Water mites (Acari, Hydrachnidia): powerful but widely neglected bioindicators – a review

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Various biomonitoring methods are used worldwide to evaluate water quality and the ecological integrity of freshwater habitats. Most of these methods are based upon macroinvertebrates, mainly insects, whereas water mites (Hydrachnidia) are widely neglected. In the present review, I summarize the diversity and ecology of water mites and evaluate their potential as bioindicators. Studies correlating water mite assemblages with water quality are presented in a detailed historical overview. Possible constraints to use this group as bioindicators are also discussed. The particular importance of Hydrachnidia in the monitoring of springs is discussed, as well as the state of knowledge on the ecology of neotropical water mites. I present the first data on water mites as bioindicators in streams in Costa Rica and Panama. The need for further research is explained and a call for collaboration is expressed.

Keywords: water mites; biomonitoring tools; monitoring of springs; freshwater assessment; Latin America

Introduction

Freshwater ecosystems are increasingly threatened by anthropogenic stressors, such as chemical and organic pollution, structural and hydrological alterations to water courses and riparian areas, changes in land use and climate change. All of these threats result in a reduction of water quality and loss of aquatic biodiversity.[1–4]

Whereas in Europe understanding of the importance of ‘ecosystem health’ has been increasing over the last decades,[5] the situation in Latin America and other parts of the tropics has not improved despite increased pressure due to rapid population growth and industrial development.[6,7] In order to prevent massive social, economic and hygienic problems, it is necessary to maintain the sustainable use of these benefits and hence to protect the ecological integrity of freshwater ecosystems and aquatic biodiversity. Therefore arises a great need for assessment, monitoring and evaluation of the quality of freshwater habitats considering the whole spectrum of human impacts.[3,5,8]

There are two principal monitoring strategies: physicochemical analysis and biomonitoring. Physicochemical analyses are important methods to get detailed qualitative and quantitative ‘snapshot’ data on water quality and the character of contamination. Together with additional microbiological analysis, they are needed e.g. in the quality control of drinking water. Conversely, as aquatic organisms spend most part of their life under the specific conditions of the site, biomonitoring offers the temporal integration of all impacts and allows the integrated analysis of different factors and their complex interactions in a reliable and cost-effective way.[6,9,10]

The first system of biological evaluation of water quality was developed in Northern Germany in the early twentieth century in order to monitor the pollution of streams with organic, biodegradable substances.[11–15] The original ‘saprobie system’ listed 500 species – including some water mites.[15] The authors already emphasized the importance of complete surveys of biota for the evaluation of a water body; furthermore they stressed the necessity to take into account different habitats as well as seasonality of the organisms.

The use of macroinvertebrates – especially insects – as bioindicators is now employed all over the world, and is even part of many national legislations.[3,6,9,16,17] Many different methods and indices are used worldwide as well as in Latin America.[6,9] In several Latin American countries (e.g. Costa Rica) the collection of biomonitoring data is even mandatory for projects affecting freshwater ecosystems.[9] Although most of the resulting data are found in unpublished ‘grey literature’ and in general no standard protocols are used,[6] there are several publications on biomonitoring and the effects of contamination on macroinvertebrate communities in Latin American streams,[18–21] – see further literature in 6

By far most studies and publications deal with the assessment of organic contamination of rivers and streams. However, bioindicators are as well used to monitor the eutrophication of lakes [12 – macrophytes as indicators of trophic levels] or to evaluate the effects of

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Water mites in general

Mites (Acari) belong to the arthropod class Arachnida—together with myriapods, they are the oldest terrestrial animals, with a fossil record dating back to Silurian (~419 Ma).[35] Members of all 16 arachnid orders colonize all types of terrestrial (in some cases even desertic—e.g. scorpions, solifuga) habitats. However, several lineages among the Acari have secondarily invaded freshwater habitats.[36–38] Several mite groups that are mainly terrestrial, have a few aquatic representatives: e.g. Mesostigmata, Oribatida, Astigmata, Gamasida, Trombidia.[39,40] But it is the Hydrachnidia (Trombidiformes: Prostigmata: Parasitengonina) with more than 6000 mainly freshwater species currently described, that are the by far most abundant, diverse and ecologically important group of aquatic arachnids.[41–43] Specific water mite assemblages are found in nearly all kind of different aquatic habitats including streams, rivers, ponds, lakes, springs and even the splashzone of waterfalls or microaquaria of bromeliads. The more than 100 families and subfamilies are grouped in seven superfamilies.[36,44] The second strictly aquatic group are the Halacaroidea Murray, 1877 (Trombidiformes: Prostigmata: Eupo-dides), with more than 1000 marine and about 60 freshwater species.[39] Hydrachnidia (or the ‘true water mites’) formerly were referred to as ‘Hydrachnellae’, ‘Hydrachnidia’ or ‘Hydracrana’ (the later as well including the freshwater species of Halacaroidea).[39] In the latest textbook [38, following 41] water mites are named ‘Hydrachnidae’.

