

Diatom research in southern and central Africa: Historical perspectives and current activities

by

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SUMMARY. – Diatom research in southern and central Africa has a rich history spanning more than a century; however, much of this research was on marine environments and the African Great Lakes. In this paper we focus on the less studied riverine habitats. Research on riverine diatoms can be loosely grouped into taxonomic and ecological studies, although we will show in this paper that these two disciplines, of necessity, overlap. We briefly summarize relevant diatom-based indices for inferring water quality in rivers and streams and systematically report on recent efforts to use diatoms for ecological monitoring in southern and central Africa. We deal in particular with the challenges faced when studying the central African diatom flora and introduce the problem of diatom species concept drift. We also relate these concepts to water quality monitoring. We discuss solutions and current efforts to resolve these issues. Importantly our work also focuses on equipping scientists based in these regions with the tools for further studies.

Diatomeeënonderzoek in zuidelijk en centraal Afrika: historische perspectieven en huidige activiteiten

TREFWOORDEN. – Diatomeeën, zuidelijk Afrika, centraal Afrika, taxonomie, biomonitoring.

SAMENVATTING. – Het diatomeeënonderzoek in zuidelijke en centraal Afrika kent een rijk historisch verleden van meer dan een eeuw. Een groot deel van dit onderzoek was echter toegespitst op marine milieus en op de Grote Afrikaanse Slenkmeren. In het huidige manuscript richten we ons op de minder bestudeerde habitatten, namelijk de rivieren. Het onderzoek op lotische diatomeeën kan ruwweg onderverdeeld worden in taxonomische en ecologische studies, maar in dit manuscript zullen we aantonen dat beide disciplines noodzakelijkerwijs overlappen. We geven een kort overzicht van relevante indices om de waterkwaliteit van rivieren en beken te bepalen die gebaseerd zijn op

diatomeeën, alsook een systematisch overzicht van recent geleverde inspanningen om diatomeeën te gebruiken in ecologische monitoring in zuidelijke en centraal Afrika. Speciale aandacht gaat uit naar de uitdagingen die ondernomen moeten worden wanneer de centraal Afrikaanse diatomeeënflora wordt bestudeerd, en we introduceren het probleem van “conceptendrift van een diatomeeënsoort”. Deze concepten betrekken we eveneens bij de monitoring van de waterkwaliteit. Verder bespreken we mogelijke oplossingen en actueel ondernomen inspanningen om deze problemen te verhelpen. Belangrijk is dat ons werk zich ook richt op het verschaffen van middelen voor verdere studies voor wetenschappers die verblijven in deze gebieden.

Recherche sur les diatomées en Afrique méridionale et centrale: perspectives historiques et activités actuelles

MOTS CLEF. – Diatomées, Afrique méridionale, Afrique centrale, taxonomie, bio-monitoring.

RÉSUMÉ. – Les diatomées forment un groupe d’algues, présentes dans le monde entier, qui se caractérisent par leur paroi cellulaire presque exclusivement composée de silice. Il y a longtemps que ces organismes suscitent l’intérêt par leur aspect esthétique attrayant et leurs formes extrêmement variées. Les diatomées ont été assez peu étudiées en Afrique où les relevés remontent à la fin des années 1800 avec quelques-uns des travaux les plus significatifs réalisés en Afrique australe. Récemment (ces quatre dernières décennies), les diatomées ont fait l’objet d’une attention accrue du fait qu’elles sont d’excellents indicateurs de la qualité de l’eau, chaque espèce ayant des besoins spécifiques et parfois bien connus. Ces relations constituent alors le point de départ des indices biologiques de la qualité de l’eau. Il existe aujourd’hui un grand intérêt pour l’instauration de ce type d’index à l’usage de l’Afrique australe et centrale; néanmoins, la connaissance de la composition des espèces est si peu étudiée que nombre d’espèces de cette région doivent être décrites et délimitées avant la mise en place du processus.

