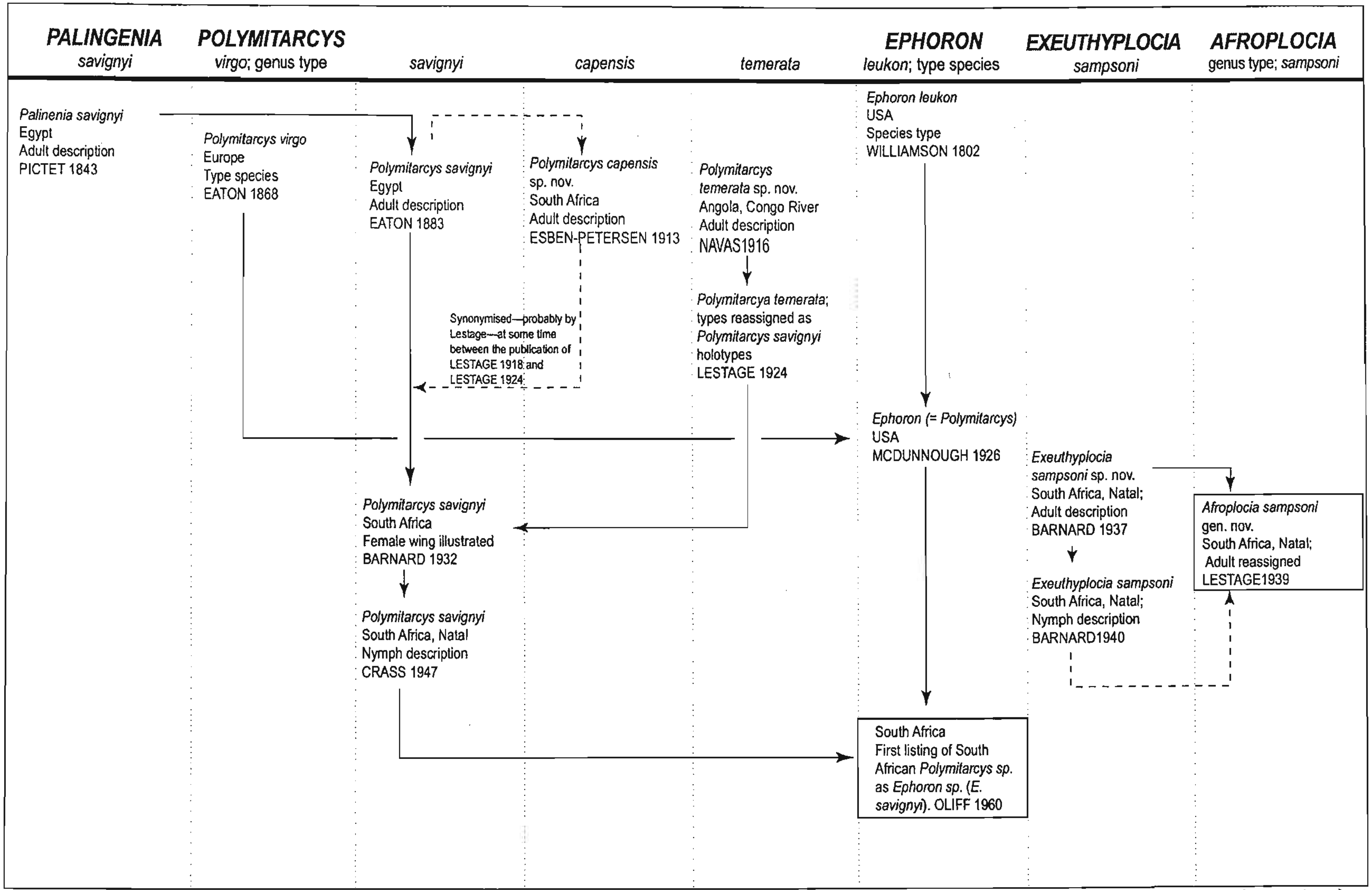


FIGURE 20: Chronology chart illustrating the fate of rejected synonyms of the Polymitarcyidae of Africa (and relevant changes for other geographic regions) from 1802 to 2001. Accepted synonyms (November 2002) are boxed. Abbreviations used; 'Ad'; adult, 'Ny'; Nymph.

2.12 KEY TO THE EPHEMEROIDEA (ADULTS) OF SOUTH AFRICA

The aim of the key that follows is to provide a single resource for the identification of Ephemeroidea that may be found in KwaZulu-Natal. To date no key has been produced for this group in southern Africa although a number of keys are available dispersed throughout a number of articles. Of particular importance are those for Ephemeridae in McCafferty & Gillies (1979), Euthyplociinae in Gillies (1980) *Eatonica* in Elouard (1986a) and *Afromera* in Elouard (1986b). Two species of *Eatonica* (*Eatonica schoutedeni* and *Eatonica crassi*) are retained in this key even though, as discussed in Section 2.4.4, there are no confirmed records of either species from KwaZulu-Natal. However, as many references refer to *Eatonica* from KwaZulu-Natal, they have been retained in this key.

1. Wings translucent—cloudy or milky in appearance, mid and hind legs poorly developed

➥ Polymitarcyidae **2**

Wings hyaline, mid and hind legs normally developed

➥ Ephemeridae **3**

2. Males with long forelimbs, forceps 4-jointed; in both sexes fork of R_{4+5} distal to fork of R_{2+3} in forewing; anal area of forewing without sigmoid parallel cross-veins (Figure 14).

➥ *Ephoron savignyi*

Males with poorly-developed forelimbs, forceps 1-jointed; in both sexes forks of R4 + 5 and R2 + 3 at approximately the same level in forewing; anal area of forewing with 9 sigmoid parallel cross-veins (Figure 14).

➥ *Afroplocia sampsoni*

3. Males with rudimentary median caudal filament and 3-segmented genital forceps (Figure 10); females and males with vein M_2 of hind wings attached to vein M_1 basally and free from vein Cu_1

➥ *Eatonica,* **4**

Males with well developed median caudal filament and 4-segmented genital forceps (Figure 13). Females and males with vein M_2 of hindwings not attached to M_1 basally and either free basally or attached basally to Cu_1

➥ **5**

4. Penes of males stout, rounded apically, with blunt divergent terminals, separated by a V-shaped notch; lateral dorsal stripes of abdomen straight to somewhat concave medially at each tergum, median dashes well defined (Figure 10); males with a W-shaped pattern on tergites 7 and 8.

➥ *Eatonica crassi*

Penes of males stout, rounded apically, possessing small sharp lateral projections near the apices, separated by a broad U-shaped notch; dorsal stripes of abdomen somewhat convex medially at each abdominal tergum, median dashes poorly defined (Figure 10).

➥ *Eatonica schoutedeni*

5. Forewing longer than 16mm; males with forceps bases only slightly projected beyond posterior margin of subgenital plate; males with a pair of continuous dorsal longitudinal (sometimes faint) stripes along abdomen (Figure 13).

➥ *Ephemera mooiana*

Forewing less than 15mm in length; males with forceps bases protruding beyond median posterior margin of subgenital plate, often giving appearance of emarginate subgenital plate; abdominal sterna 1 to 8 unmarked*.

➥ *Afromera natalensis*

*Other species of *Afromera* have markings on the abdominal sternite

3 FIELD INVESTIGATION;

CURRENT STATUS OF EPHEMEROIDEA IN THE MOOI AND KARKLOOF CATCHMENTS

3.1 INTRODUCTION

As outlined in Section 1.2 the primary focus of this project was to investigate the status of the Ephemeroidea in KwaZulu-Natal in reference to the environmental impact assessment of proposed impoundments on the Mooi and Little Mooi rivers. During the planning stages of this project in early 1998 it was decided to also include surveys on the Karkloof River in the nearby Mgeni catchment — this river had the only additional site records of *Ephemera mooiana* (see Section 2.5.6). Habitat descriptions in Section 3.2 are adapted from CRASS (1947), SWART (1995) and personal observation. Distances and altitudes, longitude and latitude were measured with an opisometer or read off 1:50 000 scale maps produced by the Chief Director of Surveys and Mapping, South Africa.

3.2 THE MOOI, LITTLE MOOI AND KARKLOOF RIVERS

3.2.1. Geology, precipitation, flow and abstraction

The Mooi River has its source in the Drakensberg Mountains in western KwaZulu-Natal at an altitude of approximately 2400 metres. It flows in a north-easterly direction for approximately 200 kilometres to join the Tugela River in its middle reaches at an altitude of approximately 500 metres. The total catchment area is 2868 km^2 (SWART 1995).

Low permeability rocks underlie the river. The headwaters are mainly underlain by basalt. Sills and dykes of diabase (referred to in some texts as dolerite, a medium-grained form of basalt) are evident at the surface at many points along the river, creating many large pools and small waterfalls. Further downstream sedimentary rocks predominate. These generally restrict percolation from the river into groundwater and result in a number of wetlands, particularly in the upper reaches below the torrential zone that flows off the Drakensberg.

The Mean Annual Precipitation (MAP) in the mountain reaches is 1300 mm, 700 mm for the lower reaches (800 mm on average for the entire catchment). However this rainfall is not distributed evenly throughout the year; typically KwaZulu-Natal experiences wet summers and dry winters. A summary of river flow is illustrated in Figure 21. As can be seen from this figure the mean flow level does not give a good idea of how variable the river flow can be from year to year.

