Article

How well are Afrotropical mayflies known? Status of current knowledge, practical applications, and future directions

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Abstract

Mayflies (Ephemeroptera) are a merolimnic insect order (part of the life cycle is aquatic) and play an important role as biological indicators of river ecosystem health. In the Afrotropical realm (including sub-Saharan Africa and Madagascar), this order presently encompasses 122 genera and more than 400 species; all species and 85% of the genera are endemic to the Afrotropics. A great part of the diversity still remains unknown. The specific and generic diversity of mayfly families from Madagascar and from 4 sub-Saharan African subregions (West Africa, western Central Africa, eastern Central Africa, and southern Africa) is presented. A concurrent comparison of this diversity with the level of taxonomic knowledge for each subregion highlights inadequacy of knowledge. It is important for freshwater conservation biologists and ecologists, and for biomonitoring programs, to have a level of certainty when identifying taxa. This preliminary synthesis is intended to stimulate future taxonomic research and collecting efforts in understudied regions that will lead to species descriptions and recognition of the biodiversity of these regions. This information will feed into regional identification keys and enable more accurate species identification. Greater understanding of the diversity of organisms, the foundation for all ecological studies, can be used to refine biomonitoring protocols for freshwater organisms.

Key words: Africa, Afrotropical, biomonitoring, diversity, Ephemeroptera, Madagascar, species, taxonomy

Introduction

Freshwater macroinvertebrates have been used for more than a century in biomonitoring of riverine ecosystems, and mayflies are well recognized as one of the key groups for this purpose (Brittain 1982, Moog et al. 1997, Bauernfeind and Moog 2000, Beketov 2004, Arimoro and Muller 2010). Mayflies are particularly well suited to such studies because the majority of their life cycle is aquatic (the winged stages are short lived), and different species cover ranges of ecological tolerances. For example, the South African Baetidae family includes species that are habitat specialists sensitive to environmental change and therefore limited in their distribution, while other species are much more tolerant. As an example, *Demoreptus capensis* (Barnard) is restricted to cool montane rivers in hygropetric and stony run biotopes (personal observations; Albany Museum records), while the more widespread *Baetis harrisoni* Barnard *s.l.* is not restricted by temperature and is found in a diverse range of rivers in several biotopes within a river (Albany Museum records; Pereira da Conceicoa et al. 2012).

The aim of this research is to assess how well the Ephemeroptera fauna of the Afrotropical region is known, whether the knowledge of currently described species is reflective of true mayfly diversity, and whether studies carried out on aquatic ecosystems are based on an adequately known fauna. This information has significant

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implications for the successful monitoring of freshwater ecosystems because without a solid foundation of species identification, results of ecological studies can be nearly meaningless. While in some cases monitoring results may be sufficient for answering a simple question, they do not provide adequate identification to the species level for problems requiring proper investigative research, as was clearly demonstrated by de Moor (2002).

We pose the question, should riverine studies be restructured to place a greater emphasis on studying the diversity of freshwater taxa such as mayflies at the species level to avoid the sweeping generalizations that often result from family-based rapid assessments? A synthesis of the current status of taxonomic knowledge of the mayfly fauna is used to guide future taxonomic research and to highlight the inadequacies of rapid bioassessment methods when the taxonomic knowledge is lacking.

Methods

The continent of Africa was divided into 5 subregions for this investigation (Fig. 1). These subregions were adapted from the freshwater bioregions of Thieme et al. (2005) by combining some of their smaller bioregions to produce subregions of more or less similar area for comparison. The focus was on the Afrotropical region, defined by Crosskey and White (1977) as sub-Saharan Africa lying south of the 254 mm rainfall isohyet forming the southern limit of the Sahara Desert (Fig. 1), and including Madagascar due to strong faunal associations. North Africa, although part of the Palaearctic realm due to its stronger affinities with European fauna (Thomas 1998), was compared here with the other subregions to provide a complete assessment of recorded mayfly diversity in Africa. The Sahara Desert was included with North Africa in this analysis.