1. Introduction

Diatoms occur in all types of aquatic ecosystems, also extending into damp sub-aerial habitats. A golden-brown mucilaginous film on the surface of a substrate indicates the presence of benthic diatoms. Planktonic diatoms occur free-living in the water column of rivers, streams, ponds and dams. The diatoms (Bacillariophyta) comprise a ubiquitous, highly successful and distinctive group of unicellular algae, whose most obvious distinguishing characteristic is the possession of a siliceous cell wall (frustule). The frustule, unique to the diatoms, is composed chiefly of hydrated amorphous silica, but which may also contain other trace elements, and comprises two almost equal halves known as the valves. Each valve is composed of two parts: the valve face and valve mantle which is connected almost at right angles to the valve face. Closely-united to the valve mantle are the girdle bands or

copulae (Round et al., 1997). As autotrophs, diatoms contribute significantly to the carbon productivity of ecosystems, forming together with other algae the base of aquatic food chains (Cox, 1996) and are responsible for the production of significant amounts of oxygen.

2. Historical notes

2.1. THE STUDY OF DIATOMS IN SOUTHERN AFRICA

The freshwater diatom flora of southern Africa received much attention in the past. The investigations were initiated in the middle 19th century by people such as Ehrenberg (e.g. Ehrenberg, 1845) and Cleve (e.g. Cleve, 1881). Their work was continued into the 20th Century by notable specialists, including Fritsch (e.g. Fritsch, 1918) and co-worker Rich (e.g. Rich, 1932). During the 1950's and 1960's the acclaimed diatom specialist, Dr. Bela J. Chohnoky, produced over 40 papers dealing with many of the diatom species found in southern Africa (e.g. Chohnoky, 1960). Later, Giffen published much valuable work in the 1960's and 1970's, dealing with marine and estuarine diatoms along with several accounts of freshwater species to be found in the Eastern Cape region (e.g. Giffen, 1966). The work of Schoeman and Archibald in the late 1970's and early 1980's has made an invaluable contribution to the knowledge of both the taxonomy and ecology of the diatoms. The most noted work of these two authors being 'The diatom Flora of Southern Africa', the first volume of which was published in 1976 (Schoeman & Archibald, 1976-1980). Further important contributions by these two authors include a detailed investigation of the Genus *Amphora* in a series of papers entitled 'Observations on *Amphora* species (Bacillariophyceae) in the British Natural History Museum' (e.g. Schoeman & Archibald, 1986).

2.1. THE STUDY OF DIATOMS IN CENTRAL AFRICA

Studies on the diatom flora of rivers and streams in central Africa have been rather restricted compared to the East African Great Lakes (Lakes Malawi, Tanganyika and Victoria). A short overview of the algal studies on the African Great Lakes and smaller lakes is given by Cocquyt (2006). Among the earliest diatom reports on lotic ecosystems in central Africa not related to the great lakes are West (1907) and Müller (1903, 1904, 1905, 1911) followed in the mid 20 century by Hustedt (1949) and at the end of last century by Mpawenayo (1996). Diatom reports from rivers and small water-bodies in DR Congo, formerly Belgian Congo and Zaire, are limited: up to the present around 260 diatom taxa were reported by Kufferath (1948, 1956a, b), Chohnoky (1964) Compère (1989, 1995) and Golama (1996), although some unpublished theses at universities in DR Congo were conducted. In Zambia and Congo-Brazzaville on the other hand, no publications dealing with diatoms have been produced. But since 2013 some papers dealing with the description of new diatom species

from the Congo and Zambezi basins were published, e.g., Cocquyt et al. 2013, 2014, Taylor et al. 2014a, b. Attempts to use diatoms as a tool for water quality of rivers in central Africa started only recently on some small rivers in the vicinity of Gombe Stream National Park in Tanzania (Bellinger et al. 2006).

2.2. THE USE OF DIATOMS AS INDICATOR ORGANISMS IN SOUTH AFRICA

The potential of diatoms as indicators of water quality was realised in South Africa many years ago. Cholnoky (1968) describes the application of the Thomasson (1925) community analysis, which he adapted to determine water quality using benthic diatom community composition. Use of the Thomasson community analysis allows for comparisons to be made between sites in the same river, or it may be used to track changes at a single site. One aspect of water chemistry is chosen for study, e.g. the amount of nitrogenous effluent. First the sum of all the species of the genus *Nitzschia* within a particular diatom community is calculated as an abundance value. The genus *Nitzschia* is known generally to be nitrogen heterotrophic (able to utilise organically bound nitrogen), and therefore the relative abundance of this genus in a sample gives a reflection of the amount of nitrogenous pollution at the study site. Similarly, abundance values of the acidobiontic diatom genus *Eunotia* can be used to track a pH gradient in a river system. Cholnoky (1968) obtained good results using this index, but the user of the Thomasson analysis method needs to have an in-depth knowledge of the autecology of individual diatom genera and species to draw accurate environmental conclusions based on diatom community composition. Cholnoky's application of the Thomasson analysis method was a forerunner of modern autecological indices, which have since become more accurate due to the development of correspondence analysis, with the advantage of being able to assign exact tolerance limits for chemical variables to not only genera, but also species.