For the area examined during this investigation, the average maximum summer temperature is 25.5°C and the minimum average experienced is 5°C (Figure 21). However, further downstream, the average water temperatures are warmer, with a minimum average of 7.9°C, and a maximum average of 27.4°C (for the year 1998 — readings taken at Keate's Drift; Mark Graham, Umgeni Water, Pietermaritzburg, pers. comm. February 2000).

As can be seen in Figure 21 river flow (and hence rainfall) is variable and unreliable in the Mooi River and this applies to the neighbouring catchments also. The main demands for water in central KwaZulu-Natal are the cities of Durban (Official population 960 800 in 1987) on the coast and Pietermaritzburg (Official population 187 200 in 1987) 80 km inland (MOUNTJOY 1987). These population centres get most of their water from two storage reservoirs on the Mgeni catchment, Albert Falls ($290.7x10^6$ m^3) and Midmar ($177.8x10^6$ m^3) (UMGENI WATER 2003).

In the Mooi River catchment (which includes the sub-catchment of the Little Mooi River), the local farming community — mainly made up of cattle farmers and the Mooi River Municipality — are the major water consumers. With the demise of Mooi River Textiles in 1999 there are no major industrial water users inside the catchment. It is impossible to accurately assess the demand of the local rural community (which excludes farming usage). However for the purpose of the flow-requirements studies, this was taken as equal to the demand of the Mooi River Municipality (SWART 1995).

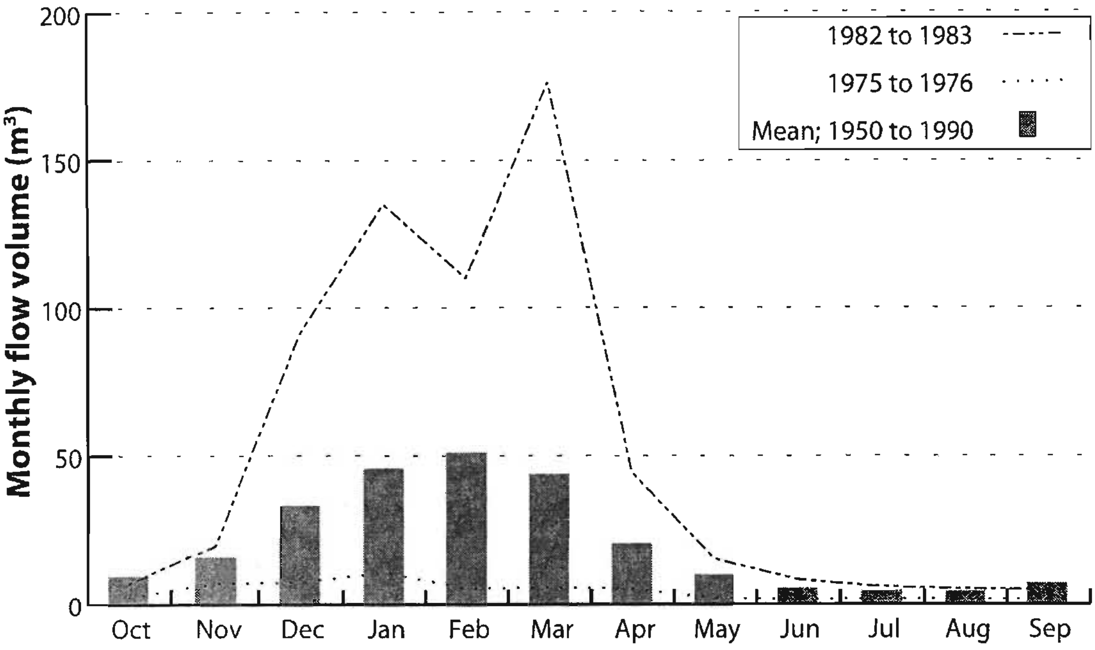


FIGURE 21: The mean flow for a section of the Mooi River from 1950 to 1990 (readings taken at a gauging station in the town of Mooi River). Also shown are a high flow year (1982 to 1983) and a low flow year (1975 to 1976) (Data from SWART 1995).

The burgeoning population of Durban and the commitment of successive governments since 1994 to provide the entire population of the country with fresh running water meant that a heavy strain was being placed on the two major storage reservoirs on the Mgeni catchment. It was realised that the water supply available from the Mgeni catchment would have to be supplemented to avoid water shortages in the future. Even prior to this, a succession of drought years in the 1970s and 1980s initiated the building of Mearns Weir on the Mooi River in 1983. This was a small (three metres high) dam wall with pump-house connected to the Mpofana River in the Mgeni catchment via a 21.6 km pipeline. This was designed to enable the flow of the Mgeni River to be supplemented from the Mooi River, which, until then had been largely unexploited in terms of water abstraction. This scheme allowed a maximum of

3.2 m^3/s to be pumped from the Mooi River catchment to the Mgeni catchment (Mark Graham, Umgeni Water, Pietermaritzburg, pers. comm. February 2000).

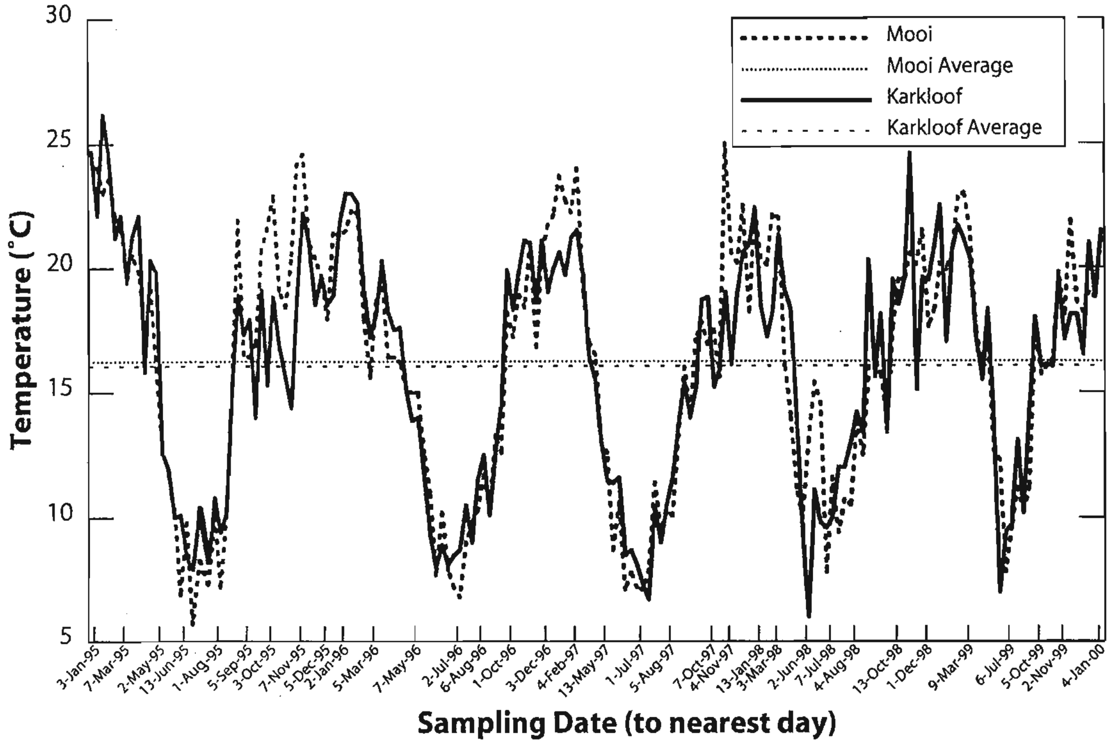


FIGURE 22: Temperature variation on the Mooi and Karkloof Rivers from January 1995 until January 2000. Note that only a selection of the data points which were used to make the chart have been labelled on the x-axis in order to preserve clarity. In many cases the two rivers have not been sampled on the same day, but within 24 hours of each other. Data provided by Mark Graham, Umgeni Water, Pietermaritzburg and areused with permission.

However, it is thought that this measure will soon become insufficient to meet growing demand and in 1993 a number of proposals were investigated for supplementing the water supply, particularly to provide an assured supply to the industrial sector of Durban City. These included increasing the size of the dam wall at Mearns to allow a greater volume of water to be pumped to the Mgeni catchment as well as two proposals for new storage dams. The first of these plans to be finalised was that of increasing the wall size at Mearns, from approximately three metres in height to approximately ten metres in height (Dr. Chris Dickens, Umgeni Water, Pietermaritzburg, pers. comm., August 1998).