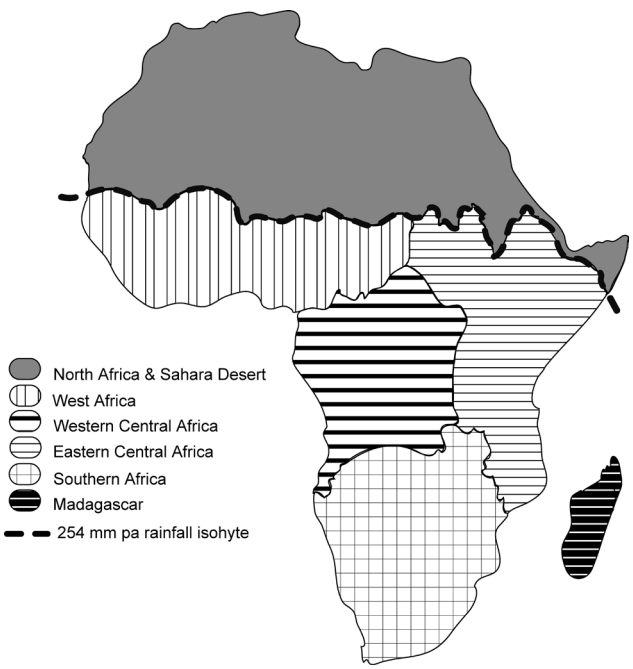

Fig. 1. Subregions used for comparative studies of mayfly faunistic composition (adapted from Thieme et al. 2005), showing the Afrotropical region south of the Sahara Desert, as approximated by the 254 mm rainfall isohyte, following Crosskey and White (1977).

Three approaches were combined to estimate species diversity and the level of taxonomic knowledge in each region. The first was a synthesis of all literature referring to species descriptions and subsequent taxonomic changes using the number of taxonomic publications as a surrogate to estimate number of species. Because some of the species occurring in North African also occur in Europe, dates of the first mention of those species in North Africa, often many years after description in Europe, were used; dates of first publication of taxon names were also included for comparison. The second approach used actual species numbers based on the checklist of mayfly species of the world, housed on the Freshwater Animal Diversity Assessment (FADA) database (Barber-James et al. 2011). In this case, North African species were represented only by their first record in Africa. A third approach looked at species composition reflected at the family level for each subregion, providing an indication of the dominance of each family in each subregion.

Additionally, the results of mayfly species determination from several localized case studies from different areas were selected as examples to estimate the proportion of the mayfly fauna that remain unknown at the species level in different regions. Some of these data are published (e.g., de Moor et al. 2000) or are in reports (Barber-James 1994, de Moor and de Moor 2008a, 2008b, de Moor and Bellingan 2010). Other data are from museum records of material collected by colleagues (Dr. Francis Arimoro, Delta State University, Nigeria; Dr. Mark Graham and associates, Ground-Truth Biomonitoring Services and Environmental Consultants, Hilton, South Africa).

Results

An estimate of species diversity in each subregion since the 1750s, based on the number of papers describing new mayfly species or taxonomic changes (Fig. 2), provides a reasonable representation of the cumulative number of actual species described per subregion over time (Fig. 3). While the trend for species increase generally matches increase in publication number, the magnitude of change differs because many species descriptions may be included in one publication. Mayfly taxonomy in Africa began in earnest in the early 1900s (Fig. 3). The earlier dates