Archibald (1972) attempted to relate diversity in some diatom communities to water quality. The diversity index approach proved to be unsuccessful, with Archibald concluding that diversity of species within a particular diatom community provides an unreliable reflection of water quality. Although Archibald's attempt to use diatoms as bio-indicators failed, the diversity approach was a parallel development in water quality monitoring with European countries in using microalgae to monitor water quality.

Schoeman (1976) used diatom indicator groups in the assessment of water quality. Schoeman simplified the community analysis method of Cholnoky (discussed above) by dividing diatom associations into four groups, each with their own particular ecological requirements. Only the groups or associations were then reflected in the table of results, instead of the lengthy tables used by Cholnoky. Schoeman concluded that these diatom associations or groupings could be successfully

employed to assess the quality of running waters especially in regard to the trophic status. Round (1993) also came to the conclusion that Schoeman (1976) found a good fit between groups of diatoms and chemical levels in the Jukskei-Crocodile River system, and went on to comment that the species used were similar to those in Europe.

In 1979 Lange-Bertalot developed a monitoring system based on groups of diatoms with similar tolerances towards pollution. Lange-Bertalot's "saprobian" classification system proved, after certain modifications, to be highly successful. Schoeman (1979) tested Lange-Bertalot's (1979) method in the upper Hennops River, South Africa and found a good correlation between the species composition of the diatom communities studied and the water quality. Unfortunately, this parallel development with Europe in the study of the application of diatoms as bio-indicator organisms terminated then in South Africa with Schoeman's (1979) work.

Diatoms, as indicators of water quality, were only again investigated in depth in South Africa by Bate et al. (2002). The investigation attempted to relate a descriptive index, based on a dataset for the environmental tolerances of diatom species found in the Netherlands, to water quality in South Africa. The environmental variables generated by the van Dam et al. (1994) index include: pH, conductivity, oxygen requirements, trophic status, saprobian status and habitat requirements of a selected number of diatom species found in waters of the Netherlands (van Dam et al., 1994). Bate et al. (2002) came to the conclusion that benthic diatoms could be useful and that they give a time-integrated indication of specific water quality components. However, Bate and co-workers went on to state that the particular data set tested in their study (that of van Dam et al., 1994), could not be transposed directly for use under South African conditions.

2.3. DEVELOPMENT OF EUROPEAN DIATOM-BASED INDICES

The various European diatom indices can be divided into different classes. The majority of the indices used are based on the weighted average equation of Zelinka & Marvan (1961) and have the basic form:

$$index = \frac{\sum_{j=1}^n a_j s_j v_j}{\sum_{j=1}^n a_j v_j}$$

where a_j = abundance (proportion) of species j in a sample, v_j = indicator value and s_j = pollution sensitivity of species j . The performance of the indices depends on the values given to the constants s (indicator value) and v (pollution sensitivity of species) for each taxon and the values of the index ranges from 1 to an upper limit equal to the highest value of s . Diatom indices differ in the number of

species used and in the values of *s* and *v* which have been attributed after compiling the data from literature and from canonical correspondence analysis (Prygiel & Coste, 1993).

In 1979 Descy proposed the first true diatom index using the equation of Zelinka & Marvan (1961) on the basis of an investigation carried out on the Belgian section of the Sambre and Meuse Rivers (Prygiel et al., 1999).

Using Descy's method (Descy, 1979) Coste (in CEMAGREF, 1982) proposed an index known as the Specific Pollution sensitivity Index (SPI). The SPI index is based on 189 surveys carried out during a national monitoring programme in the period 1977 to 1980 at sites in the Rhône-Méditerranée-Corse basin. The index has been updated since 1982 in order to incorporate changes in taxonomy and new knowledge of diatom ecology.

Following the SPI, a Generic Diatom Index (GDI) was proposed (Coste & Ayphassorho, 1991) containing 174 taxa, including new genera, proposed by Round et al. (1990).