Water mites exhibit great morphological variability and inhabit a great diversity of freshwater habitats. Many species are colourful (often red), the shape varies from rounded to elongate, several species are soft-bodied, some bear elaborate plates or are completely sclerotized. Depending on the habitat and type of locomotion, the legs can be stout with spine-like setae or slender with swimming hairs. The external morphology, in particular the organization of the coxal plates (insertion areas of the eight legs) and genital field (especially the acetabula), as well as the palps, provide good taxonomic characters. The abundance of water mites in stream riffles can reach up to 5000 individuals/m².[44] The α-diversity in such samples can reach up to 50 species in 30 genera.[44–52] Similar samples from eutrophic lakes may yield up to 2000 individuals representing up to 75 species in 25 genera.[44] In some springs up to 40 species in 25 genera can be found.[53] The overall global diversity of water mites is estimated at least 10,000 species.[54] In the neotropics, a total of 5500 species (about 1830 for Central America alone) is estimated.[55] The life cycle of water mites is characterized by complex interaction with other macroinvertebrates. Adults and deutonymphs are predators, feeding on crustaceans, insect eggs and larvae; proto- and tritonymphs are pupa-like resting stages; larvae are parasitic-phoretic on adult insects (showing variable host specificity). Whereas most larvae leave the water with their hosts, all other stages are obligatorily aquatic. The immobile resting stages of several species have specific complex autecological habitat demands, often beyond the requirements of adults or deutonymphs (high oxygen level, natural sediment structures), and therefore cause dependency of the respective species on clean water conditions.[44,56] The main evolutionary diversification and adaptive radiation of water mites probably occurred already in the Triassic or early Jurassic period together with the radiation of aquatic insects, mainly Diptera.[44]

Water mites as bioindicators

Lotic systems

The first observations of relationships between water mite assemblages and environmental conditions date back to the early twentieth century.[57–60] The importance of calcium carbonate concentration for different species was discussed by Walter [59] and Lundblad,[61] and laboratory studies on the resistance of water mites towards dehydration and salinity were published by Lundblad [62] and Szalay [63]. In the 1950s and 1960s many studies revealed clearly distinct assemblages in streams and springs [64] and even in different spring types [65,66] as well as in different stream zones.[64,66–72] In his classic study ‘Water mites as indicators of the
biocenotic zonation of the Breg, Brigach and upper Danube’ (south-west Germany) Schwoerbel [73] described a clear stream zonation based on the water mite fauna, with clearly separated, typical communities and several exclusive, characteristic species (‘Leitarten’): Hygrobatis norvegicus-zone (springs), Hygrobatis foreli-zone (epirhithron), Lebertia sparsicapillata-zone, Hygrobatis calliger-zone, Hygrobatis fluviatilis-zone, Torrenticola amplexa-zone, etc. In natural streams similar water mite zones (with comparable associations and typical species) can be found according to the ‘locality complex’ of different environmental variables (e.g. elevation, temperature, geology of the watershed).[73,74] Biesiadka [75] found respective characteristic zonations of water mite assemblages in a river system in Poland even at genus level.

