# The relevance of diatoms for water quality assessment in South Africa: A position paper#

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## Abstract

Water quality assessment protocols based on the use of diatoms are now well developed and their value substantiated at an international level. The use of diatoms is not designed or intended to be a "rapid" technology. The detailed level of information generated from the procedure outweighs perceived disadvantages of the additional time required for sample preparation and analysis to species level. The method is applicable across a wide range of aquatic ecosystem types, namely freshwater, brackish, and estuarine, and is inclusive of both lentic and lotic environments, wetlands and their associated damp, marginal and littoral zones. Details provided by diatom assemblages support palaeoecological investigations, historical reconstruction of water quality and the determination of prevailing water quality conditions. Deliberate determination of responses to management strategies or impacts arising from a variety of anthropogenic activities can be achieved via the simple expedient of retrieving living material from introduced artificial substrates. Previous studies in South Africa and elsewhere have shown that on a site-by-site basis the use of diatoms provides a fine level of diagnostic resolution of the causes underlying changes in water quality and environmental condition.

The South African Diatom Collection ("the Collection"), a repository of diatom specimens and records that spans the length and breadth of this country, contains an as-yet unutilised wealth of ecological and taxonomic information. More importantly, the historical data analysis records provide an insight into water quality conditions prevailing 40 to 50 years ago – in many cases prior to the "development" of many of our rivers, streams and wetlands. The real value of its existence underpins the great potential for renewed attention to the value of diatom-based approaches to water quality assessments. In addition, the Collection provides a ready-made foundation on which a locally relevant tool for water quality assessment may be established to augment the current use of invertebrate indicators.

It is now appropriate that the full potential of the use of diatoms in water quality assessments, and the information contained in the Collection, be developed and utilised for water quality assessment in South Africa.

**Keywords**: diatoms, water quality, Cholnoky, Archibald, biotic indices

## Introduction

### Assessing water quality using biotic indices

Few people involved with ecohydrology and water resource management doubt the value of water quality assessments derived from the use of biotic indices, i.e. assessments based on observations of the resident floral and faunal communities (Chutter, 1972; Patrick, 1973; Schoeman, 1976; Descy, 1979; Kelly et al., 1995; Kelly, 1998a; Bate et al., 2002). Assuming requisite levels of ecological experience and taxonomic proficiency on the part of the assessor, such evaluations provide a description of the water quality that is often not achievable from elemental analyses alone. The value of an integrative biological response provided by the analysis of diatom associations offsets the inconsistency of rapid changes in water chemistries that render the use of conventional analytical approaches inadequate. A further potential advantage is that the diatom-based approach could obviate the need for additional and expensive toxicity testing protocols – particularly because of the attendant uncertainty of extrapolation to the real environment of the responses of selected single species testing gauged under laboratory conditions. Ecological risk assessments are more appropriately based on biological endpoints in the field than on measures of chemical constituents (Karr and Chu, 1997). Monitoring procedures based on the biota measure the health of a river and the ability of aquatic systems to support life, as opposed to simply characterising the chemical and physical components of a particular system. This is the central purpose of assessing the biological condition of aquatic communities of a river (Barbour, 1997).

Karr and Chu (1997) have stressed that chemical criteria based on laboratory-derived dose-response curves for single toxicants cannot account for cumulative, synergistic or antagonistic interactions of the suite of chemicals found in a polluted river system. Comprehensive and accurate multimetric indices explicitly embrace several attributes of the sampled assemblage including taxon richness, indicator taxa and the health of individuals. In many cases, biotic indices provide an indication of the existence or absence of life in stream water where routine chemical measurements of "indicator elements", even at the limits of analytical detection are not definitive.