Leclercq & Maquet (1987) applied the method of Descy (1979) to the Belgian Ardennes watercourses (Samson catchment area). The authors proposed new *s* and *v* values for 210 species, following an exhaustive compilation of the autecological data in scientific literature. The index was updated (Leclercq, 1995), and now includes 403 species.

In 1991 Descy & Coste developed a diatom index for use in general water quality monitoring across Europe. The Commission for Economical Community index (or CEC) is calculated from a two-entry table, which contains 208 taxa. Horizontally, there are 8 groups of taxa ranked according to decreasing tolerance for pollution by biodegradable organic matter; vertically from left to right, there are 4 subgroups of the more stenocous species representing the upstream-downstream succession along a theoretical running water ecosystem.

The Artois-Picardie Diatom Index (APDI; Prygiel et al., 1996) was the result of the need expressed by French water management for a technique for wide application in monitoring networks. The APDI was designed to combine ease of use and reliability with standardised techniques. An attempt was made to reduce the number of units to be counted, the level of identification and a reduction in number of taxa to those of the most significance for index calculation (i.e. those taxa with a high indicator value). The requirements for ease of use and reliability were met by combining the most recent version of the GDI index and the SPI index, yielding an index based on the identification of 45 genera and 91 species.

The wide use of GDI and SPI in France lead to the creation of the Biological Diatom Index (BDI; Lenoir & Coste, 1996) to meet the need for an index capable of being applied to monitoring networks throughout the whole of France. The BDI was designed on the basis of 1332 biological and physico-chemical surveys and includes 1028 diatom species and varieties. To maximise the usability of the BDI, morphologically similar species that are difficult for the non-specialist to identify with light microscopy were combined. This reduced the number of taxa. Rare species (less than 5% of the

inventory) were eliminated from the list, which resulted in 209 taxa being kept (Prygiel & Coste, 1999).

Dell'Uomo (1996) proposed an index known as the Eutrophication/Pollution Index (EPI). The EPI was designed on the basis of investigations concerning 8 measurement stations in the river Chienti, a watercourse in the Central Apennines, Italy. The EPI is a specific sensitivity index, which integrates the saprobic (pollution tolerance), the trophic (trophic levels) and halobic (specific salinity requirements) aspects attributed to 93 diatom species.

Sládeček (1986) applied the method of Descy (1979) in the context of the saprobic system. Saprobity refers to the differing levels of tolerance or sensitivity towards organic pollution (domestic and industrial). The values within the formula of Zelinka & Marvan (1961) of s (pollution sensitivity) and v (indicator value) are attributed to 323 species according to their affinity for organic material expressed in the measurement of BOD₅ (Biochemical Oxygen Demand; Sládeček, 1973, 1986).

Schiefele and Kohmann in Hofmann (1996) proposed a Trophic Diatom Index (TDI) on the basis of a three year study of 31 sampling sites in 5 German federal states. Indicator values relating to dissolved inorganic phosphate (DIP), total phosphate (TP), nitrate and ammonia were calculated for 105 diatom species. The formula of the trophic diatom index conforms to the saprobic index of Zelinka & Marvan (1961), and is intended to be its trophic counterpart. As a measure of the indicator quality, species-specific tolerances are weighted (1 to 7) and included into the calculation. Analogous to the saprobic system, the TDI divides quality status into seven levels covering oligotrophic to hypereutrophic conditions. This TDI index is only calibrated for mesotrophic to hypereutrophic conditions (Prygiel et al., 1999).

A similar Trophic Diatom Index (TDI) was proposed by Kelly & Whitton (1995), this based on investigations at 70 sites representing 14 hydrographical basins located in England and Scotland. The TDI index is not a general quality index, but should be considered an auxiliary tool for decision-making on phosphorus treatment in wastewater plants. The index should not be used on its own but should be complimented by the percentage of organic pollution-tolerant taxa. Easy identification and high indicator values were the criteria for the selection of 86 taxa. A sensitivity value between 1 and 5 was given to each taxon, depending on the concentration at which taxa were most abundant. The final value is comprised between 1 (very low nutrient concentrations) and 5 (very high nutrient concentrations). This technique is original in that, while working with species and genera in a way, which is analogous to APDI (Prygiel et al., 1996), it also takes into account the cell size of the species. A number of changes have been implemented since the 1995 Kelly & Whitton paper, namely scale extension from 1-5 to 1-100, removal of predominantly planktonic taxa from the calculation of the index and slight changes to pollution sensitivity and indicator values for some taxa (Prygiel et al., 1999).