Given the existence of ‘characteristic water mite assemblages for distinct habitats’, this leads to the question whether water mites can be ‘good environmental indicators’? In a study of water mite assemblages in springs, Schwoerbel [65] differentiated calciphilic, calciphobic and calcium-tolerant species. Kowalik and Biesiadka [76] found negative correlations of water mite diversity and abundance with inorganic nitrogen. Many studies in Europe [64–66,69,73 – Germany, 75 – Poland] and North America,[77– US] showed as well, that water mite assemblages (diversity, abundance and community structure) are sensitive to contamination. The effects of the introduction of wastewater clearly superpose all natural factors. Besides these field observations, experimental studies revealed different reactions of individual water mite species towards variations in temperature, oxygen and carbonate concentrations.[66] Therefore water mites can be designated as ‘true ecological indicators’, as preferences of individual species for different habitats are motivated by different physiologies and variable tolerances towards environmental factors.[66]

Beyond the described general relationships, Kowalik and Biesiadka [76] showed that water mite assemblages actually indicate different levels of contamination and individual species could be correlated with certain saprobic values (oligo- to polysaprobe): In the Wieprz river in Poland, several more sensitive species were exclusively present in the oligosaprobe zone, more tolerant species were still present in the ß-mesosaprobe, while just very few most resistant species were still found in the α-mesosaprobe zone. In polysaprobe conditions no water mites were found.[76] Consequently the authors concluded that ‘water mites are exceptionally sensitive to any changes in environmental conditions, therefore their usability as indicators of water purity had been recurrently emphasized. Up till now, however, too few investigations were carried out in this line.’[76] Ciccolani and Di Sabatino [78] also demonstrated the possibility of using several water mite species as indicators of certain saprobic levels for southern Europe (Italy). In a further study [79] the authors showed the existence of certain species characteristic for unpolluted habitats, as well as for sites with different levels of contamination. In this study a clear reduction of water mite diversity with increased contamination was shown, as well as correlations of the diversity (according to the Simpson and Shannon–Wiener Indices) with an established water quality index based on macroinvertebrates (but excluding water mites).

Very important aspects of the response of lotic water mite assemblages towards anthropogenic impact are changes of the community structure – especially the reduction of rheobiont species and a general shift of the fauna from typical sensitive, lotic, towards more tolerant, euryoecious, lentic species.[33,56,80] However it has to be emphasized, that not all lotic species are sensitive and not all lentic species are tolerant. In their study on stream mites in the Netherlands, Van der Hammen and Smit [80] found a reduction of the percentage of rheophilic species in the stream faunas from 80–90% to ~20%, furthermore 40% of the rheophilic water mites have become locally extinct during the twentieth century. The authors explain this development mainly by changes in the stream hydrology and nutrient load.[80]

Many studies on the effects of contamination on water mite faunas in many European countries revealed groups of rather tolerant species, forming typical assemblages in polluted water: Belgium,[81,82] Bulgaria,[83] Germany,[66,73,84,85] Italy,[78,79,86] Luxemburg, [Dohet et al. unpublished data] Poland,[76,87] Romania,[88] Switzerland,[58] the Netherlands.[80] Even though regional differences exist in these taxa lists, in all of these (and many other) studies the European species most tolerant to organic pollution is Hygrobatis fluviatilis (Ström, 1768) (Hygrobatidae). This species is dominant (and is often the only water mite species) at moderately polluted sites. The relatively high abundance of this species at polluted sites however should not be interpreted as a special affinity towards high nutrient levels, but rather as a higher resistance against unfavourable conditions.[66] The ‘natural habitat’ of this euryecious species includes rivers and streams of moderate current and rather high temperature amplitude.[85] On the other hand, within the European water mite fauna, there is a group of more sensitive species, including e.g. several species of the Torrenticolidae.[56,83] A diverse fauna including some of these sensitive species definitely indicates aquatic systems of high ecological quality. Similar data on typical water mite assemblages in unpolluted waters differentiated by habitat types (springs and springbrooks, streams, ground water, stagnant waters, brackish waters, parasitic in mussels and snails), were published for the Japanese fauna.[89] Due to the importance of the hyporheic interstitial in the life cycle of several water
mitic species (e.g. Torrenticolidae, see above) the water mite fauna of streams as well provides information on the ecological conditions of this special habitat underlying the streams.[56,90,91] In general the water mite fauna as well reflects the effect of mechanical degradation and the loss of natural habitat elements in streams.[56]

Springs

Springs are hotspots of aquatic biodiversity inhabited by complex assemblages of specialized taxa.[53,92–96] According to Di Sabatino et al. [97] spring habitats contribute 1/3 of regional freshwater biodiversity, including many endemic and relict species. In many regions they are very important for the supply of drinking water, provide a unique access for the evaluation of ground water and have enormous potential for detecting impacts of climate change, alterations in land use, etc.[98] At the same time, springs all over the world are heavily threatened by human impact (capturing, pasture, deforestation, eutrophication, sinking ground water tables, climate change). [56,92,94, see further references in 99] Even though studies on spring faunas started early in the twentieth century [see literature in 99] and the high diversity and specificity of spring faunas has long been known,[65,66] still no biomonitoring system has been established for these habitats.