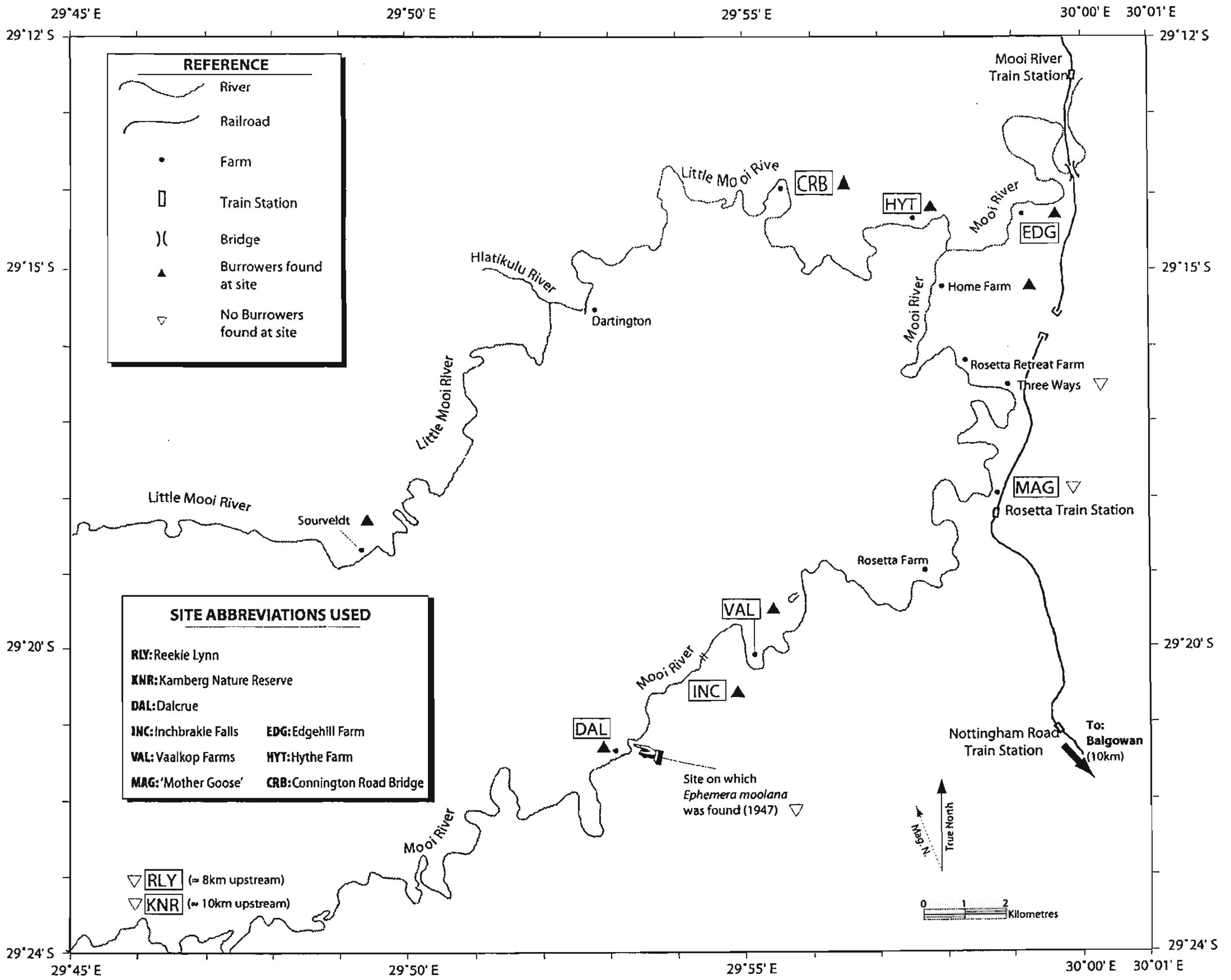


FIGURE 23: Simplified map of a section of the Mooi River catchment, KwaZulu-Natal, South Africa illustrating field sites investigated during the course of this fieldwork, the presence or absence of the burrowing mayfly *Ephoron savignyi* and the major towns, farms and roads in the area.

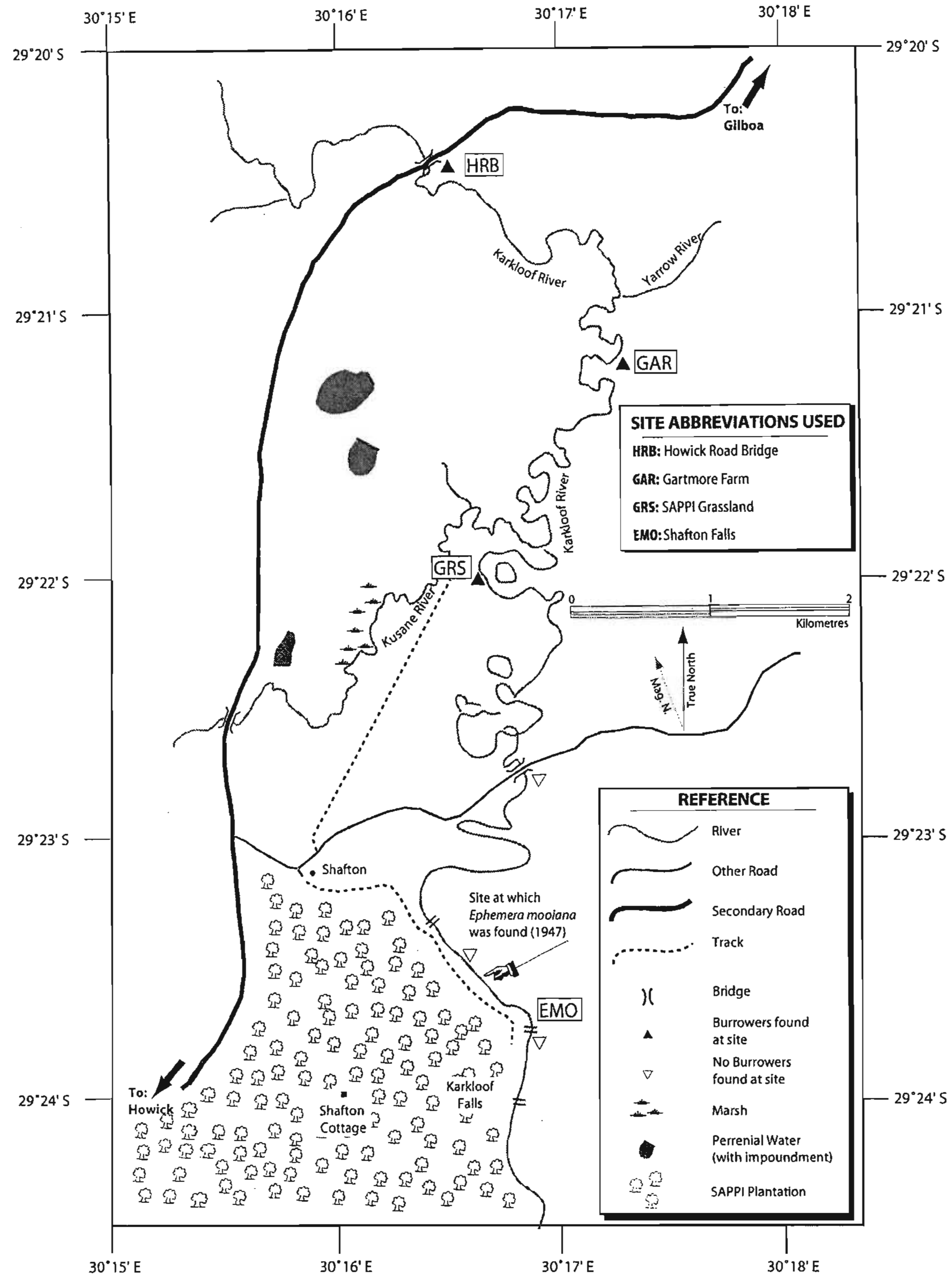


FIGURE 24: Simplified map of the Karkloof and Yarrow Rivers, KwaZulu-Natal, South Africa illustrating field sites investigated during the course of this fieldwork, the presence or absence of the burrowing mayfly *Ephoron savignyi* and the major towns, farms and roads in the area. Note that this map has been produced to a different scale than that for the Mooi River catchment.

3.2.2. Local topography; Drakensberg to Mooi River Municipality (Figure 23)

From its source near Giant's Castle the Mooi River is little more than a montane stream. It is joined by a number of small streams about four km above Kamberg Nature Reserve. At this point the river flows westwards through Kamberg Nature Reserve and is approximately three metres wide. Sandstone blocks ranging from cobble to boulder sizes are prominent in this region of the river. A number of deep (in excess of two metres) pools are also evident, although riffles dominate the topography. It is also at this point that the introduced weed, black wattle (*Acacia mearnsii* de Wild 1906), makes its appearance on the riverbanks. This fast growing tree contributes to evapo-transpiration and shades out native more slowly growing species and is in evidence along the riverbank all the way to the coast.

The river is impounded at Kamberg Nature Reserve (KNR) Trout Hatchery by an approximately two-metre high dam. Thereafter it continues unregulated for approximately 12 km, forming meanders and ox-bow lakes. About two km above the confluence with the stream Reekie Lynn (RLY) there is a wetland on the western bank of the river, administered by Kamberg Nature Reserve. Just below the confluence with the Reekie Lynn the river goes through an extensive (about one km long) complex of riffles and tips over an eight-metre waterfall.

From this waterfall at approximately 1600 metres elevation the river flows in a north-easterly direction for about 25 km towards the village of Rosetta at 1 400 metres. The first few kilometres of river in this stretch have clay banks, but these then disappear, as the river again becomes more torrential. The land bounding the river is mainly made up of cattle farms. The only major waterfall is the seven-metre Inchbrakie Falls (INC) about 18 km below the previous one at Reekie Lynn. From this point the river passes a small wetland at the base of a hill on its northern bank before meandering through a mix of pools and riffles to the town of Rosetta.