Diatom analyses are included in the European Water Framework Directive of 2000 and with implementation date of 22 December 2003.

3. Recent application of diatom indices in southern Africa

3.1. WHY USE DIATOMS AS INDICATOR ORGANISMS?

No single group of organisms is best suited for detecting the diversity of environmental perturbations associated with human activities (Kelly, 2002). If the maintenance of ecosystem integrity is the aim of environmental management of a river system, the need to monitor the status of different taxonomic groups is vital. Diatoms provide interpretable indications of specific changes in water quality, whereas invertebrate and fish assemblages may better reflect the impact of changes in the physical habitat in addition to certain chemical changes (McCormick & Cairns, 1994).

Round (1991) lists several reasons why animal (fish and aquatic macroinvertebrates) components of an ecosystem may not provide a satisfactory index system. Animals have complex reproductive cycles which are often linked to the seasons; animals are largely motile and this may cause difficulty during sampling; animals may have many different life stages and may undergo metamorphosis; animals have specific habitats and niches; diatoms are actively grazed; and closely linked to flow conditions, rendering their distribution uneven from headwaters to estuaries. In addition, watercourses that are too deep or dangerous to wade across may prove difficult if not impossible to evaluate using a macro-invertebrate index along the length of the river.

Diatoms have several advantages over the animal (fish and aquatic macroinvertebrates) component of streams and rivers. Diatoms are an abundant, diverse and important component of algal assemblages in freshwater bodies. Diatoms comprise a large portion of total algal biomass over a broad spectrum of trophic levels (Kreis et al., 1985). While diatoms collectively show a broad range of tolerance along a gradient of aquatic productivity, individual species have specific habitat and water chemistry requirements (Patrick & Reimer, 1966; Werner, 1977; Round et al., 1990). In addition, diatom communities live in open waters of lakes (plankton), or primarily in association with plants (epiphyton), rocks (epilithon), sand (epipsammon) or mud (epipelton) in littoral, nearshore habitats. Eutrophication of surface waters has a severe influence on general water quality. Numerous problems are posed in the chemical monitoring of eutrophication. Criteria for assessing trophic status from total phosphorus concentrations are based on annual average values (OECD, 1982) and, in turn, criteria for assessing trophic status from total nitrogen are based on averages for the summer months (DWAF, 1995). The ratio between these two elements needs to be determined before an accurate assessment of trophic status can be made.

Diatoms are useful organisms for the bio-monitoring of eutrophication as they are sensitive to changes in nutrient concentrations (Pan et al., 1996), supply rates and ratios (e.g., Si:P; Tilman, 1977; Tilman et al., 1982). Because diatoms are primarily photo-autotrophic organisms, they are directly affected by changes in nutrient and light availability (Tilman et al., 1982). Each taxon has a specific optimum and

tolerance limit for nutrients, which can usually be quantified to a high degree of certainty (e.g. P: Hall & Smoll, 1992; Reavie et al., 1995; Fritz et al., 1993; Bennion, 1994, 1995; Bennion et al., 1996; N: Christie & Smol 1993).

Diatom assemblages are typically species rich. This diversity of diatoms in different population densities, composition and overall abundance, contains considerable ecological information.

Moreover, the large number of taxa provides redundancies of information and important internal checks in datasets, which increase confidence of environmental inferences (Dixit et al., 1992).

In addition to the above factors the response of diatoms to perturbation and recovery is rapid (Zeeb et al., 1994). Diatoms have one of the shortest generation times of all biological indicator groups (Rott, 1991). They reproduce and respond rapidly to environmental change and provide early warnings of both pollution increases and habitat restoration success. Rapid immigration rates and the lack of physical dispersal barriers ensure that there is little lag-time between perturbation and response (Vinebrooke, 1996).