Referring to the diversity, percentage of crenobiont taxa and habitat specificity, water mites are the most characteristic group within the spring fauna.[53,77,92–97,100–103] The species composition and structure of water mite assemblages in springs provide the characterization of different spring types.[53,104] Therefore – and because of their complex relationships with other macroinvertebrates (see above) – water mites have a particular importance in the assessment and monitoring of the biological impact of environmental changes of springs.[53,56,65,92,100,102,105–107]

Until very recently, data on tropical springs were completely lacking. As constant, low temperatures has been regarded as the crucial factor promoting habitat specificity of crenobionts, the existence of a specific fauna in warm tropical springs has even been unclear.[94] However studies on water mites including many different habitats in Costa Rica revealed a very distinct and species rich crenobiont fauna.[50,94,108] Similar to the available data from springs in temperate regions, the water mite fauna in Costa Rican springs is characterized by high diversity and specificity: springs accommodate more than half of the Costa Rican genera; 18% of all taxa are strictly crenobiont; the water mite fauna of different spring types is also very distinct.[94,108] These studies showed that a specific tropical spring fauna exists and that water mites are highly suitable for the monitoring of these habitats.

Other habitats and biomonitoring aspects

By far most studies on the bioassessment abilities of water mites deal with organic contamination of lotic systems. However, there are several further aspects of human impact in streams and other habitats in which water mites turn out to be suitable and powerful bioindicators.

Acidification and eutrophication of lakes

Brodin and Gransberg [109] found that water mite assemblages in a Scottish lake had been affected by anthropogenic acidification. Studies in Poland showed that water mites provide detailed information on the ecological situation of lakes.[43,110] Biesiadka [111] described faunal changes over 40 years and explained it by eutrophication and increase in touristic exploitation. Although the study of the effects of eutrophication on the water mite fauna of lakes in Northern Germany revealed no general reduction of the water mite diversity compared with the situation more than 60 years ago, [112,113] individual species specialized on deeper lake zones have disappeared because of reduced oxygen concentration in these deeper lake zones as consequence of higher nutrient levels.[114]

Degradation of small water bodies

Smit and Van der Hammen [115] investigated the effect of sinking groundwater tables and nutrient influx on water mite assemblages in coastal dune ponds in the Netherlands and Northern France. Water mites turned out to be very good indicators for the hydrological conditions and anthropogenic impacts on these habitats.

Ecological situation and restoration of peatlands

In a study on the composition and structure of invertebrate assemblages in restored bogs in Northern Germany, [116] the diversity and composition of water mite assemblages reflected the state of restoration of the natural vegetation. In bogs rewetted 25 years ago, the water mite assemblages were similar to that of remnant peatland habitats.

Influences of metals, pesticides and other toxic substances

Bolle et al. [81] investigated the influence of industrial sewage mainly containing iron and zinc on water mite
assemblages in a stream in Belgium. The authors found a significant reduction of the water mite abundance and clear changes of the community structure. As with respect to organic contamination, *Hygrobatis flaviatricilis* turned out to be the most tolerant species. Wagener and La Perriere [117] found that water mites were the most affected group of organisms in streams deteriorated by mining.

In laboratory studies on the effects of different biocides, Nair [118] found the water mite species *Hydrachna trilobata* to be especially sensitive to chlorinated hydrocarbons. Dieter et al. [119] suggested that the number of mite species in wetlands might have been decreased by the use of organophosphate pesticide.

**The use of water mites in biomonitoring**

Even though the suitability of water mite assemblages for stream assessment has been shown in many studies – and most of these data have been known for decades [73] – there are very few investigations truly using water mites as bioindicators. Exceptions are two very detailed studies from Australia [32] and Italy [3]:

Grows [32] compared six polluted and six unpolluted stream sites near Sydney, Australia. The author found out, that water mites provide a very useful, efficient and economic bioindication tool:

- Abundance and diversity of water mites was significantly higher at the polluted sites – their abundance, diversity or community composition are each sufficient to differentiate the sites.
- The water mite fauna of riffles and stream edges were very distinct, even at genus level. In Australian lowland streams, riffle sample sites are rare and in general the macroinvertebrate fauna of the edge is very unspecific – mainly formed by broadly tolerant species – in contrast, a very specific water mite fauna was found as well at the edge of streams. Therefore, water mites were the most suitable indicators in these streams.
- Polluted and unpolluted sites could clearly be separated just on the basis of the water mite fauna.
- Water mites can easily be determined to genus level by non-acarologists without slide mounting the specimens.