The building of the small Mearns Weir at Edgehill Farm (EDG) has impacted much of the river flow from Rosetta to the town of Mooi River. At Rosetta the river is approximately six metres wide. The final three kilometres or so to the dam wall are slow moving with deep riverbanks, mainly made up of clay. Below Mearns Weir the riverbanks are made up of a hard, shattered shale and clay. The relatively deep water and absence of riffles continues all the way to the town of Mooi River due to a small boulder impoundment to regulate flow for the purposes of farm irrigation and then, a short distance afterwards, a small dam constructed for the supply of water to Mooi River Municipality.

3.2.3. The Little Mooi River (Figure 23)

The Little Mooi River, a tributary of the Mooi River, joins the main river approximately three km upstream of Mearns Weir at Edgehill Farm. The two rivers flow parallel to each other for much of their distance, the Little Mooi flowing approximately eight km to the north of the Mooi River. While the topography and geology of the basin are similar, there are no major settlements on the Little Mooi sub-catchment, and farms tend to be set further back from the riverbanks.

3.2.4. The Karkloof and Yarrow Rivers (Figure 24)

The Yarrow Stream originates in a swampy area NNE of Howick, east of Rosetta, at an elevation of 1600 metres (Crass 1955). It flows south through peaty soils before dropping through a chasm. For the next few kilometres the river drops at approximately 50 m per km. The gradient of the river is gradually reduced and the river goes over a number of smaller diabase sills. The last of these is to be found approximately three km upstream of Gartmore Farm (GAR, Figure 24). The Karkloof and Yarrow Rivers join approximately 500 m upstream of GAR.

The Karkloof River originates to the west of the confluence with the Yarrow. The river flows along a gentle gradient. Until the confluence with the Yarrow the river is deep, with clay banks. After the Yarrow confluence the river (now known as the Karkloof River), flows along a much flatter gradient and spreads out to form exaggerated meanders and a number of oxbow lakes. The river continues through the three sites described below (GAR, GRS, EMO) before tumbling over Karkloof Falls and on to the confluence with the Mgeni River east of Howick.

The Yarrow and Karkloof Rivers are remote from major settlements. Some abstraction is carried out for land irrigation purposes. Four kilometres downstream of the confluence with the Mgeni River Albert Falls Dam impounds the river.

3.3 SELECTION OF FIELD SITES

The primary aim of this project was to determine whether rare burrowing mayflies were present at any of the sites earmarked by Umgeni Water and DWAF for dam development on the Mooi River (see Page 1). When this project was initiated some investigations had already been carried out and found no burrowing mayflies present at the sites concerned. In order to thoroughly assess the distribution of burrowing mayflies at each of these sites however it was obviously necessary to investigate more of the catchment to see where and if burrowing mayflies were present. This would provide information about the relative abundance of each species within the catchment. More importantly however it would enable a profile of the preferred habitats of burrowing mayflies to be compiled; such a profile could potentially contain information on factors such as preferred sediment, water chemistry and riparian land use/condition, amongst others. These habitat profiles could be used to help assess the dam sites. Particular attention could be paid to areas that correlated with factors suggested by the profiles.

The first stage was to select and assess sites throughout the catchment. These included sites with known records for burrowing mayflies, sites that anecdotal evidence suggested may have burrowers, and 'control sites' that had not been previously assessed specifically for burrowing mayflies. Each site was made up of a stretch of river that it was felt possible for one person to survey in 4 hours. This generally meant that sites were no longer than 20 to 40 metres in length, although where the river had a large number of deep pools which made surveying treacherous (for example the SAPPI Grassland, [GRS Section 3.3.4.3], sites were longer.

The list of sites was to be narrowed as data were accumulated; eventually assessments would only be carried out on sites at which burrowing mayflies were found.

3.3.1. TYPES OF SITES

A. Sites with a previous record for burrowing mayflies

Three sites were of primary concern; Dalcrue (DAL), Shafton Falls (EMO) and Mearns Weir (EDG). DAL on the Mooi River and EMO on the Karkloof River comprised the only known localities for *Ephemera mooiana* and were therefore of most interest. During previous assessments, EDG had produced specimens of *Ephoron savignyi* and *Afroplocia sampsoni*.

B. Sites with anecdotal evidence of burrowing mayflies

Two types of sites fall into this category. Firstly are sites at which a small number of burrowers had previously been found. These included Inchbrakie Falls (INC) and Connington Road Bridge (CRB). Secondly were those sites that may or may not have been previously assessed, but had habitats that were felt to be potential burrower sites; for example deep clay banks or sand/silt deposits. Such sites were selected by referring to aerial photographs, 1:50 000 maps and an aerial video of the catchment that had been produced by Umgeni Water for the purposes of river assessment. Sites in this category included Vaalkop Farms (VAL), Hythe Farm (HYT), Howick Road Bridge (HRB), SAPPI (South African Pulp and Paper Industries) Grassland (GRS) and Gartmore Farm (GAR).

C. Other sites

These are sites that had no obvious evidence for potential burrowing mayfly populations, but were felt to be important sites either due to evidence of high water quality (Kamberg Nature Reserve, KNR) or presented habitats not found in sites assessed under the previous two categories. For example the 'Mother Goose' site (MAG) allows access to a particularly long stretch of riffles upstream of a site thought to support a burrowing mayfly population (Mearns Weir at EDG). Also in this category are a number of sites on the Karkloof and Little Mooi Rivers. There are no imminent plans to impound these rivers, but it is felt that they were be able to provide valuable information regarding habitat preferenda of burrowing mayflies due to their proximity to the Mooi River catchment, and the historical presence of *Ephemera mooiana* in the Karkloof River.

The sites that were selected on the basis of these three categories and surveyed more than once are described in more detail below. The relevant information for these sites is summarised in Table 5.

3.3.2. FIELD SITES ON THE MOOI RIVER (Figure 23)

3.3.2.1. Kamberg Nature Reserve (KNR)

Kamberg Nature Reserve is at the foothills of the Drakensberg mountains, near to the source of the Mooi River. It allows the highest altitude road access to the river. A trout hatchery and three-metre weir are present (the highest altitude impoundment on the river). From this point upstream the river is approximately 2.5 metres or less in width. It is primarily rocky-bottomed with a number of deeper pools. With no significant agriculture upstream of this area it is presumed to be of pristine water quality. The river was surveyed at the weir and at a number of points upstream, to a distance of about three kilometres from the trout hatchery.

3.3.2.2. *Reekie Lynn (RLY)*

S 29°23′18.5″ E 29°44′22.0″

The Reekie Lynn is a small tributary of the Mooi River a few kilometres outside the south-eastern border of Kamberg Nature Reserve (in fact this is, due to the irregular shape of the reserve, the second time that the Mooi River leaves the reserve, but it loops back in again). The river has a sandy bottom and sandy banks. Cobbles and boulders are also present in the stream. After it joins the Mooi River the river goes through a 30 metre long stretch of riffles, over two one-metre high waterfalls, a 2.5-metre waterfall, then a six-metre waterfall in quick succession. A deep pool and sandy shores are present at the bottom of the waterfall. By this point the river is an average of five or six metres wide. The river then goes through another stretch of riffles. This is the last significant waterfall between this point and Inchbrakie Falls.

3.3.2.3. *Dalcrue (DAL)*

S 29°21′43.0″ E 29°52′28.8″

Dalcrue was the name used to describe the site from which the original nymphs of *Ephemera mooiana* were found. However, Dalcrue is the name of a farm on the 'Stockton 14870' farmland (as can be seen on the 1990 edition of the 1:50 000 scale map available from the South Africa Surveyor General), and the site referred to in McCAFFERTY's (1971) species description has the co-ordinates given above. Due to recent changes in the minor roads in the area, it is no longer possible to access this site with a vehicle from the 'Stockton 14870' farmland — vehicular access is only possible from further west, from the 'Avon 10487' farmland road, continuing north-west to a bridge on the junction of 'The Bend 14880' farmland with 'Sussex Farm 11178' farmland and then following the road north-east along the river for approximately three km back to the site.

The river at this point is relatively sluggish, even during the rainy season. The banks are nearly vertical, primarily made up of clay. The river bottom is predominantly medium gravel and coarse sand with some cobbles. The riverbed is horizontal and it is possible to wade across the river with little change in depth.

3.3.2.4. Inchbrakie Falls (INC)

S 29°20′20″ E 29°54′21″

This site is similar to Reekie Lynn (see Section 3.3.2.2 above) in that it is, once again a fairly large waterfall (five to six metres) preceded by riffles and followed by a deep pool and more riffles. However this site is at much lower altitude, and the river is wider.

3.3.2.5. Vaalkop Farms (VAL)

S 29°20′27″ E 29°55′12″

The Vaalkop Farms are a number of smallholdings on a hillside a couple of kilometres below Inchbrakie Falls (INC). The river again commences its meandering nature and the banks of the river are largely tree-lined. There are a number of riffles and deep pools along the length of this section. There is a small wetland at the bottom of the hill (the hill is called Vaalkop; there is a second farm called 'Vaalkop' nearby).

3.3.2.6. 'Mother Goose', Rosetta (MAG)

S 29°17′55″ E 29°58′36″

This shop in Rosetta has access to a one-km (approximately) stretch of the Mooi River. The river flows over a wide diabase sill.