Round (1993) lists numerous reasons why diatoms are useful tools for bio-monitoring, amongst which the following bear special relevance to the southern and central African situation: diatom-based methods are cost effective; data is comparable (national and international); techniques are rapid and accurate; identifications and counts can be done by trained non-specialists, if they are provided with illustrated guides. Diatom-based indices could be particularly valuable in assessing rivers because a one-time assay of species composition of diatom assemblages in the system could provide better characterisations of physical and chemical conditions than conventional physico-chemical techniques (Stevenson & Pan, 1999). In addition, by sampling stream biota, a reflection of the biological integrity of the stream may be gained. The structure of the community may not directly reflect the measured concentrations of water quality variables. This may be due to a number of reasons: either the chemical constituent was not sampled for or, if sampled it was below the levels of detection in the particular laboratory performing the analysis, or, either synergistic or antagonistic reactions took place between several chemical constituents within the stream or river. For this reason, measuring the integrity of the biotic community sampled, rather than just the relationship between biota and chemical concentrations, provides an indication of general stream health, as stream biota are directly exposed to all the elements within the particular water body which they inhabit. The community structure of a selected group of organisms provides an integrated reflection of all the chemical variables that influence that particular group of biota.

Taxonomic difficulties may also be avoided by using a simplified diatom index such as the Generic Diatom Index (GDI) of Coste & Ayphassorho (1991). GDI allows for the determination of water quality at a particular site, based on the identification of diatoms to the genus level. GDI index has been found comparable to indices such as the Specific Pollution sensitivity Index (SPI; CEMAGREF, 1982), which is based on a large number of taxa (Kelly et al., 1995; Kwandrans et al., 1998). The genus-level approach has also proved to be successful in Taiwanese waters using a specific index

based on only six genera and the ratio of occurrence between these six genera (Wu & Kow, 2002). Strong correlations were found between the Taiwanese generic index and other diatom-based indices of water quality (Wu & Kow, 2002). Currently this may be the only sensible approach to adopt for central African rivers (see discussion below).

3.2. THE APPLICATION OF EUROPEAN DIATOM-BASED INDICES IN SOUTH AFRICA

Diatom indices developed in Europe were identified as possible useful tools for monitoring water quality and were tested in South Africa. Taylor (2004) and Taylor et al. (2007a; 2007b) examined the use of numerical diatom indices for indicating water quality in some of the most important river systems in South Africa. In general, these studies conclude that European, diatom-based numerical water quality indices could be used with success in South Africa. However, Taylor et al. (2007b) highlighted the following potential problems:

- i) The list of taxa included in the indices needs to be adapted to the studied region. Most European diatom indices may be used in many regions and also in South Africa as they are based on the ecology of widely distributed or cosmopolitan taxa. However, special attention should be paid to taxa occurring in pristine water (e.g. *Achnantheidium standeri* (Cholnoky) J.C. Taylor, Morales & Ector) as well as endemic taxa which are absent in the indices reference lists (e.g. *Gomphonema venusta* Passy, Kociolek & R. L. Lowe). When these taxa are abundant, water quality may be misinterpreted.
- ii) Diatom taxonomy is undergoing rapid changes, especially at the genus level. Local floras, guides and methods to be used must be consistent. Some European indices (as discussed above) have been proposed in the seventies or in the eighties and have never been revised. Thus, several common and abundant taxa, some of which being newly or recently described, may not be taken into account and lead to erroneous results. There are also several different approaches to taxonomy when calculating index scores. For example, *Achnantheidium pyrenaicum* (Hustedt) H. Kobayasi is part of the BDI (Biological Diatom Index, Lenoir & Coste 1996) taxa list, even if lumped with *Achnantheidium minutissimum* (Kützing) Czarnecki, but is not considered in other European indices such as TDI (Trophic Diatom Index, Kelly & Whitton 1995) for example. Such an exclusion will possibly change index scores as these two taxa have a different ecology, *A. pyrenaicum* is characteristic of pristine calcareous rivers while *A. minutissimum* is considered as a cosmopolitan pioneer taxon. In the case of BDI, many taxa have been lumped because of the difficulty to separate them in routine surveillance, even if their ecology is different.
- iii) It has been highlighted in other studies that classification systems based on species tolerances should be carefully considered as built, to a greater or lesser extent, from local data. For example, Rottet al. (2003) noted that when using BDI, resulting index scores classified Austrian rivers as relatively good, even though large nutrient loads should have led them to be classified as eutrophic,

poor quality rivers. It should be noted that BDI was developed from data collected from the French national monitoring network which was aimed almost solely at monitoring impacts on water quality.

The index approach was deemed useful in South Africa to provide information on water quality impacts on rivers and streams. The studies also demonstrated that many widely distributed diatom species have similar environmental tolerances to those recorded for these species in Europe and elsewhere.