Miccoli et al. [3] evaluated the ecological status of lotic ecosystems (81 locations in 34 streams) in Central Italy, according to the EU Water Framework Directive.[17] The authors tested six macroinvertebrate based indices – the established indices Star-ICMi, BMWP, ASPT, IBE and two new ones, beside other macroinvertebrates also including water mites. The proposed index PTHfam is the first numeric index including the number of water mite families for water quality assessment. The evaluation of PTHfam showed:

- The proposed index was the ‘most robust and reliable for the purpose of macroinvertebrate based rapid bioassessment of lotic systems’. [3]
- The index provided distinct, expressive information, without the comparison of reference sites.
- It was the only index significantly separating all classes of water quality.
- Water mites are especially indicative of relatively clean ecosystems (high-quality classes) and therefore especially suitable for ‘early warning systems’.

**Water mites as bioindicators – summary of the current state of knowledge**

Many studies from Central Europe and North America have shown that water mites are excellent bioindicators and powerful tools in the assessment of the ecological quality of freshwater habitats. Some of these ‘classical studies’ date back for decades.[73,75,77] Over the last 50 years many studies mainly in different European countries, but as well in Australia, confirmed and expanded on these results. [3,16,32,79,80,84,85,88,96,110,115,120–122] In general water mites rather show the general ecological status of the habitat, than the influence of an individual parameter.[56,76,80]

The current state of knowledge on the biomonitoring possibilities of water mites can be summarized as follows.

1. Different aquatic habitats are inhabited by different, typical, water mite assemblages (including characteristic species):

   - The water mite fauna of springs and streams is clearly separated.[64]
   - Different spring types are characterized by different water mite assemblages.[65,66]
   - In lotic systems a ‘biocoenotic zonation’ can be observed, with typical water mite assemblages characterizing the different sections.[73]

2. There are clear and predictable relations between water quality and the composition of the water mite fauna:

   - Any contamination causes structural changes of the water mite fauna – even at low impacts sensitive species are replaced by more broadly tolerant species.[80] Moderate declines in water quality result in a (in most cases statistically significant) reduction of water mite abundance and diversity; intense contamination leads to a collapse of the water mite fauna.[76]
   - Typical species and assemblages can be found for both clean and contaminated sites. As water mites show differentiated reactions towards different levels...
of contamination they are suitable for a fine resolution in the assessment of intermediate contamination.[82]

- After a period of recovery without further input of contaminants, water mite assemblages can re-establish; however, usually without the most sensitive species.[73]
- Clear correlations exist between water mite diversity and other biological indices as well as physicochemical data.[79]
- Due to the high sensitivity of many species – several very sensitive species are restricted to very clean water and immediately respond to early contamination by their absence – water mites are excellent indicators for pure water conditions and provide a powerful early warning system.[3,43]

Furthermore, water mites comply with all requirements considered as necessary requisites for adequate bioindicators [5,6,9,123]: (1) wide distribution (geographically as well as variety of habitats); (2) species richness, including wide range of responses towards different disturbances; (3) relative sedentarity, in most parts of their life cycle they are bound to a certain habitat (therefore contamination can be referred to spatially); (4) sufficiently long life cycle to allow long-term integration; (5) sampling is easy and cheap; (6) the taxonomy is clear/well known at least at family/genus level; (7) the sensibility of many taxa towards different types of contamination if well known and (8) experimental data exist on the effects of contamination towards different species.