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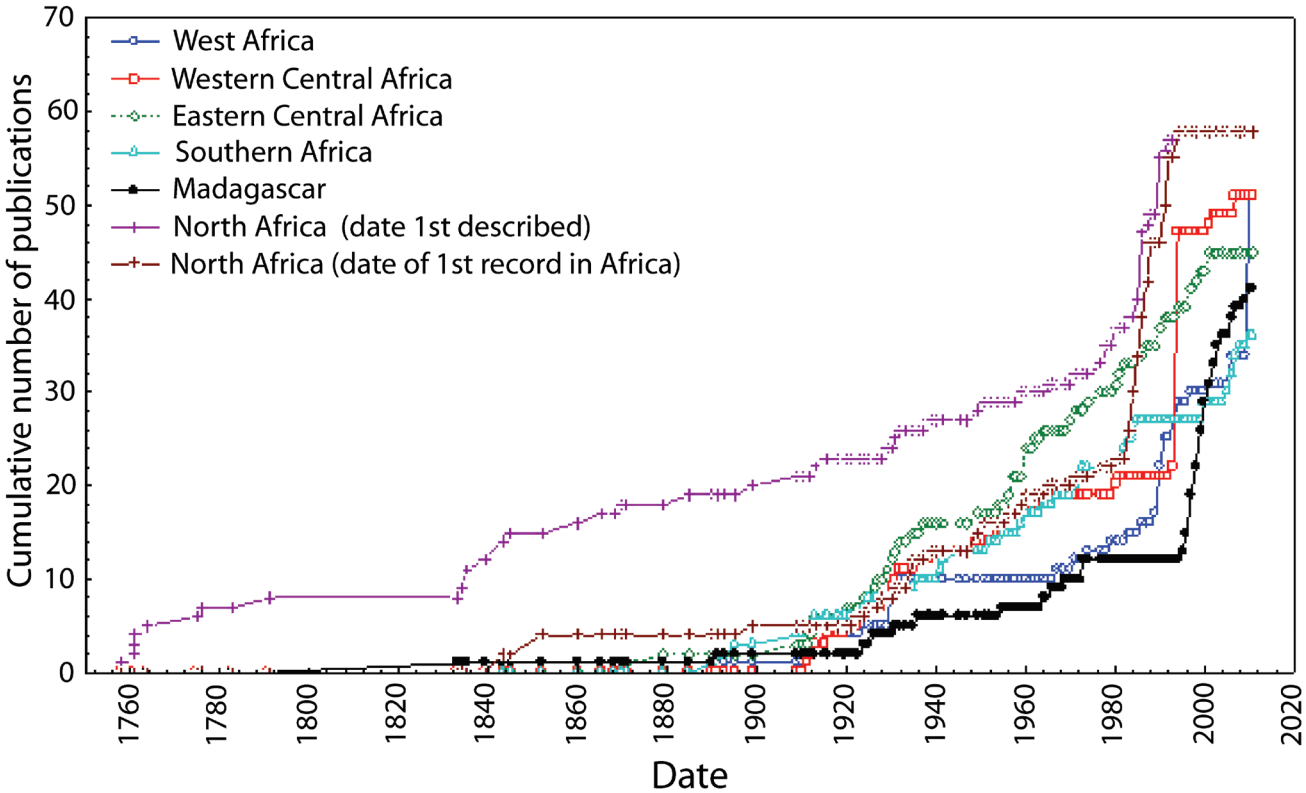

Fig. 2. Cumulative number of publications per subregion dealing with mayfly systematics. Note that for North Africa, the line showing the date of first description of a species differs from that showing the first record of species in Africa because several Palaearctic species occurring in North Africa were described earlier from Europe.

(Fig. 2) reflect descriptions of European species that were subsequently discovered in North Africa. The data for first records in North Africa show that records of newly discovered species in the region peaked in the 1980s.

The pie diagrams (Fig. 4) show the dominance of species representing particular families in each subregion. The number of species in Baetidae in relation to the total number of species of Ephemeroptera in each of the 6 subregions indicates that Baetidae is clearly the dominant family throughout Africa and Madagascar. Other families are also notably more speciose in some regions than in others: for example, Heptageniidae and Leptophlebiidae in North Africa, Caenidae in eastern Central Africa, Leptophlebiidae in southern Africa (with an endemic genus), and Tricorythidae in Madagascar (with 2 endemic genera; Barber-James and Lugo-Ortiz 2003, Barber-James et al. 2011).

A summary of selected case studies shows the proportion of mayfly species identifiable to species level in different studies (Table 1) and clearly indicates the inadequacy of knowledge of the Afrotropical mayfly fauna. All cases had a number of undescribed species, including one new genus from the brown acidic rivers of the Tsitsikamma area in the southern Cape of South Africa, an area considered well known. In 2 studies (rivers in Delta State, Nigeria, and the dolomitic rivers of the Molopo region in northwest South Africa), more species were unknown than known. Recent preliminary unpublished identifications of mayfly specimens from Zambia (S. Lowe, University of Glasgow, May 2011, pers. comm.) indicated at least 2 unknown genera and many unknown species.