3.3.2.7. Mearns Farm, Edgehill Farm, Mearns Weir (EDG)

S 29°14′56.2″ E 29°57′57.1″

The Mooi River forms the boundary between these two farms. The westernmost side of this area is the location of the confluence between the Mooi and Little Mooi Rivers. The river from the confluence to Mearns Weir is deep with soft clay banks and grass and reeds right up to the water's edge.

Mearns Weir itself is a three-metre high reinforced concrete wall, with adjacent pump-house to extract water out of this catchment to the Mgeni catchment. The 20 metres or so of riverbank downstream from the weir are largely artificial and are made up of cobbles and boulders, held together with fencing wire, placed there during the construction of the impoundment. Downstream of this the riverbanks are different to those upstream of the impoundment; the banks are steep and largely vertical and made up of brittle shale and clay. Several willow trees are present on the riverbanks. Further downstream there is a small 1.5-metre impoundment of boulders (for a farm irrigation pump-house), and then the river goes through a concrete causeway. After this causeway the river widens significantly. By this point the shale banks have reverted to clay banks and these banks are severely eroded. After half a km of wide, relatively shallow water, the river once again narrows as it goes past a rocky hill on the western bank. The banks here are largely shale (although not vertical) and the bottom is composed of gravel.

3.3.3. FIELD SITES ON THE LITTLE MOOI RIVER (Figure 23)

3.3.3.1. Connington Road Bridge (CRB)

S 29°22′38.0″ E 29°55′30.5″

The Little Mooi River is accessible at this point, where it is spanned by a bridge (the bridge is on a road known as Connington Road which connects the Hlatikulu Road from Mooi River to Hlatikulu with the Rosetta to Kamberg road). The river is relatively shallow during the dry season with stable vertical clay banks and a clay and cobble bottom. Trees overhang the river.

3.3.3.2. Hythe Farm (HYT)

S 29°14′24.6″ E 29°57′19.5″

This farm (approximately ten km downstream from Connington Road) is on the western boundary of Edgehill and Mearns farms on the Mooi River. A causeway crosses the river. The river is relatively deep at all times of year. The riverbanks are sub-vertical in most areas and made up of well-consolidated clay. The river-bottom is largely clay, although there is a stretch of rocky riffles to the west of the causeway.

3.3.4. FIELD SITES ON THE KARKLOOF & YARROW RIVERS (Figure 24)

3.3.4.1. SAPPI Shafton Plantation, Howick Road Bridge (HRB)

S 29°22′38.0″ E30°16′48.2″

This road-bridge is located approximately five km further along the Howick to Gilboa road past the turnoff for Shafton Polo Grounds. The Karkloof River is approximately five metres wide, spanned by a modern concrete bridge. The riverbed provides stable footing and a range of bank types from soft unconsolidated silt pockets to well-consolidated mud/sand mixture.

3.3.4.2. SAPPI — Shafton Falls (EMO)

S 29°23′27.8″ E 30°16′38.2″

The Karkloof river is impounded just downstream of this point by a large diabase sill, during the course of which the river drops by approximately 15 metres to a deep pool before pouring over Karkloof Falls a few hundred metres further downstream. The river is of poor clarity at this point — Secchi disc depths of less than a metre were found at most times of the year. The riverbanks are steep with dense growths of reeds, brambles and grass and are particularly difficult to access. Wading in this section of river is further hampered as the banks and riverbed are covered with a thick layer of light silt. This is one of two sites at which CRASS (1947, 1955) found nymphs of *Ephemera mooiana* (the other is Dalcrue, see (DAL) above).

3.3.4.3. SAPPI — Grassland (GRS)

S 29°21′56″ E 30°15′26″

This grassland forms a buffer between the SAPPI conifer plantation to the west and the Karkloof River to the east. The eastern bank is farmed with a sugarcane plantation. It is situated approximately two km due north of the Shafton Falls (EMO) site described above, downstream of the confluence with the Kusane stream. The banks at this site are more stable than those found at EMO with little fine silt. However the banks are deep and access to the river for wading is particularly difficult. This site was chosen due to its proximity with site EMO above and the map and aerial photographs suggested that there were a number of meanders in the area. On-the-ground-survey confirmed this. The river forms a maze of islands and inlets, but deep water and steep banks with long reeds and rushes make sampling a treacherous process.

3.3.4.4. Gartmore Farm (GAR)

S 29°21′22″ E 30°15′26″

Gartmore Farm is situated about one km NNW from the grassland site described above. The farm roads in the area allow for relative ease-of-access to the river.

At some points the banks are heavily eroded, allowing direct wading from the shore without having to contend with steep riverbanks. Wide ranges of habitats are available within a relatively short distance including gravel and cobble riffles and muddy banks as well as mud and rock bottomed pools. At the northern end of this property the Yarrow River tumbles over a number of small rocky waterfalls.

TABLE 5: Summary information relating to the sites investigated during this study.

Locality		Grid Ref (S)	Grid Ref (E)	River (Figure No.)
Kamberg Nature Reserve	KNR	N/A	N/A	Mooi (18)
Reekie Lynn	RLY	S29°23'18.5"	E29°44'22.0"	Mooi (18)
Dalcrue	DAL	S29°21'43.0"	E29°52'28.8"	Mooi (18)
Inchbrakie Falls	INC	S29°20'20"	E29°54'21"	Mooi (18)
Vaalkop Farms	VAL	S29°20'27"	E29°55'12"	Mooi (18)
'Mother Goose', Rosetta	MAG	S29°17'55"	E29°58'36"	Mooi (18)
Edgehill Farm/Mearns	EDG	S29°14'56.2"	E29°57'57.1"	Mooi/Little Mooi (18)
Connington Road Bridge	CRB	S29°22'38.0"	E29°55'30.5"	Little Mooi (19)
Hythe Farm	HYT	S29°14'24.6"	E29°57'19.5"	Little Mooi (19)
Howick Road Bridge	HRB	S29°22'38.0"	E30°16'48.2"	Karkloof (19)
SAPPI; Shafton Falls	EMO	S29°23'27.8"	E30°16'38.2"	Karkloof (19)
SAPPI; Grassland	GRS	S29°21'56"	E30°15'26"	Karkloof (19)
Gartmore Farm	GAR	S29°21'22"	E30°15'26"	Karkloof/Yarrow (19)

3.4 FIELD METHODS

3.4.1. Sampling

Nymphs were sampled qualitatively in an attempt to determine simple presence or absence by dip–netting and by digging out burrows with a trowel, when the riverbanks were accessible enough to make this possible. Dip-netting involved holding a net flush with the river substrate while the substrate a short distance (0.5 m) upstream is stirred up by kicking. It was possible to trap dislodged insects in the net. Two types of net were used; a steel mesh with a 1 mm mesh, and a canvas net with a 25 µm mesh.

When convenient the sample was sorted immediately and the desired specimens preserved. When immediate sorting was not possible the entire sample was preserved and sorted later in the laboratory.

Nymphal burrows were often found in patches. It was found to be impractical to transport sediment samples back to the laboratory intact for characterisation of sediments. Instead samples were categorised in the field into the broader categories outlined in Table 6 (such categorisation is based on the texture of the sample in the hand and its appearance, ideally when compared with a grading chart, widely available in many geological textbooks).

On many occasions other postgraduate students or staff members from Umgeni Water were available to assist in the surveys.

Adults were light-trapped using an ultraviolet light (powered by a 12 volt battery) either hung over a tray of water in which some detergent had been added to break the surface tension (wet trap), or placed behind a square metre of white cloth stretched between two metal poles (dry trap). The wet trap allowed different stations on the river to be sampled simultaneously (as the dry trap requires the researcher to be present to pick off the desired sample). The wet trap has the disadvantage that, as insects are left in the water for some time (sometimes overnight) they are frequently not in as good a condition as those that are trapped in the dry trap and preserved immediately. On warm mornings the wet trap was often found to contain predatory beetles and there was evidence that some of the sample had been damaged. Cows and otters also damaged such unattended traps on occasion.

For the dry trap, insects attracted to the cloth were picked off individually. It was found that creasing the fabric at the base so as to form a 'gutter' was useful —

Ephoron adults have poorly developed limbs and they were never seen to grasp onto any surface. After being attracted to the trap they usually made no effort to take to the wing again, but rather struggled, the females eventually releasing their two egg packets on the ground.

In the last half hour before sunset it was sometimes possible to catch adults flying close to the water surface with a butterfly net.

TABLE 6: Specific terminology is generally used to describe different particle sizes of substrates as outlined in the table below. Adapted from ERIKSEN 1963 and PLUMMER & MCGEARY 1991.

Sediment	Size range (mm)
Boulder	>256
Cobble	64 to 256
Pebble	16 to 64
Gravel	2 to 16
Very coarse sand	1 to 2
Coarse sand	0.5 to 1
Medium sand	0.25 to 0.5
Fine sand	0.125 to 0.25
Very fine sand	0.0625 to 0.125
Silt	0.0039 to 0.0625
Clay	<0.0039

3.4.2. Preservation of insect material

Adults were routinely preserved in 75% alcohol, but occasionally were frozen in paper packets or plastic sample bottles within half an hour of capture. Freezing was found to be a more satisfactory method of preservation than in 75% alcohol in which wings become slack and easily damaged or in 95% alcohol, where they became overly brittle. Frozen wings remained firm and usable even when defrosted. Nymphs were preserved in 75% alcohol or 2% formalin solution.