Cairns (1981) highlighted the need for standard methods for the bio-monitoring profession because he recognised that the condition of individual species and of communities of indigenous biota was one of the best measures of the health of an ecosystem. In an effort to

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provide a reliable assessment tool within as short as possible a time frame, the search for rapid assessment technologies in South Africa centred largely on the use of aquatic insects, and protocols such as the South African Scoring System (SASS), now in its 5th iteration, were derived (Dickens and Graham, 2002). Subsequently the value and validity of rapid assessment biological methods have been challenged by Taylor (1997) and he contends that further refinements of these rapid techniques will be less useful than improving established methods. With proficient and professional use SASS provides a great deal of insight into the condition of invertebrates within a particular riverine environment. Nevertheless there is also an inappropriate tendency, perhaps borne of the apparent absence of any alternative, to extend the use of SASS into other environments, such as wetlands. The diatom approach provides a viable and already-developed alternative protocol for the health assessments of wetlands.

### The need to augment invertebrate-based protocols

The presently preferred use and value of the aquatic invertebrate method is variably limited by hydrology, substrate(s), habitat, food availability, seasonality and distribution patchiness. The latter aspect places an obvious demand on the number of samples that need to be taken in order to produce a quantitative result within regional considerations and a host of anthropogenic factors – not least the major modifications in assemblages occurring downstream of dams and weirs (Dallas,1997). While invertebrate indices do not provide a reliable indication of eutrophication, diffuse- and point-source impacts have previously been positively identified by direct measurements of the diatom associations found in South African river systems (Cholnoky, 1960; 1968; Archibald, 1972; Schoeman, 1976). Charles (1996) stressed that the use of algae for monitoring rivers has increased because of limitations of benthic invertebrates and fish as indicators. Coupled with significant improvements in technologies for algal assessment that increase the information/cost ratio, there is a realisation and acceptance by water authorities of the value of biological monitoring, particularly where multiple groups of organisms (i.e. from different trophic levels) are included in the evaluation.

Justification for and recognition of the value of such a scientific management approach is demonstrable in the existence of the South African Diatom Collection. The meticulous manner in which our former dedicated colleagues - Cholnoky, Giffen, Archibald and Schoeman - recorded sample localities, their results, and preserved the collected material, has provided an invaluable environmental legacy for South African aquatic systems. It has become a matter of concern therefore that since the late 1980s the real value of this material has gone unrecognised amongst water management authorities and aquatic scientists, if only because the information and its existence have not been sufficiently advertised.

While assessments such as SASS should undeniably remain in the toolbox of water quality assessment professionals, there exists a pressing demand for additional protocols that will confirm and/or augment the value of invertebrate-based evaluations. Ideal attributes for such additional tools would be:

- Wide-ranging applicability across aquatic ecosystem types and their adjacent (damp) environments
- Indicators should be retrievable under all hydrological conditions, including stagnant and dry and – most important – should lend themselves to forensic interrogation – i.e. palaeoecological assessment
- The results obtained therefrom should be incontrovertibly linked to water quality.

One group of organisms fulfils these core requirements, and more – the algal Class Bacillariophyceae. Diatoms occur in all types of aquatic ecosystems, and extend into the more saline estuarine environments as part of the river continuum. They comprise the major component of the microphytobenthos (bottom-dwellers), performing essential photosynthetically driven, microbial functions at the base of the food chain (Cox, 1996). Accordingly they respond directly to growth stimulants (nutrients) and/or stressors such as toxicants, as well as to physical factors.

## The use of diatoms as an "added-value" assessment tool

Importantly, the ability to use diatoms to evaluate present and past conditions of water quality and environmental change in just about any aquatic environment has been recognised world-wide for many decades (Patrick, 1973; Van Dam, 1974; Chessman, 1986; Whitmore, 1989), but has been limited in South Africa – until now – by perceptions of seemingly onerous sample preparation and time-consuming dedication required to develop key taxonomic skills. State and regional river-monitoring programs for algae in the United States tend to rely solely on analysis of diatom assemblages (Charles, 1996).