Beyond this, water mites are especially suitable and powerful bioindicators – probably more than many other members of the macrofauna regularly used in biomonitoring – for the following reasons:

- Water mites often show the highest percentage of species characteristic for certain habitats and environmental conditions.[16,53,92]
- During most parts of their life cycle they are strictly bound to the aquatic habitat (just their larval stage leave the water for a short period). Therefore, readily identifiable adults of most species can always be found in the habitat.[53]
- Especially the resting stages (proto- and tritonymphs) of many lotic species found in the hyporheic interstitial have specific ecological requirements: due to their immobility and high oxygen demands, they are very sensitive to sludge deposition or any kind of clogging of the sediment.[105]
- Water mites provide a high integration power due to their complex interaction with other members of the macroinvertebrate fauna (mainly insects). As predators ( deutonymph, adult) and parasites (larvae) they are bound to prey and host populations. Due to this intense interconnectedness, water mite assemblages are likely to reflect as well the synecological habitat demand of large parts of the community.[3,16,54,56,82,124]

Therefore, the question arises:

**Why are water mites still neglected (or lumped together to ecologically completely insignificant groups as ‘Acari’) in general limnological studies as well as in biomonitoring programs?**

Various authors have discussed this phenomenon and the possible reasons [3,32–34]:

**Possible constraints in the use of water mites as bioindicators**

- Maybe water mites are insignificant because of their low abundance and diversity?

In a comparative study in Queensland, Australia six streams were sampled in order to compare the diversity of water mites and other stream invertebrates.[34] The generic diversity of water mites in each stream was higher (in most cases more than double) than in any insect order (classical biomonitoring organisms).

Samples from North American streams may yield up to 5000 individuals/m² of up to 50 species in 30 genera.[44] – Even though at most sites this high abundance and diversity is not reached, several studies from Central Europe as well as North and Central America generated at least similar values.[45–52]

→ Hence, the available data clearly lead to the conclusion that the above hypothesis has to be refused. On the contrary, water mites often show high abundance and diversity (at least at pristine habitats).

- Maybe water mites are too small to be found in standardized samples of general monitoring programs?

In order to test this hypothesis, Proctor [34] surveyed samples taken in general river monitoring studies in Queensland, Australia: 98.5% of these samples (in total from 653 sample sites) included water mites for a total of over 6000 individuals and 47 genera, representing 81% of the known genus-level fauna of Queensland, plus 9 new records; the generic richness per sample was 1–12 (>50% of all samples had more than 3 genera).

In a similar study, Martin and Brinkmann [33] examined 736 samples taken in a general monitoring program in Baden-Württemberg, Germany. These samples contained 4182 water mites from 46 species and 14 genera.
Several studies arrive at the conclusion that this second hypothesis has to be refused as well. Material from ‘official’ standardized samples made by non-acarologists is adequate (in terms of abundance and diversity) and the water mites collected can easily be used for biomonitoring (even though some genera are probably not collected and more thorough and specialized sampling would be better).

- Maybe water mites are too difficult to identify?

In the comparative study from Australia mentioned before,[34] most water mites could be identified to genus level with a stereomicroscope, without mounting (in some cases one palp was removed and observed in lateral view with a microscope). On average 83% of the collected water mite specimens, but just 70% of the Trichoptera and 23% of the Ephemeroptera could be identified (via sufficiently intact specimens of mature instars) to genus level.

Furthermore for the regions discussed so far good and suitable keys to genera are available ([44] – North America,[125,126] – Europe,[127] – Australia).

- Finally the examination of this third hypothesis also reaches the conclusion that it has to be refused, as water mites can be identified very well, at least as easily as some insect groups regularly used in biomonitoring or general limnological studies.

In order to illustrate the circular argument that is hampering the broad use of water mites as biomonitoring tools, and its implications, a comparative study on water quality assessment in Luxembourg [16] shall be cited here: The purpose of this study was the evaluation of appropriate indicator groups to define reference and degraded stream types for the Water Framework Directive (WFD).[16,17] The main objective of the WFD was ‘to achieve good ecological status for surface waters’ – therefore a high resolution in the range of relatively good water quality is needed. Water mites would provide exactly the demanded ‘high resolution in the good quality range’ (see above). Consequently in this study water mites had the highest number of significant indicators of different stream types and environmental conditions relative to the total number of species.[16] Furthermore the authors considered water mites as the ‘best indicator-group’, as they are affected by contamination in two different ways: directly by the pollutants, as top predators in the aquatic food webs, and indirectly by the dependence on the host insect populations.[16] In the final evaluation, however water mites are – again – not considered, due to the ‘poor state of taxonomic knowledge and cost related to expertise required for identification’[16] – even though the authors emphasize that for most problems a higher taxonomic level is sufficient and a determination key for the palaearctic genera [125] had long been available. Furthermore at that time a revised determination key for several groups had been published,[128] the further groups had been in preparation.[129] The authors therefore dispense with the use of the – according to their own study – most powerful bioindicator group, because of assumed determination problems. As identification keys are (and have been) available though, it must be supposed that – as mentioned before – the main and underlying reason is simply the lack in cultural precedent (‘we never used them, why should we do so now?’).