Discussion

Certain periods of immense increase in species number are often the product of the efforts of one person or team focusing on a particular region. For example, the large increase in species number in southern Africa during the 1930s is due to the work of Barnard (1932), who described 22 new species, while in the 1940s it was due to Crass (1947), who described 20 new species. Gillies worked on East African mayflies (Gillies 1954, 1957, 1960, 1974, 1977, 1985), then collaborated with Elouard on West African Baetidae (Gillies et al. 1990, Gillies and Elouard 1990). Gillies described more than 20 species between 1954 and 2001, mainly Baetidae. In the 1960s and 1970s,

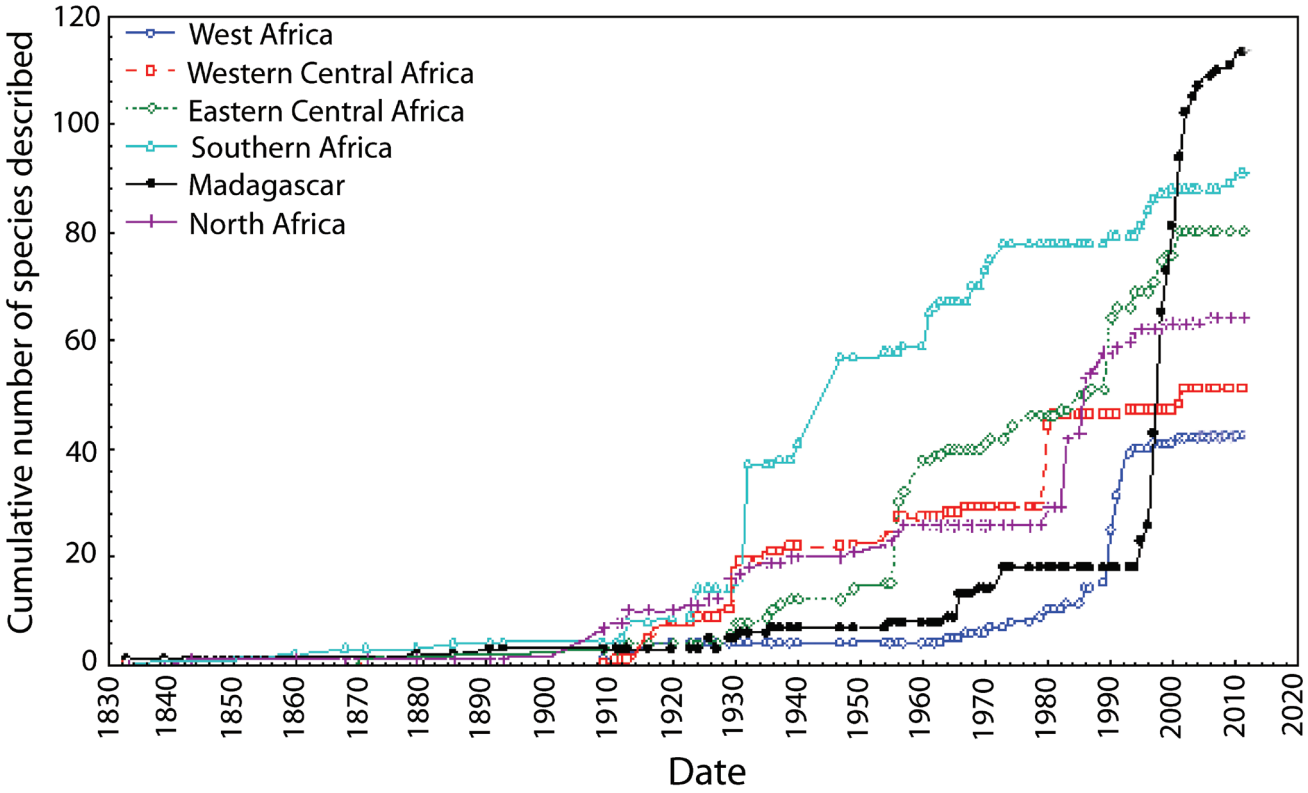

Fig. 3. Cumulative number of species described per subregion, determined from the Freshwater Animal Diversity Assessment (FADA) database (Barber-James et al. 2011).