The authors' personal experience from using the most recent and modern computer technology, supported by image analysis software, and informed by recently published literature, is that this has resulted in a marked reduction in time required and greater confidence in the results. Difficulties with the taxonomy and nomenclature of the diatoms can now be resolved through comparison of images via rapid e-mail communication with other experts – as is the common norm in many disciplines of scientific investigation. Kociolek and Stoermer (2001) hold a strong view that studies on accurate taxonomy and ecology of diatoms in the 21st Century will and must be linked. They also emphasise that this approach will be driven by integrated research programs (e.g. river health studies) and can now be facilitated by technological advances (e.g. computer toolkits and image analysis) that support both accurate taxonomy and improved ecological interpretation.  They envision a research paradigm that closely integrates diatom taxonomy and ecology to develop conservation biology in which microbial communities (e.g. diatoms) can be used to define 'natural' habitats requiring conservation.

Diatoms have for some time, and latterly increasingly so, been used for the assessment of short- and long-term environmental change (Dixit et al., 1992). Assessment approaches based on diatom indices were developed in the lacustrine environment, and have since been extended to encompass the riverine systems (Round, 1991a; b; Stevenson and Pan, 1999 and Eloranta and Soininen, 2002). Diatom-based information can be gleaned not only from natural surfaces (sediments, stones-in-current and marginal vegetation) but also from just about any other substrate or surface type in an aquatic environment. The living component can also be deliberately gathered in a controlled fashion using the simple expedient of artificial substrates – a significant advantage in the formulation of stressor-response models (Gold et al., 2002). High frequency, multi-parameter water quality monitoring programs are simply not cost effective in the present South African situation – and an alternative for assessing change over time is urgently required. The examination of living diatoms in sediments and on stones, together with the invertebrates, provides a method that combines two independent indicator systems at different trophic levels (Smol, 1992; Hofmann, 1996).

Diatoms provide the following essential suite of diagnostic attributes (e.g. De la Rey et al., 2004):

- They collectively show a broad range of tolerance along a gradient of aquatic productivity, with individual species having specific water chemistry requirements
- They have one of the shortest generation times of all biological indicators (~2 weeks). They reproduce and respond rapidly to environmental change and provide early measures of both pollution impacts and habitat restoration
- They are sensitive to change in nutrient concentrations, supply rates and silica/phosphate ratios. Each taxon has a specific optimum and tolerance for nutrients such as phosphate and nitrogen, and this is usually quantifiable. Moreover, whereas the use of historical water chemistry data are constrained by the level of analytical sophistication prevailing at the time of sampling, the associations of diatoms with water quality remain unchanged
- Their assemblages are typically species-rich – augmenting the information gained from a diversity of ecological tolerances. Moreover, the large number of taxa provides redundancies of information and important internal checks in datasets, increasing the confidence of environmental inferences
- They respond rapidly to eutrophication. Because diatoms are primarily photoautotrophic organisms, their growth response is directly affected by changes in prevailing nutrient concentrations and light availability
- Their rapid immigration rates and the lack of physical dispersal barriers ensure that there is little lag-time between perturbation and response
- Diatom frustules have a lasting permanence in sediments, such that sediment cores provide details of changes in the quality of the overlying water for as far back as one is able to search. This attribute alone has significant and far-reaching relevance for the determination of reference conditions, not only climatic but also the condition of the system prior to intrusion from anthropogenic development
- The taxonomy of diatoms is comprehensively documented. Species identifications are largely based on frustule morphology – an attribute readily identifiable with modern light microscopy and image analysis techniques, and are not dependent on electron microscopic techniques as is commonly misconceived
- Diatoms can be found on substrata in streambeds even when dry can be sampled at most times of the year and still accurately reflect recent or prevailing conditions

Additionally the use of diatoms is supported by the attributes identified by Schoeman and Haworth (1986):

- Their ease of collection, preparation for observation, and storage (small sample volumes, no desiccation risk) for reference purposes
- The considerable amount of tried and tested ecologically-associative information already available, both nationally and world-wide
- Their suitability for diversity analysis
- The availability of interpretive software package.