All these studies and considerations led to the conclusion, that there is no scientific rationale for ignoring water mites in biomonitoring programs or in general environmental and limnological studies. The only reason for doing so is a fundamental lack in cultural precedent.[34]

Water mite-based biomonitoring in the neotropics

As traditions about which groups ‘can be used and which not’ are not as firm and incrust as in Europe with its long in use and mainly institutionalized water monitoring systems, the question is especially interesting, whether water mites are good bioindicators in neotropical streams as well??

Many studies mainly from Europe provide detailed data on the correlation of water mite species and assemblages with environmental parameters, water quality and different levels and types of contamination. Respective detailed data so far have not been published from tropical regions. However, the available data correlating individual taxa and communities with environmental parameters demonstrate that neotropical water mites not only show high diversity and habitat specificity but as well high sensitivity towards water quality.[50,54,94,108,130–135]

Two Central American studies [136 – Costa Rica, 137 – Panama] show that detailed correlations exist between water mite assemblages and different levels of contamination and that water mites are powerful tools in freshwater assessment, as well in the neotropics:

Costa Rican example

In a study on the water mite fauna of Costa Rica, about 20,000 specimens comprising 74 genera were collected in more than 500 samples from different habitats.[50] The water quality was evaluated in four rough classes from no (most samples) to clearly heavy organic contamination. A clear relationship between the water mite
fauna of Costa Rican streams with different contamination levels was found [136]:

- The water mite diversity (number of genera, Shannon-Index) declined with higher contamination.
- The faunal structure completely changed at the contaminated sites:
  
  1. a small number of genera showed strong numerical dominance (just five genera represent 90% of all individuals, compared to 12 genera at unpolluted sites);
  2. rather tolerant genera became more abundant at polluted sites (e.g. Sperchon 15% (clean) → 36% (polluted), Atractides 5% → 11%), whereas more sensitive genera were greatly reduced (e.g. Limnesia 10% (clean) → 0.09% (polluted), Koenikea 7% → 0.6%)

The fact that a lentic genus (Limnesia) is more sensitive than two lotic genera (Sperchon and Atractides) interestingly modifies the results of European studies mentioned before (lotic species more sensitive than lentic [80]).

As in Europe, Torrenticola is one of the genera mainly restricted to clean streams (two European species as well occur in mildly polluted streams). However, a detailed analysis of the distribution patterns of the 42 Costa Rican species of the genus [132] differentiated this picture, as three species showed clearly higher tolerance towards pollution than all others.[133]

**Panamanian example**

In 15 Panamanian streams (5 pristine, 5 rural and 5 urban) in the Panama Canal Watershed 3528 water mites in 31 genera and 14 families were collected.[137] As the study focussed especially on the comparison of the three contamination levels, the relationship of the water mite assemblages with the water quality was even clearer than in the Costa Rican example described before. This study presents the first data correlating neotropical water mite taxa and assemblages with detailed water quality parameters. It is the first example in Latin America really using water mites as indicators to evaluate differences between streams with different levels of contamination [137]:

- A significant reduction of the water mite diversity at genus as well as family level was observed along the contamination gradient.
- Whereas the abundance of most taxa was strongly reduced at higher contamination levels, members of some genera (especially Atractidella) are found in higher abundances at urban sites.

- Multivariate analyses (CCA) showed that faunistic differences are mainly explained by different levels of anthropogenic impact: a group of sensitive genera was clearly associated with pristine sites and high oxygen concentrations, the more tolerant ones with urban sites and higher nitrate and phosphate concentrations.

The results of these studies from Costa Rica and Panama – as well as other existing data (see above) – show that water mites can be used without any problems or restrictions in comparative studies on water quality in the neotropics and that they provide excellent information on the ecological status of different streams.

The data available on the biomonitoring potential of water mites mainly from Europe (but as well from other parts of the world) are completely transferable to Latinamerica. Neotropical water mites show the same sensitivity towards anthropogenic impact as European water mite assemblages, including clearly differentiated reactions towards different levels of contamination.

There is no reason to doubt that water mites are powerful tools in bioassessment as well in Latin America!

