DIATOMS AS INDICATORS OF WATER QUALITY IN SOUTH AFRICAN RIVER SYSTEMS

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EXECUTIVE SUMMARY

The project was sub-divided into two parts. The title of the first part was "The preparation of a river water diatom identification database for use in South Africa". The title of the second part was "The use of diatoms in the assessment of water quality".

The initial hypothesis was that the database used in the Netherlands to assess water quality would be suitable for use in South Africa. For that reason, the aims in the first part were:

1. To produce a genus identification database consisting of all 238 genera described by Round et al. (1991). This was completed.
2. To obtain literature on the descriptions of all the 948 taxa of the Netherlands database. However, because the results of this study showed that the Netherlands database was not entirely suitable for use in South Africa (see later), descriptions were not confined to the Netherlands taxa. The available literature was obtained via interlibrary loans and purchases.
3. To produce a database and an identification system containing all the 948 diatom species used by van Dam et al (1994) to determine water quality in the Netherlands. For the reasons stated in 2 above this was not considered relevant to the study.
4. Construct identification systems for each genus of the Netherlands database. Because the study showed that the Netherlands database was not suitable for use in South Africa, this was not considered relevant to the study. Instead, the identification system was confined to all the genera as described in Round et al. (1990) because this is the latest text and it is in English.
5. Run a workshop for interested persons to test the system. A workshop has been run on two occasions for the staff of the CSIR (Durban). More workshops will be presented on demand.

The aims in the second part were:

1. To survey the benthic diatom flora of identified river systems and to relate the dominant taxa to the chemical water quality in those rivers. This was completed for rivers in the Eastern Cape, the Western Cape and Mpumalanga.

2. To determine the extent to which the diatom database developed in the Netherlands is relevant to South African rivers and their water quality. The conclusion was that the Dutch database was inadequate for South African use.

In the first part of the study, a Microsoft Excel spreadsheet was prepared from descriptions of each of the known diatom genera in Round et al. (1990) (see Appendix A). In the spreadsheet, all the possible characteristics (i.e. raphe, araphid, striae number, shape, etc.), were positioned across the page. The names of each of the possible genera were positioned down the LHS of the page and in each appropriate cell the genus was awarded a 1 if the characteristic applied or left blank if the characteristic did not apply. A visit was made to the University of Bristol, to Professor F.E. Round (senior author of the definitive text "The Diatoms") and, over a period of three days, each of the characteristics was checked. The table was then taken into a MS Access database system where a series of forms were produced, one for each genus. This database allows users to identify any diatom genus. The MS Access database was made available to the CCWR who placed it on the WRC web site.

The genus database is available to anyone interested in using it and can be accessed either from the CCWR web site or, by arrangement and a small charge to cover the cost, can be supplied as an MS Access database or as an MS Excel spreadsheet. These data have been supplied to the CSIR, Durban

The aims in the second part (literature) were achieved using Inter-library loans through the University of Port Elizabeth. Some of the aims of the second part very largely fell away as the project progressed. The number of taxa found was so small that the use of a species ID system was deemed to be more difficult for the potential user than to present each of the dominant taxa in visual format. Many of the more common dominant taxa are presented as plates in an Appendix C of this report.

Benthic epilithic and epipelic diatoms were sampled from 16 rivers in the Eastern Cape, the Western Cape, the Olifants River system (Mpumalanga) and, during a two-year survey every month in the Swartkops River, near Port Elizabeth. A species was considered dominant if it constituted the major number of specimens in a sample. Any species that was not dominant but constituted more than 10% of the total was included as a sub-dominant.

A total of 148 epilithic and 180 epipelic diatom taxa were studied. Of these, there were 102 species identified from all sites that came from only 31 genera. The total number of taxa when all future riverine data are available is likely to be less than 70 genera and 200 species. All the required information to enable future workers to identify all the taxa found should be easy to document. Only two genera are likely to require a system to enable species identification. These are *Navicula* and *Nitzschia.*

A water class index was constructed for the range of water qualities found from the 16 rivers sampled. Diatoms appear to be very suitable biomonitoring organisms. They give an accurate indication of the water chemistry within water quality classes. The system appears to be more specific than the system of van Dam et al. (1990) for the Netherlands. There are several possible explanations for the observed lack of correlation (in most instances) between the Van Dam index and observed conditions. Firstly, the species identifications are mostly based on European floras. Round (1993) pointed out that there might be subtle variations in appearance of diatoms collected in the Southern Hemisphere. Species are then identified to the nearest form in a European flora. This does not have to be a concern when the data are interpreted locally (e.g. calculating indicator values from the local data set). However, when comparisons are made that were developed in entirely different regions, the discrepancies in identification could interfere with the level of relevance.