Concerns that the wealth of diatom-based information developed in the north-temperate zone might not be directly applicable to the southern latitudes have been comprehensively quelled by more recent findings that diatoms are 'subcosmopolitan', i.e. they occur anywhere where particular environmental conditions are fulfilled (Kelly, 1998b). This concept suggests that geographical location is not the determining factor in the distribution of diatom species and the composition of communities but rather the specific environmental variables prevailing at a particular site (Gold et al., 2002). Comparison of South African examples of paired sets of diatom and water quality data confirms that several of the diatom indices are directly applicable locally in certain rivers (De la Rey et al., 2004). In fact Cholnoky's South African work at the CSIR 30 years ago supported the identification of water quality and environmental change parameters at relatively fine spatial scales. An analysis of the Upper Hennops River in 1979 revealed that use of the Lange-Bertalot method – or saprobian system in which diatom taxa are placed in 9 different classes according to their specific pollution tolerances was adaptable to South African conditions (Schoeman, 1979).

Importantly, the use of diatom-based approaches is now supported by a better understanding of the relationship between diatoms and environmental variables (Prygiel and Coste, 1993, Gomez, 1999, Juttner et al., 2003). Predictive models exist that demonstrate their direct applicability for use in some South African rivers (De la Rey et al., 2004). Numerous case studies that provide clear guidance on the validity and strength of the approach abound worldwide (Prygiel et al., 1999; Stevenson and Pan, 1999; John, 2000; Wu and Kow, 2002). Moreover our work indicates that a significant amount of historical water quality information (providing a 'reference condition') is contained in the SA Diatom Collection (see below).

The aforementioned attributes have led to diatoms becoming firmly established, although not yet in South Africa, as important indicators of the present and past nature and condition of the aquatic environments in which they may be found. Diatom communities typically range from opportunistic tolerant species in areas of severe pollution, giving way to less tolerant and more competitively dominant species at the most distant location from the pollution source. Given that the types of diatoms dominant in nutrient-poor waters (oligotrophic) are distinct from those in enriched (eutrophic) environments and/or in potentially toxic conditions, the pattern of cultural eutrophication can be readily discerned (Cholnoky, 1960a Canter-Lund and Lund 1995). To quote Round, an eminent UK diatomist, "*the value of using diatoms lies in the fact that the flora reflects rather precisely the water quality at any one point and, by monitoring changes in the flora, subtle changes in water quality conditions will be detected*."

## The South African diatom collection

While many water resource managers and aquatic scientists may not realize it, South Africa possesses one of the most comprehensive collections of diatoms in the world. This substantial collection is currently housed at the offices of the CSIR (KwaZulu-Natal, Durban), and was considered to be the largest in the Southern Hemisphere. Information on this collection may be found at www.dhec.co.za/diatoms. During the early- to mid-20$^{th}$ centuries, two types of botanical collectors criss-crossed this country – viz. botanists and diatomists. Were it not for the untiring efforts of these early 'explorers' much of what our natural history of aquatic systems was like would still be unknown. Notable amongst these early efforts is the work of diatom specialists such as Cholnoky, Giffen, Archibald and Schoeman. Between them they conscientiously collected samples from a wide range of South and Southern African aquatic environments – many of which have been subjected to infrastructural development such as dams, weirs, water-transfer and abstraction schemes. Diatom material was also obtained from many parts of the world. The availability of computerised diatom assessment procedures now enables re-working of these data and comparison with current conditions. This information will be invaluable in judging both the impact of man-made alterations to aquatic systems and the efficacy of remedial management strategies.

Some selected examples of the Southern African coverages are:

### Gauteng

- *Diatom Indicator Groups in the Assessment of Water Quality in the Jukskei-Crocodile River System* (Schoeman, 1976)
- *Diatoms from the Vaal Dam Catchment Area, Transvaal* (Archibald, 1971).

### Eastern Cape

- *Diatoms of the Swartkops Estuary* (Eastern Cape) (Cholnoky, 1960a)
- *Diatoms of the Estuaries of the Eastern Cape Province* (Giffen, 1963)
- *The Diatoms of the Sundays and Great Fish Rivers in the Eastern Cape Province of South Africa* (Archibald, 1983).