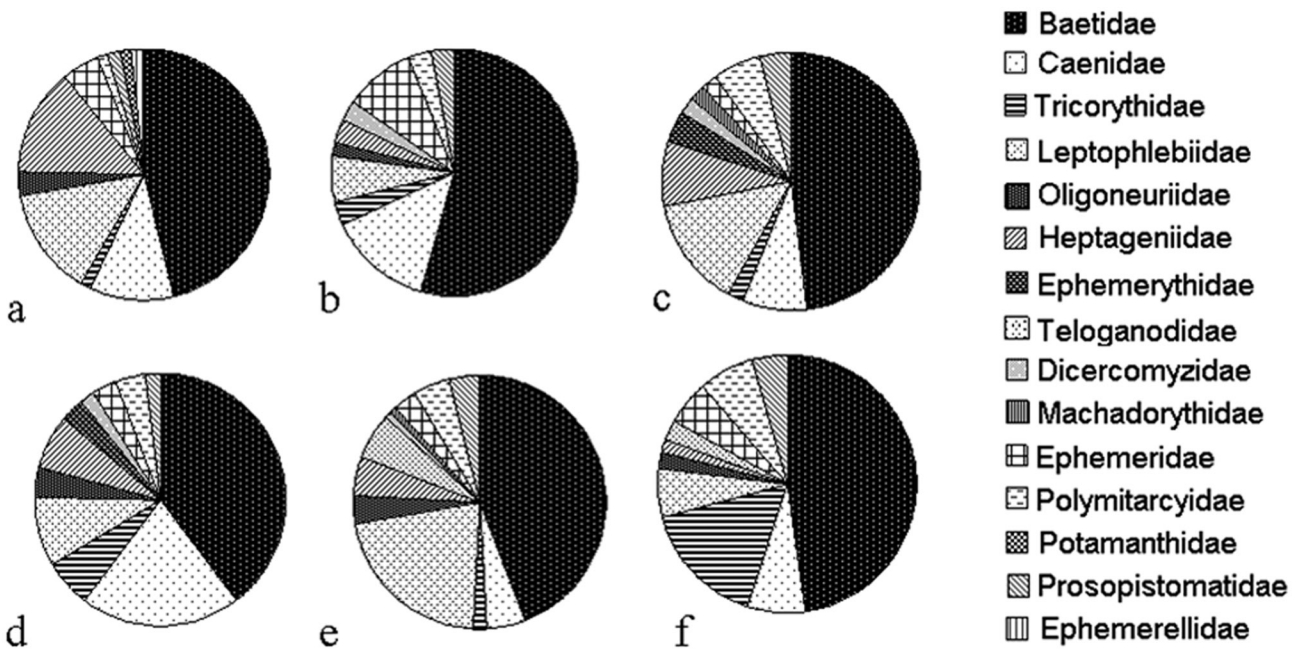

Fig. 4. Distribution of the species among families (named clockwise) in the different subregions: (a) North Africa, (b) West Africa, (c) western Central Africa, (d) eastern Central Africa, (e) southern Africa, (f) Madagascar.

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Table 1. Examples of river surveys, showing the number of Ephemeroptera species collected, and percentage of undescribed species recorded. All data are from Albany Museum records.

Region and dates of study	No of species collected	No of undescribed species	% species new to science	No of new genera
Nigeria – Delta State (3 rivers) 2005, 2008	16	12	75%	0
DRC (Kasai Province) (3 rivers) 2007	17	5	35.7%	0
Namibia – Cunene River (1 river) 1997–1998	44	13	29.5%	0
South Africa – Molopo Oog (4 rivers) 1995	27	15	55.5%	0
South Africa – Tsitsikamma Rivers (11 rivers) 2005–2010	22	8	36.4%	1
South Africa – Mkomazi and Mooi Rivers, KwaZulu-Natal 1995–1996	52	8	15.4%	0
Mozambique (lakes and wetlands) 2008	9	4	44.4%	0

Demoulin described several mayfly species, often citing a letter or number as a species reference rather than a formal name; he also produced the first monograph on Afrotropical mayflies (Demoulin 1970), which was updated by Elouard and Vololomboahangy (1992) and again periodically from 1997 onward by Barber-James in the form of on online updatable checklist with synonyms (for the current version see Barber-James 2011). During the last 20 years, Malzacher has been studying Caenidae from East and West Africa, as well as from Madagascar; half of the caenid species known from the Afrotropics were described by him (Malzacher 1990, 1993, 1995), mostly in adult stages.