As taxonomic knowledge of the neotropical fauna is at an earlier stage than e.g. the European, it is very important to note that analysis at genus (or even family) level already provides very valuable information on different water quality levels.[3,16,32,33,56,75,79,94,108,133,136–140]

Identification keys to genera already exist for North [44] and South America,[141] a key for Central America is currently prepared.[142] Furthermore instructions on the collection and preservation of water mites are available online.[143]

**Research needs**

All that is still hampering the completely unrestricted use of water mites as bioindicators in tropical regions is the lack – or very limited availability – of baseline data on the ecology and distribution patterns of certain genera and species. In order to fully use the great potential of water mites as biomonitoring tools, further research should aim to close these gaps and:

- extend the knowledge of the neotropical fauna – this includes further sampling as well as taxonomic work; identified and properly preserved water mites should be incorporated in general limnological studies in order to generate a broader database on the ecology and distribution patterns of the different taxa (the overall goal should be complete baseline inventories of at least some reference areas, including streams and springs);
• build up reference collections of identified and properly preserved water mites at natural history museums in Latin America;
• find and describe pristine reference sites (and their faunas) for different spring types, stream types, stream zones and regions;
• describe typical species and communities for different quality levels (of the respective habitat types);
• correlate individual species/genera with water quality data in order to obtain and develop individual indicator values; compare the respective data of different regions;
• investigate and document the natural variability and seasonal fluctuations of water mite species and communities;
• study the life cycle (rearing and describing larvae) and ecology (including predator-prey, parasite-host interaction) of selected species;
• elaborate systematic revisions and identification keys (to species level, as well as rough local keys to a higher taxonomic level), in order to give access to these powerful indicators as well to non-acarologists.

Invitation for using water mites in biomonitoring → call for collaboration

However as explained by Proctor [34] the availability of identification keys alone will not solve the ‘problem of ignorance’ towards the use of water mites in biomonitoring. First of all we need to create the consciousness of their immense potential. Therefore this review is as well a call for collaboration, to include water mites in biomonitoring studies!

• Water mite assemblages should be compared/discussed with existing biomonitoring data of other macroinvertebrates as well as physicochemical data of different sites.
• Water mites should be included in general biomonitoring programs – including the development of indices taking into account the water mite diversity (as well at higher taxonomic levels) and indicator species for certain habitats or particular ecological situations.
• Due to the peculiarities and special abilities of water mites, they are particularly suitable for early warning systems showing even slight or beginning reduction of water quality and the long-term monitoring of springs (see above).

In many sampling protocols however 500 μm nets are used or samples are washed through coarse sieves to get rid of fine materials that make picking out the macroinvertebrates difficult. This can result in loss of many specimens of mites, especially in lotic habitats where species tend to be smaller. Someone would have to be willing to use fine nets (mesh size 250–300 μm) or go through the fine residuals to pick out the mites.

It has to be emphasized, that there is no scientific rationale for ignoring water mites in biomonitoring programs or in general environmental and limnological studies. The only reason for doing so is a fundamental lack in cultural precedent.[34] However, the current ignorance of water mites is both harming our possibilities to fully understand the ecology of freshwater communities (with all negative implications for biomonitoring possibilities) and is widely hampering the understanding of the ecology and distribution of water mites.[34]

We should finally start using the powerful tools water mites can provide by their diversity, ecology, habitat specificity and intense interactions with other members of the macroinvertebrate community, for understanding, biomonitoring and protecting freshwater systems.

Conclusion

Water mites can be found in great abundance and diversity in every freshwater habitat. Due to complex habitat demands and intense interrelationships with many other members of the macrofauna they have the ability to provide high integrative and differentiated monitoring potential. They have special importance in spring communities and the classification and monitoring of these habitats. Adults can be found in the water year round, identification to the genus level is usually possible without slide-mounting and identification keys are available for most parts of the world. Water mites provide meaningful data on the ecological status and the quality of their habitat at genus or even family level. Water mites can be powerful tools in biomonitoring in the neotropics as well as in other parts of the world. These facts are long known, and were confirmed in countless studies. The previously wide neglect of water mites in biomonitoring is not based upon scientific reasons, but just reflects a lack of tradition and consciousness.[34] There is no justification for the common practice of ignoring water mites in ecological studies or lumping them together in ecological meaningless categories like ‘Acari’ or ‘Hydrachnidia’. [53]

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