All the sites surveyed during the course of the project are shown in Figure 23 and Figure 24. Each site was visited at least twice between June 1998 and September 1999. On average each site was surveyed for 4 hours per visit. Between 22 October and 23 December 1999 daily spot sampling was undertaken along a five km course of the Mooi/Little Mooi Rivers near Mearns Weir (EDG and HYT)

Light trapping at Howick Road Bridge (HRB) and Connington Road Bridge (CRB) was not undertaken for reasons of personal security and safety, and at Reekie Lynn (RLY), Dalcrue (DAL) and Inchbrakie Falls (INC) no authorisation to enter private lands at night could be obtained and therefore no sampling was possible.

3.5 RESULTS—NYMPH MATERIAL

Throughout the duration of the fieldwork of this project (June 1998 to April 2000), only one species of burrowing mayfly was found, *Ephoron savignyi*.

Nymphs of *Ephoron savignyi* were found at all sites investigated at some point over the duration of the fieldwork period except Shafton Falls (EMO); Mother Goose, Rosetta (MAG); Reekie Lynn (RLN); and Kamberg Nature Reserve (KNR).

Due to the patchy nature of the distribution of the nymphs it was not possible to estimate numbers of individuals per unit area.

Two types of nymphal material were found during these surveys. Live nymphs and nymphal exuviae.

Live Nymphs: Nymphs of *Ephoron savignyi* were found in most types of substrate surveyed with the exceptions of fine silt, decomposing vegetation and clay with large amounts of plant roots. They were found most frequently and with greatest abundance in burrows in clay riverbanks and in streambeds composed of mixed small cobble, gravel and mud.

Exuviae: Nymphal exuviae were found on a few occasions in kick samples in rocky streambeds and floating on the water surface during adult emergences. On a couple of occasions nymphal exuviae were found when there was no evidence of recent adult emergences. It may be that these exuviae were discarded by nymphs during juvenile inter–instar moults, and that these only rose to the surface when disturbed by kick sampling.

TABLE 7: Summary of trapping results for ephemerid mayfly adults and nymphs, July 1998 to April 2000. (# surveyors) refers to the number of people who surveyed at the site; (# light traps) refers to the number of light traps used at the site (one night of light-trapping lasted for approximately four hours). The figures have not been multiplied together, so for example 8 (2) signifies that two people each spent eight hours surveying. The number of hours spent sampling at Edgehill Farm (EDG) have not been given here (marked with *); EDG was surveyed nightly (weather permitting) from September 1999 until late December 1999. For an explanation of the locality abbreviations, refer to Table 5 (Symbols used: area not surveyed ◎; adult/nymph trapping unsuccessful ✗; adult/nymph trapping successful ✓)

Locality	Nymphs	Hours sampling (# surveyors)	Date sampled; nymphs	Adults	Hours trapping (# light traps)	Date sampled; adults
KNR	✗	8 (2)	May 99	✗	4 (3)	Apr. 99
RLY	✗	4 (2)	May 99	◎	____	________
DAL	✓	16 (1)	Jul. 98; Apr. 00	◎	____	________
INC	✓	8 (4)	Jul. 98; May 99	◎	____	________
VAL	✓	12 (1)	Apr., Jul., Oct. 99	✗	12 (3)	Apr., Jul., Oct. 99
MAG	✗	4 (1)	Sep., Nov. 99	✗	4 (3)	Sep. 99
EDG	✓	*(1)	Sep. 99 to Apr. 00	✓	*(2)	Dec. 99 to Apr. 00
CRB	✓	24 (1)	Jul., Nov. 98; Jul., Sep 99; Apr. 00	◎	____	________
HYT	✓	20 (1)	Oct. 98; May, Oct. 99	✗	12 (3)	Jul., Oct. 99
EMO	✗	12 (3)	Oct. 98	✗	12 (3)	Oct. 98; May 99
HRB	✓	4 (1)	May 99	◎	____	________
GRS	✓	8 (1)	Sep. 99	✓	8 (2)	Apr. 99
GAR	✓	8 (1)	Sep. 99	✓	4 (3)	Mar. 00

3.6 RESULTS—ADULT MATERIAL

Live adults of *Ephoron savignyi* were only rarely encountered before nightfall. When possible these were trapped with the butterfly net.

No mating swarms were ever seen (it is presumed that the insects did swarm after dark). This made it impossible to sample quantitatively to ascertain the proportion of the sexes at different times of day. However when it was possible to catch adults in the butterfly net, most were found to be male, indicating that many males may emerge prior to the females. Males were often seen flying close to the surface of the water, their subimagal skin frequently drifting behind them, still connected to the ends of their caudal cerci.

Adults were found at all sites at which nymphs had been found with the exception of Hythe (HYT) and Vaalkop (VAL). Adults of *Ephoron savignyi* were first found in light traps on 04 December 1999. Numbers of adults trapped remained low (below ten per trapping session), until 19 December, when in excess of 100 individuals were trapped. Numbers trapped reached a peak on 18 January, when in excess of 1500 individuals are estimated to have been trapped. By 09 March less than five individuals were caught in light traps. The last light-trapping session was carried out on 10 April. On that occasion, no *Ephoron savignyi* adults were caught. This information is summarised in Figure 25 (these figures are estimates — the large emergences from 23 December to 20 January precluded the use of a wet trap, which is only large enough to effectively trap approximately 200 insects. It was judged to be undesirable to retain all the individuals attracted to dry traps as the sole purpose of removing these individuals and their eggs from the ecosystem was to count them. Some individuals were retained on every occasion for taxonomic purposes however).

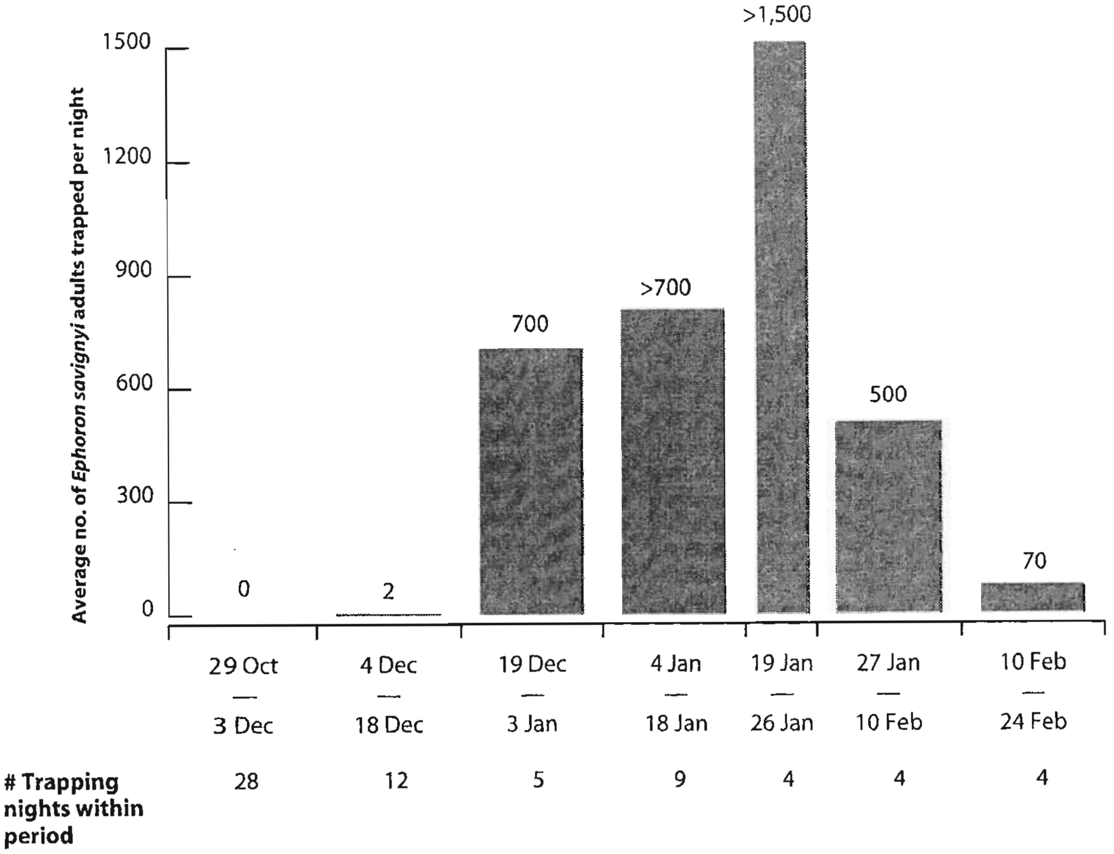


FIGURE 25: Summary histogram of trapping results from 04 December 1999 to 24 February 2000. The estimated number of adults (imagoes and subimagoes) of *Ephoron savignyi* per trap, per night caught at light traps on or near Mearns Weir, Edgehill Farm (EDG). Note the variable scale of the x-axis.

3.7 DISCUSSION

3.7.1. Assessment of methods used to trap nymphs

A. Digging

Digging for nymphs was found to be the most reliable method of catching nymphs. Using this method it was possible to characterise approximately what type of substrate the nymph was dwelling in.

The burrows of nymphs of *Ephoron savignyi* could usually be easily recognised from the water surface when light was good and the water was clear. The only other invertebrates that made similar looking burrows were oligochaete worms and alder-fly larvae. However oligochaetes generally have a distinctive fibrous burrow, and alder-fly larvae (Neuroptera; Sialidae) were only rarely encountered.