The basis of the Van Dam index is that authors' own published and unpublished observations together with hundreds of other (international) publications. The index was specifically designed to be applied to watercourses and lakes in the Netherlands. Environmental conditions are likely to be quite different in South African rivers. Water quality is just one of the suite of variables (such as light, temperature or disturbance) affecting the structure of benthic diatom assemblages. These factors possibly override the water quality component when comparing the Van Dam index with South African conditions. This makes the calibration of a local diatom index necessary. The senior author of the Van Dam index was not surprised when he was advised that the application of the index in its present form did not result in a highly significant correlation with the South African data (H. van Dam, pers. comm.).

The data indicate that dominant diatoms do not change with season in the Swartkops River. The same diatom was dominant through all seasons at sites where the water quality was not influenced by pollution. This is an important finding because it means that the total number of taxa do not increase because of temperature (season) effects.

Water of a given quality will not result in a specific diatom being dominant. However, the presence of a dominant diatom will indicate the general quality of the water. The reason is that habitat characteristics other than water quality have an influence. Both epilithic and epipelic diatoms can be used as water quality indicators. Epipelic diatoms may be sampled with less operator influence than epilithic diatoms. However, epilithic diatoms may integrate water quality over a shorter time span.

The use of abbreviated names may be useful if the diatom system is applied as a biomonitoring tool. If the use of diatoms is adopted, the Environmentek division of the CSIR may be suitable to curate all the information. A single document containing the identification data for all dominant SA freshwater diatoms needs to be produced, preferably cheaply on a compact disk.

There is an urgent need for the information and techniques to be transferred to other professionals. There are no other researchers in South Africa at present that are specialising in the ecology of freshwater benthic diatoms.

The biological monitoring of water quality in river systems is beneficial if the variability of the conditions inferred from the organisms present is lower than the periodic chemical analysis of the water. Benthic diatoms have the potential to be used as biological indicators as they are ubiquitous members of riverine ecosystems, react rapidly and predictably to changes in water quality and their taxonomy has been well described. Diatoms are now being incorporated in standard protocols for water quality monitoring in various parts of the world. So far the use of benthic diatoms as indicators of river water quality in South Africa has been limited. There is, however, a demand for a biological indicator capable of integrating specific water quality conditions.

Benthic diatoms were collected in rivers located in the Eastern Cape, Western Cape, and the Olifants River (Mpumalanga) to assess the correlation between water quality and the relative abundance of epilithic and epipelic diatoms. The temporal variability between and within epilithic and epipelic assemblages was studied during a two-year survey along a pollution gradient in the Swartkops River in the Eastern Cape. Seasonal influences were not significant. The correlation between the relative abundance of benthic diatoms and water quality variables was investigated with Canonical Correspondence Analysis (CCA). Alkalinity, ammonium, conductivity, nitrite/nitrate, pH, phosphate and silicate had significant effects on the distribution of the diatom taxa in various rivers. Where the size of the data sets allowed it, weighted-averaging regression and calibration models were developed for these water quality variables. The models were tested with cross-validation (jack-knifing) and showed better performance with epilithic than with epipelic taxa, suggesting that the epilithon is the preferred habitat for biological monitoring of short-term (one-month) changes in water quality. The epipelon reflected long term integrated water quality patterns.

The variability of diatom inferred water quality values was significantly lower than the variability in measured water chemistry, indicating that diatoms are valuable indicators of water quality that give a time integrated assessment of prevailing water quality conditions. The application of the Van Dam diatom index, designed for lakes and watercourses in the Netherlands, showed a low correlation with observed water quality conditions in South Africa. This indicates that the calibration of a local diatom index, designed for specific regions, is the way forward.