Species known from western Central Africa were largely described before the mid-20th century, except for 17 new species described from the Kalengo mountains near Lake Kivu in the Democratic Republic of the Congo (Kopelke 1980). Almost all these species are still only known in the imaginal stage and have not been subject to subsequent inclusion of the pre-imaginal stages and revision. Specific identification of nymphs from this subregion is, in most cases, impossible except for species that may have been described from other subregions.

Contributions of Elouard and coworkers are of great importance to the knowledge of mayflies from West Africa (Guinea, Ivory Coast, Mali, and Sénégal); their input concerns several families, generally with the description of both nymphal and imaginal stages (Elouard 1986, Elouard and Gillies 1989, Elouard et al. 1990, Elouard and Hideux 1991).

McCafferty and coworkers' contributions, especially those of Lugo-Ortiz, were also of great importance, describing 44 unknown species among them from 1971 onward, with a peak of activity in the 1990s focussing mostly on Baetidae (Lugo-Ortiz and McCafferty 1996a, 1996b, 1997, 1998, McCafferty 1971, 2001). McCafferty and collaborators also solved several nomenclatural problems, especially concerning generic attribution (Lugo-Ortiz and McCafferty 1999, Jacobus et al. 2006). Collaboration between Barber-James and Lugo-Oritz (2003) produced the first comprehensive field guide to genera for the Afrotropical mayflies.

Improved knowledge of the Malagasy fauna was quite recent and rapid (Fig. 3) due to the collecting efforts of Elouard and his Madagascan-based team between 1990 and 1999. During the last 20 years about 100 new mayfly species were described from this island (Elouard and Gibon 2001), half belonging to the single family Baetidae (Gattolliat and Sartori 2003) and 39 being described by Gattolliat from 1998 onward (Gattolliat 2000, 2001a, 2001b, 2002a, 2002b, 2006, Gattolliat and Sartori 1998, 1999, 2000, Gattolliat et al. 2009, Gattolliat and Monaghan 2010). Although this highlights the great diversity of mayflies found on the island, it is not a full accounting, especially considering that families with high potential diversity such as the Leptophlebiidae are still poorly known (Elouard et al. 2003).

The regional differences (Fig. 4) may be partly the effect of collecting effort and taxonomic studies rather than a true reflection of mayfly diversity. For example, the higher number of Caenidae in eastern Central Africa is due to the work of Malzacher (1990, 1993); the low number of Caenidae for southern Africa is certainly a reflection of under-study and would likely more than double with a proper family revision. Historic biogeographic influences also bear relevance; for example the Teloganodidae, a temperate Gondwanan relict family (McCafferty and Wang 1997, Sartori et al. 2008), are confined to the southern tip of Africa and Madagascar.

Some species are known in only one life-cycle stage (adult or nymph), so one may be attempting to identify a nymph described only as an adult. Alternatively, the specimen might represent an undescribed species, but this is difficult to tell without rearing associated nymphs and adults or associating the 2 stages using genetic methods (Gattolliat and Monaghan 2010). Thus, large gaps in taxonomic knowledge still exist for many areas. Knowledge of North African species is complicated by the close association of this fauna with Europe. North Africa forms part of the Palaearctic region rather than the Afrotropical because many of the species reported from North Africa are commonly found in Europe, in most cases being recorded in North African countries many years after first being described in Europe. An extreme case is *Paraleptophlebia cincta* (Retzius), which was first recorded in Algeria 200 years after it was first described in Europe. Molecular studies would validate these species determinations and reveal the true level of relationship between the North African and European mayfly populations and species. Even supposedly well-known Afrotropical mayfly species, such as the ubiquitous *Baetis harrisoni*, has recently been shown through molecular studies to consist of more than one ecologically defined clade (Pereira da Conceicoa et al. forthcoming 2012). For much of the Afrotropical freshwater invertebrate fauna, the alpha taxonomy has not been addressed, much less the more refined steps of uncovering cryptic species complexes. Other problems are evident within the taxonomy of the Ephemeroptera. A number of species still have dubious taxonomic placement; for example, of the 10 species nominally placed in *Baetis* in the Afrotropics, 5 are not true *Baetis*. Half the African species have been designated as belonging to different genera at least once (Elouard 2001); thus, many species still await discovery, description, and correct taxonomic assignment.