4. Diatom taxonomy and diatom species concept drift

When diatoms were first systematically studied and documented, a brief description was accompanied by an often minute drawing (e.g. Kützing, 1844). These drawings were also made from freshly collected material or material dried to thin sheets of mica. Surprisingly despite this some species concepts remain remarkably stable (see discussion in Taylor et al., 2014c). However, others are far less stable, especially when the original author of the taxon did not provide a clear species concept (see discussion below). As diatom studies advanced, diatoms were documented, again mostly with drawings, but from cleaned material mounted in media with a high refractive index allowing the morphology of the cells to be better observed, and such drawings are open to interpretation. When photomicroscopy became more accessible and commonly used species concepts could be firmly established. Added to this the rules for botanical nomenclature changed in 1958 necessitating the description of a species from a single type slide/sample allowing less room for error in interpretation of the original authors concept by later workers. Drawings of cells are always open to interpretation and shifts come about as one author identifies what he assumes to be a previously described taxon and then in turn often illustrate this taxon themselves (their concept). This new illustration may sometime be easier available to the scientific community than the original. If the concepts of the species differ the newer illustration can take precedence simply because of the availability of literature. This has been in particular true for Africa as literature, even now with the availability of electronic resources, still remains difficult for central African scientists to obtain locally. With drawings as illustrations these subtle shifts can occur several times distancing the species far from its original concept and perhaps even from the generic classification. As mentioned before, as photographic floras were published, species concepts became more stable but these stable concepts may still have been based on misinterpretation. Several attempts to remedy this problem have been made: Schoeman and Archibald (1976-1980) set about describing in detail the diatom flora of South Africa by checking the type slide of each species they discussed, collecting together the original drawings, light microscope and electron microscope images. Unfortunately for a number of reasons this work was discontinued. Recently however, there has been a resurgence within the diatom community of the notion that we cannot accurately describe and discuss the ecology of taxa without referring to the type material (e.g.

Taylor et al., 2014c, Morales et al., 2013, Wetzel et al., 2013). However such research is time consuming and the investment of time may not be necessary to successfully apply indices. For this reason the use of species based indices is not currently recommended for central Africa. We propose for the moment that genus based indices be used in this region but this approach will need careful testing and calibration in order to determine its usefulness.

5. Conclusions and recommendations for the use of diatom indices in central Africa

For the foreseeable future the application of species level diatom indices will not be possible in central Africa, the reasons for this are manifold but include in particular the following:

- diatom species, and even some genera, from this region are relatively unknown and many undescribed;
- published literature from the region on species identification and environmental tolerances is scarce but necessary to construct indices;
- lack of expertise in central Africa to identify diatoms.

In South Africa when index testing began, although exhaustive knowledge of the local taxa and their requirements was not known, these indices were applied in river monitoring programs to reflect water quality (Taylor et al., 2007a). Although this is far from an ideal situation, the inclusion of these techniques allowed for sample and data collection which in turn could be used to fill taxonomic gaps (e.g. Taylor et al., 2010) and gain information on species distribution and environmental tolerances. Coupled with the production of guides for identification and methodology (e.g. Taylor et al., 2007b; 2007c) the technique has now gained impetus and has become a routinely used part of the suite of biomonitoring tools nationally.

We would propose a similar solution for central Africa. As discussed, species identifications cannot be made with any great certainty, however genus identifications may be simpler to achieve. Recently diatom taxonomy and nomenclature have undergone a number of changes, in particular very large diatom genera have been split into more natural groups. These splits also very often have very specific environmental tolerance (e.g. *Humidophila* (Lange-Bertalot & Werum) R. L. Lowe, Kociolek, Johansen, Van de Vijver, Lange-Bertalot & Kopalová). In essence there are now more genera so that we can expect greater resolution in the use of genus-based indices. If accurately identified taxa could be used for the calculation of a genus level index and this in turn could be used to indicate, with some degree of accuracy, reigning environmental conditions. A region specific guide is a vital resource. Such guides are by no means exhaustive, neither do they pretend to be, but instead provide a first introduction into the world of diatoms for many students and other interested workers. Once a reliable guide (coupled with relevant methodology) to the genera of tropical Africa is available, scientists in

central Africa can receive adequate training in diatom identification and begin with the application and testing of indices based on diatom genus level.

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