B. Kick Sampling

Of the two net types employed (a canvas/nylon net and a stainless steel mesh), the stainless steel mesh was found to be generally more useful. While the minimum size of material caught was relatively large due to the large mesh diameter size of the net, this also meant that less silt was caught in the net and it could be used for longer without clogging. The durability of the net ensured that it could be used to scour mud and rocks without damage to the net. The canvas/nylon net was useful if placed a metre or two downstream of the kicking site as this allowed some of the silt to settle or disperse before clogging the net.

B. Van Veen Grab

The Van Veen grab was not found to be useful. It was employed on one occasion as a method of surveying water that was too deep for wading — between 1.5 and 2.5 metres. However, the messenger used to close the jaws was unreliable due to the short distance that it had to travel and the jaws were almost always jammed by rocks when they did manage to close partially. No satisfactory method of surveying water of this depth was found.

3.7.2. Results of nymphal survey

The biggest problem with the field survey was that no method was found to satisfactorily sample pools that were too deep for wading but not deep enough to use a remote grab such as the Van Veen grab used during this survey. This may help to explain why this superfamily of insects is so poorly known from the nymphal life stages. McCAFFERTY & GILLIES (1979 and Dr WP McCafferty, Purdue University, Indiana; 2000 pers. comm.) have commented that nymphs probably dwell in such 'deep' pools. This may be especially characteristic of rivers like the Mooi showing extreme hydrological variability, where deep pools would provide the only habitat refugia, persistent throughout the year. McCAFFERTY (pers. comm. 2000) has also noted that even with knowledge from light trapping that a population of ephemerid mayflies is probably present in a stretch of river and this is subsequently proven, it can take days of physical sampling in a relatively small area to get any samples of the nymphs.

3.7.3. Results of adult survey

Qualitatively, adult surveys produced generally satisfactory results — adults of *Ephoron savignyi* were found at all sites where nymphs had been found with the exception of two sites. As can be seen from Table 7 these sites were sampled for a shorter period than other more successful sites, so this failure may be due to the amount of time dedicated to sampling at each site. While all surveys only produced one species — *Ephoron savignyi* — the results of earlier workers in finding *Afromera natalensis* with relative frequency in the last 50 years does suggest that this mayfly should still be present on the river. It may be that the adults of *Afromera natalensis* (or any of the other species not found during the field surveys) are not attracted to lights.

Quantitatively the results of this work are of little value. In theory dry-traps allow the surveyor to derive quantitative results; it is possible to determine exactly the number of insects picked off the cloth of the trap per unit time. Unfortunately the reality is that it is difficult preserve individual insects when in the midst of the millions of insects attracted to the light trap. Wet-traps have the advantage of allowing one surveyor to set up multiple traps and to sort and assess the contents of the traps at a future time. However they rapidly fill up with other insects precluding the entry of other insects (caenid mayflies were found to be abundant in the traps), meaning that it is impossible to derive a quantitative result because it is not possible to assess which insects have escaped the trap.

3.8 Conclusions

The field survey component of this work produced results typical of other surveys of Ephemeroidea in Africa (EDMUNDS & MCCAFFERTY 1986, ELOUARD 1986a, MCCAFFERTY & GILLIES 1989); nymphs were found haphazardly in the rivers and adults sampled in relatively large numbers seasonally.

The fact that the larvae were encountered irregularly does offer some hope that those species that were not sampled during the course of the study have not become extinct, but rather were not successfully sampled in the time available. In particular, it was impossible to sample deep river pools during this study; drift netting in such pools combined with periodic light trapping may be of great help in determining whether Ephemeroidea are present in the Mooi, Little Mooi and Karkloof rivers.

4 CONCLUSIONS

This work was only partially successful in the completion of the aims set out in Section 1.2. A comprehensive taxonomic review of the Ephemeroidea of KwaZulu-Natal was carried out. However, disappointingly, verifiable type specimens were not found for *Eatonica schoutedeni*, *Afromera natalensis*, *Afroplocia sampsoni* or *Ephoron savignyi*. The recent discovery of new species of *Eatonica* in Africa and the lack of a quality type specimen for *Eatonica schoutedeni* indicates that it would be highly desirable for the appointment of a new type specimen for *Eatonica schoutedeni*. In accordance with ICZN guidelines such a specimen should come from the Democratic Republic of the Congo.

The status of *Ephoron savignyi* would also benefit from the appointment of a new type specimen. It is not sufficient to rely on the 'holotypes' of the Royal Museum for Central Africa (TER) as they are not acceptable under ICZN guidelines (it is not possible to have two holotypes). Instead a new type specimen should be appointed. While a large number of specimens identifiable as *Ephoron savignyi* were trapped during the course of this research, as they do not come from near the original type locality for *Ephoron savignyi* (The Nile, Egypt) they have not been appointed as types for this species.

The nymphs of *Ephoron savignyi* are widespread in the rivers of the KwaZulu-Natal midlands. During this study nymphs were found in U-shaped burrows in riverbanks composed of most substrates including shale conglomerates and in river bottoms, but not in fine silt or riverbanks that contained dense plant roots. The greatest densities of nymphs were found in well-consolidated homogenous clay riverbanks and in gravely river bottoms with little sand. As this species is widespread in the rivers of the province there is no reason to feel that impoundments would have a serious negative impact on this species in KwaZulu-Natal. Indeed the presence of large numbers of *Ephoron* specimens at Mearns Weir, Edgehill Farm

(EDG) indicates that *Ephoron savignyi* may be well adapted to living in close proximity to a man-made impoundment.

The adults of *Ephoron savignyi* are readily attracted in large numbers to ultra violet lights making this species relatively easy to sample.

There are no collections of *Eatonica schoutedeni* recorded from KwaZulu-Natal. Future collectors should however be aware that the closely related species *Eatonica crassi* has probably been misidentified as *Eatonica schoutedeni* in the past and therefore care should be taken when identifying any species of Ephemeridae collected in southern Africa.

No specimens of *Ephemera mooiana*, *Afromera natalensis* and *Afroplocia sampsoni* were trapped during the course of this study.

The finding of only one species of ephemeroid mayfly in KwaZulu-Natal leads to two possible conclusions. Firstly, the sampling effort was too limited in time and space to capture specimens of species other than *Ephoron savignyi*. Secondly environmental changes since previous in-depth surveys, in particular the work of CRASS (1947, 1955) have resulted in the extirpation of the mayflies in question. The limited evidence currently available makes it impossible to choose between these two possibilities.

The failure to find four of the five species of ephemeroid mayfly recorded from KwaZulu-Natal meant that this research failed in its aim to determine whether impoundments would have a deleterious effect on species resident in the river.

However, the systematic reappraisal which forms the focus of this study suggests that the prevailing perceptions regarding high mayfly species diversity in this river system arise partly from ambiguous or invalid systematic information. The corrections identified in this study ideally require further confirmation by future studies. Nevertheless these findings suggest that the impact of impoundments on mayfly biodiversity on these rivers may have been overstated.

The systematic synopsis undertaken here will provide a firm foundation for further investigations of mayflies in southern Africa.

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Appendix 1.

SUPRASPECIFIC CLASSIFICATION OF RECENT EPHEMEROPTERA

(McCafferty 1991a)

The following list details the most up to date supraspecific classification of recent Ephemeroidea (as proposed by McCAFFERTY 1991a).
Asterisked genera are those which, according to McCAFFERTY (1991a) require further analysis to be certain of their placement in this classification.
Taxa recorded from South Africa are emboldened thus; (**Genus *Ephoron***).
World distribution of subfamilies is indicated by the following appended abbreviations: **AF**, Afrotropical; **HO**, Holarctic; **MA**, Madagascar; **NA**, Nearctic; **NT**, Neotropical; **NZ**, New Zealand; **OR**, Oriental; **PA**, Palearctic; **PT**, Pantropical.

- **Superfamily Ephemeroidea**
    - **Subfamily Polymitarcyidae Banks** [AF]
    - Subfamily Euthyplociinae Lestage [MA, OR, NT]
        - Genus *Campylocia* Needham & Murphy*
        - Genus *Euthyplocia* Eaton*
        - Genus *Mesoplocia* Demoulin*
        - Genus *Polyplocia* Lestage*
        - Genus *Proboscidoplocia* Demoulin*
    - **Subfamily Exeuthyplociinae Gillies** [AF]
        - **Genus *Afroplocia* Lestage**
        - Genus *Exeuthyplocia* Lestage
    - **Subfamily Astenopodinae Edmunds & Traver** [PA, PT]
        - Genus *Asthenopus* Eaton
        - **Genus *Povilla* Eaton**
    - Subfamily Campsurinae Traver [NA, NT]
        - Genus *Campsurus* Eaton
        - Genus *Tortopus* Needham & Murphy
    - **Subfamily Polymitarcyinae Banks** [AF, HO, OR]
        - **Genus *Ephoron* Williamson**

- Family Potamanthidae Albarda [HO, OR]
    - Genus *Rhoeanthus* Eaton
        - Subgenus *Rhoeanthus*
        - Subgenus *Potamanthidus* Lestage
    - Genus *Anthopotamus* McCafferty & Bae
    - Genus *Potamanthus* Pictet
        - Subgenus *Potamanthus*
        - Subgenus *Stygifloris* Bae, McCafferty & Edmunds
        - Subgenus *Potamanthodes* Ulmer

Continued overleaf...