These examples highlight a serious problem for ecologists, a threat that is often ignored because most river health biomonitoring programs look at family level identifications of taxa only, without knowing what species are present or their ecological significance. Earlier biotic indices, such as Chutter's (1972) empirical biotic index of water quality for South African rivers, required detailed identification of the faunal composition of a river to monitor water quality. This approach, which needs considerable taxonomic faunal knowledge, has not been favoured due to the time consuming process of species-level identification and the corresponding need for specialist guidance. Thus, biomonitoring protocols tend to develop rapid methods that do not require specialist knowledge. In response to the need for rapid biomonitoring, Chutter (1994) developed the South African Scoring System (SASS) for biomonitoring in southern Africa, currently in its fifth version (Dickens and Graham 2002). Similar protocols are being developed for other parts of Africa, such as the Nigerian Scoring System (NISS; F. Arimoro, Delta State University, Nigeria, Sep 2011, pers. comm.).

Rapid assessment methods, although useful as a warning of change in a river ecosystem, tend to require only family-level identification, which is often too coarse to recognise real time changes (e.g., sensitive species may have been eliminated, but a family may still be represented by more tolerant species). Thus, although rapid biomonitoring techniques are extremely useful in some cases, they result in reduced assessment of actual diversity and are less sensitive. Absence of species from a river can sometimes give as much information about the state of a river as presence; however, before absence data can be used, the fauna must be well known. This emphasizes that biomonitoring tools should only be used for their designed purpose. Rapid assessment tools provide information on water quality and environmental degradation but cannot be used to assess biodiversity. Investigative research including detailed ecological assessments and species identification surveys is needed to contribute to greater understanding of ecosystems (de Moor 2002).

Conclusions

The results of this synthesis of mayfly diversity knowledge clearly show that the mayfly fauna of the Afrotropical region and North Africa is still generally poorly known, highlighting the urgent need for further taxonomic studies to produced more comprehensive inventories of species for each region. Many species still need to be described. For biomonitoring purposes the focus is on nymphs, and species known only in the adult stage are not useful in such cases. Adults and nymphs need to be associated, and ecological requirements and life-history adaptations need to be established for each species. In many cases, the distribution of species, the degree of regional endemism, and the extent to which they are threatened by environmental changes remains unknown. If the fauna of a particular river or region is well documented, faunal change can reliably indicate changes in water quality status and climate. Unfortunately, most river surveys are undertaken to determine effects of pollution, whether from organic sources such as effluent from human development (Mantel et al. 2010, Arimoro and Ikomi 2009), deforestation (Benstead et al. 2003), or heavy metals from mining effluent (Emoyan et al. 2006, de Villiers and Mkwelo 2009), rather than to establish the natural state of biodiversity. In such cases, the fauna being investigated is already under threat, and species more sensitive to a particular type of pollution may already have been lost from the system or at least from the polluted section. Thus, the natural biodiversity may never be known,

and species may become extinct before they have been documented.

Region-specific identification keys are needed to help improve local knowledge of the fauna in any region, taking into account the faunal variation even within one country. Because such regional identification keys are not available for much of Africa, river ecologists resort to using European or North American guides, resulting in wrong identifications. For example, names of non-Afrotropical, European mayfly families (e.g., Potamanthidae) and genera (e.g., *Potamonathus*, *Ecdyonurus*, *Heptagenia*, *Rhithrogena*, *Lachlania*, *Acentrella*, and *Centroptilum*) have appeared in several international journal publications on West and East African river ecology within the past 10 years. These errors perpetuate false information in the literature.

Ecologists must be cautious in their interpretation of faunal surveys because these are limited by the lack of taxonomic knowledge. This caution applies to most freshwater invertebrate groups. For applied purposes, faunal variation with respect to water quality needs to be established through active surveys with the specific purpose of developing inventories and determining species assemblages in each ecological region across the continent, thus building base-line knowledge as a foundation for better informed management decisions in the future. Furthermore, a sound understanding of the biodiversity of a region provides the cornerstone for future research investigating the evolutionary processes and biogeographical principles that influence mayfly distribution and affect the relationships between mayflies and other freshwater organisms, both within Africa and globally.

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