### Western Cape

- *New and Rare Diatoms of the Cape Province* (Cholnoky, 1959)
- *An Account of the Littoral Diatoms from Langebaan, Saldanha Bay* (Giffen, 1975)
- *Marine Littoral Diatoms from the Gordon's Bay Region of False Bay* (Giffen, 1971)

### KwaZulu-Natal

- *Contributions to Our Knowledge of the Diatom Flora of Natal (Tugela, Mooi, Mkomaas, Umgeni, Pongola, and Umfolozi Rivers* (Cholnoky, 1960b)
- *New and Rare Diatoms from Africa – Diatoms from the Tugela System* (**I, II** and **III**) (Cholnoky, 1956;1957)
- *Diatom Associations of St Lucia Lake* (Cholnoky, 1968b)

### Other Southern African areas

- *Diatoms of the Okavango* (Cholnoky, 1966a)
- *Diatoms of Bechuanaland* (Cholnoky, 1966b)
- *Diatoms from Sewage Works in the Republic of South Africa and South West Africa* (Schoeman, 1972a)
- *Diatoms of Swaziland* (Cholnoky, 1962).

## Evaluation of the SA diatom collection

The findings of the aforementioned studies were documented and stored in slide collections, but have remained in almost permanent disuse since the early 1990s. More recently, new research efforts have contributed to the revival of interest in diatom associations as indicators of water quality in South African rivers (Watt, 1998 and Bate et al., 2002). The main aim of the WRC-funded work of the latter has been to survey benthic diatom flora and to relate the dominant taxa to the chemical water quality of selected river systems of the Eastern Cape, Western Cape and Mpumalanga. This study concluded that "*benthic diatoms have the potential to be used as biological indicators as they are ubiquitous members of riverine systems, react rapidly and predictably to water quality and their taxonomy has been well described*". Unfortunately, the historical value of the resources contained in the South African Diatom collection were not fully realised, perhaps leading to the comment that "*so far the use of benthic diatoms as indicators of river water quality in South Africa has been limited*". They did conclude, however that "*diatoms appear to be very suitable biomonitoring organisms. They give an accurate indication of water chemistry within water quality classes*".

## Diatom assemblages: Indices and interpretive tools

Within the last decade diatom-based indices have gained considerable popularity throughout the world as a tool to provide an integrated reflection of water quality, and in support of management decisions for rivers and streams (Kelly, 1998b; 2002; Prygiel and Coste, 1993). Work on the applied use of diatoms as bio-indicators has proceeded such that diatom indices have replaced those of invertebrates as the biomonitoring method of choice in certain situations e.g. canalised waterways (Prygiel and Coste, 1993)

The bulk of the developmental diatom work has been carried out in French drainage basins – with testing on the scale of a territory as large, and as typologically diversified, as France; enabling the general application of these indices on the European continent (Prygiel and Coste, 1993). In other examples diatoms have been integrated into a suite of testing methods required to support nutrient reduction directives (Kelly, 2002). The design of software programs such as OMNIDIA for the calculation of diatom indices has greatly enhanced the use of diatom-based methods (Le Cointe et al., 1993). A variety of diatom indices have been adopted and tested by many European countries including Finland (Eloranta, 1999) and Poland (Kwandrans et al., 1998).

The majority of the diatom indices are based on the weighted average equation of Zelinka and 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:

$\mathbf{a_j}$ = abundance (proportion) of species **j** in sample
$\mathbf{v_j}$ = indicator value
$\mathbf{s_j}$ = pollution sensitivity of species **j**

The performance of the indices depends on the values given to the constants **s** and **v** 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 ordinations (Prygiel and Coste, 1993).

## Concluding remarks

The use of diatoms as a diagnostic tool, and the value of the historical information contained in the SA Diatom Collection, can no longer be ignored. International precedents and local experience clearly indicate the versatility and durability of this protocol as a scientifically robust tool. It should be used in conjunction with the SASS invertebrate method as two independent indicator systems comprising a more comprehensive ecosystem health screening protocol in South Africa. If the ability to inform strategic water resource assessments is to be appropriately developed at a higher level of confidence, then any delays in attention to the diatom-based assessment methods would be both administratively and functionally negligent. Not least, a failure to do so would flout the considerable amount of effort that has been historically invested in the development of the resource base that is the SA Diatom Collection.

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