- **Family Ephemeridae Latreille**
  - Subfamily Ichthybotinae Demoulin [NZ]
    - Genus *Ichthybotus* Eaton
  - **Subfamily Ephemerinae Latreille** [AF, HO, OR]
    - **Genus *Ephemera* Linnaeus**
      - **Subgenus *Ephemera***
      - Subgenus *Aethephemera* McCafferty & Edmunds
    - **Genus *Afromera* Demoulin**
  - **Subfamily Hexageniinae** [AF, HO, OR, NT]
    - Genus *Hexagenia* Walsh
      - Subgenus *Hexagenia*
      - Subgenus *Pseudeatonica* Spieth
    - Genus *Eatonigenia* Ulmer
    - **Genus *Eatonica* Navas**
  - Subfamily Pentageniinae McCafferty [NA]
    - Genus *Pentagenia* Walsh
  - Subfamily Palingeniinae Albarda [AF, MA, OR, PA]
    - Genus *Palingenia* Burmeister
    - Genus *Anagenesia* Eaton*
    - Genus *Chankagenisea* Buldovskij *
    - Genus *Cheirogenesia* Demoulin*
    - Genus *Mortogenesia* Lestage*
    - Genus *Plethogenisia* Ulmer*

Appendix 2.

PERSONAL COMMUNICATIONS

The following pages contain edited versions of e-mails of relevance to this work cited in the thesis as personal communications (pers. comm.). A summary of the information requested is given before the text making up the personal communication. In all cases the communications have been edited for brevity, clarity or confidentiality. Deletions are marked with an ellipsis (...), additions with square brackets ([ ]).

****

Information Requested:

a. The locality for *Afroplocia sampsoni* nymphs cited in EDMUNDS & MCCAFFERTY, 1996.

b. Informed Dr. McCafferty of presence of probable female Adult of *Eatonica crassi* in Pietermaritzburg entomology collection.

Reply from: Dr WP McCafferty, 08 Feb 2000.

...According to the only data I have on the locale, it was "Natal: Mooi River, just below the town of Mooi River, 1360 m elevation, 9-20-1990, W.P. McCafferty, N. McCafferty, and B. Fowles." ... It was only after moving out of the muck and onto a more mixed substrate that a young *Afroplocia* larva was kicked up. I believe the population must have primarily been in water too deep at the time to safely collect because I could not come up with additional specimens ... That I did not get any other specimens could also have meant that the larva drifted in from upstream. Anyway, because I did not come up with additional specimens, the habitat observations remain incomplete and anecdotal, as you can tell from the short comments in the Edmunds and McCafferty note that you referred to ...

...I have recently seen some ... large populations of *E. crassi* males and females taken at light on an island in Lake Malawi ... It would not surprise me if *E. crassi* occurred even farther south. Such wide ranges of species are very typical of the hexageniine group of the Ephemeridae. Many of our North American species of *Hexagenia* occur from coast to coast, just about. Some *Euthyplocia* are also excellent dispersers and are known transcontinentally (from Brazil to Mexico in the Western Hemisphere)...

****

Information Requested:

a. Discussion on the difficulty of finding specimens of burrowing mayflies

Reply from: Dr WP McCafferty, 09 Aug 1999

... It can be very difficult to locate larval population of burrowing mayflies, both ephemerids and polymitarcyids. For years we searched for the larvae of *Pentagenia* in areas where we regularly would get adults. Finally we discovered huge populations in the cut banks (burrowing initially horizontally into the banks) in deep large rivers that were particularly difficult to collect ... We don't have much problem with finding *Ephoron album* and *leukon* locally, once you know about where they are (but the two sister species strangely have quite different microhabitat requirements)...

****

Information Requested:

a. confirmation of the ID of *Afromera natalensis* female adult in a light trap from the Mooi River, 1996

Reply from: Helen Barber-James, Albany Museum, Grahamstown, RSA, 09 September 2000

...I have just checked the specimen concerned, and then got Carlos [Lugo-Ortiz, visiting from Purdue University, Indiana, USA] to identify it separately as a back up. We both agree that it must be *Afromera natalensis*. It is a female, so no genitalia to confirm the id ...

****

Information Requested:

a. One of a series of e-mail discussions noting the fact that only one species of burrowing mayfly was found during the fieldwork for the project.

Reply from: Dr F deMoor, Albany Museum, Grahamstown, RSA, 29 February 2000

... In the sample I collected in January 1996 out of the sample of burrowers examined we noted that there were 400 female *Ephoron savignyi* and one female *Afromera natalensis*. ...Also the species of *Afromera* and other ephemerids may not be attracted to lights. It furthermore appears that there is a distinct difference in the start of flight activity in males and females of *E. savignyi* with the former appearing to fly some time earlier maybe before dusk?

Timing of the life span of adults was this from emergence to death? It is well documented that many of the burrowers once they have taken flight actually never settle down and the females die "spreadwing fashion" expelling all their eggs in bursts of abdominal convulsions as they die on the water surface...

****

Information Requested:

a. If Dr. De Moor knew of the recorded location of type specimens of *Ephoron savignyi* from Barnard's or Crass' collections.

Reply from: Dr F deMoor, Albany Museum, Grahamstown, RSA, 24 March 2000

...Regarding the *Ephoron* type material. You will have to contact the institutions where it is supposed to be housed to find that out. The specimens of Barnard and Crass appear to be missing. They are not types though...

****

Information Requested:

a. In personal conversation with Dr. De Coninck at Tervuren, asked if she would be able to determine the location of 'Fetish Rock', a type locality for *Ephoron savignyi* from the Tervuren collection.

Reply from: Dr E De Coninck, Royal Africa Museum, Tervuren, Belgium, 31 July 2000

The "Fetish Rock" locality is mentioned in the publication of R.P. Longinos Navás, S.J. (1916): Neurópteros nuevos o poco conocidos – Memorias de la Real Academia de Ciencias y Artes de Barcelona, Vol. XII, Num.13, page 220.
The author made a mistake by situating Fetish Rock in the "Congo belga": it belongs to Angola and is located very near to the border of the former Belgian Congo and the Congo river, the coordinates are: 5° 55'S/12° 58'E and the name in portuguese is "Pedra de Feitico"...

****

Information Requested:

a. Regarding Eaton's (1883) discussion of the colouration of *Ephoron savignyi* and his reference to a colour 'VanDyke Grey' requested advice from Winsor Newton.

Reply from: Dr A Foster, ColArt Ltd [Winsor Newton], England, 02 August 2000

We can find no reference to a VanDyke Grey, it could be specific to a manufacturer. Artists' colours are not generally colour matched to any system, and the colour name does not specify an exact hue. One manufacturer's VanDyke Brown is likely to be different from another. VanDyke Brown was a natural bituminous earth and its colour has varied from a reddish brown to a greyish brown over the last 50 years. Winsor & Newton are one of the few manufacturers who still use the natural pigment but it has to be tinted to maintain a consistent colour.

****

ACKNOWLEDGEMENTS

It would have been impossible to undertake and finish this piece of work without the generous support and help of the following people and institutions:

my supervisor Professor Rob C. Hart, University of KwaZulu-Natal, Pietermaritzburg;

my co-supervisor Dr. Ferdy de Moor, Albany Museum, Grahamstown;

Dr. Chris Dickens of Umgeni Water, Pietermaritzburg for facilitating project bursary and funding from Umgeni Water and the loan of equipment;

my parents;

Mr. Gerry McGuinness;

Mr. Neville and Mrs. Margaret Kean, Mooi River, for providing lodging during the course of fieldwork;

the staff of the Department of Aquatic Invertebrates, Albany Museum, Grahamstown, in particular Ms. Helen Barber-James;

the staff of the entomology departments of The Royal Museum for Central Africa in Tervuren, Brussels, in particular Dr. Eliane de Coninck and her staff, The Royal Belgian Institute for Natural Sciences, Brussels and The Natural History Museum, London, in particular Mr. David Goodger;

Dr. Naoshi C. Watanabe, Kagawa University, Japan, kindly provided papers and samples of Japanese Polymitarcyids;

the staff of the SAPPI plantation at Shafton, Howick allowed access to the Karkloof River in the plantation;

for help in the field; Sven Bourquin, Hallam Payne, Nick Rivers-Moore, Carol-Ann Rolando, Eden Wildy;

for advice and information on technical aspects of the project; Ms. Angela Beaumont, Mr. Billy Boodhoo, Dr. Harriet Eeley, Mr. Mark Graham (Umgeni Water), Dr. Michelle Hamer, Dr. Simon Lorentz (CCWR), Dr. Ray Miller, Mr. Cobus Pretorius (CCWR), Dr. Jaishree Raman, Ms. Val Taylor (CCWR), Mrs. Colleen Westwood, Mrs. Gael Whitely, and the staff of the Electron Microscopy Unit;

thanks are also due to Eoghan Doyle, Mrs. Jane Flockhart (UNP), Dr. Ken Irvine (TCD), Aiveen Kemp, Dr. Pat McCafferty (Purdue University, Indiana), Dr. Ian Donoghue (TCD), Dr. Julian D. Reynolds (TCD), Dr. Tim Power (CMU, Pittsburgh), and Sophie Vanwambeke.