The methods of field collection of diatom assemblages and processing techniques used during this study are straightforward and uncomplicated. With the development of a diatom species identification database, the use of diatoms for water quality monitoring in South Africa has the potential to become a valuable tool for local and national water authorities.

Diatoms were sampled from two distinct substrata: stones and sediments. The methods for diatom collection defined, to some extent, the boundaries for each habitat. The stones that were selected for the collection of an epilithic sample all had an obvious diatom growth, judged by their appearance and feel and lack of attached filamentous algae. Loosely attached algae were removed before the more tightly attached algae were sampled. This was done by rubbing the stone surface with a finger. The samples mainly contained prostrate (e.g. *Achnanthes*), stalked (e.g. *Cymbella*) and apically attached (e.g. *Synedra*) life forms. Mobile taxa (e.g. *Navicula* and *Nitzschia*) were also observed but usually in much lower relative abundance than in the epipelon.

Epipelic diatoms were collected with the 'cover slip method', which was particularly aimed at the collection of these mobile taxa. This was largely successful, although *Achanthes delicatula* and *A. engelbrechtii* (mono-raphid and therefore less mobile than their bi-raphid counterparts) were repeatedly found to be more abundant in the epipelon. Observations of live samples revealed that these species had actively attached to the cover slips and that they were not 'contaminants' originating from the epipsammon. Special care was taken to ensure that no, or very few sand grains, were collected along with the cover slips.

Species diversity was generally higher in epipelic than epilithic assemblages. This was mainly due to the larger number of mobile species in the epipelon. Most epilithic species were also found in the epipelon, although with lower relative abundance. The 'coverslip method' therefore seems to not just be picking up mobile life forms but also other taxa that can actively attach to the glass surface within the six to eight hours of 'incubation'.

Physico-chemical data are, strictly speaking, representative of the conditions at the moment of sampling. The composition of a biological sample is an integration of the variation in physico-chemical conditions over a period. The 'snap-shot' data of water quality to which diatom distribution has been correlated in this study is therefore not ideal. Under the circumstances, however, it is the 'next-best-thing'. Where possible, historic data (2-3 weeks before diatom sampling) was taken into account, but most often, these data were not available. The only solution to this problem seems to be to increase the frequency of sampling sites, especially for nutrients (e.g. Pan *et al.*, 1996). This is because nutrients are taken up rapidly in shallow streams (e.g. Borchard, 1996) and their variability is high (e.g. France and Peters, 1992). The seasonal study of diatoms in the Swartkops River showed that the increased sample size and extensive gradient in water quality resulted in a strong correlation between water quality variables and diatom distribution. The weighted-averaging and calibration models showed a good performance, especially when based on epilithic diatoms. Water column variables explained the variance in epilithic assemblages better than the variance in the epipelon. Epipelic diatoms have resources supplied from the water column in addition to the sediments (McCormick, 1996). Resource supplies from the sediments could explain a considerable part of the variance.

Although diatoms have the potential to be indicative of general river health, efforts in this study were concentrated on water quality variables. No attempts have been made to give a full account of the ecological diversity of benthic diatoms in South African rivers. Other groups of organisms are already employed for the assessment of ecosystem integrity within the National Biomonitoring Programme (Uys *et al.*, 1996). Benthic diatoms could be a useful addition to this programme as they give a time-integrated indication of specific water quality components.

The use of weighted average indices of water quality conditions that are presented in this study, is just one of the ways of employing diatoms in environmental assessments. Lange-Bertalot (1979) classifies species according to their tolerance to certain stressors that improve the characterisation of environmental variability as well as integrated environmental conditions. The data sets on which those classifications are based are a result of many years of research.

No single group of organisms is always best suited for detecting the diversity of environmental perturbations associated with human activities. If the maintenance of ecosystem integrity is the aim of the 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 and Cairns, 1994). Diatoms possess many desirable attributes as indicators of ecosystem integrity and water quality in particular:

- Diatoms are an ecologically important group in riverine ecosystems and occur throughout the river, throughout the year;
- Diatoms are sensitive to a wide range of water quality variables (e.g. pH, conductivity and nutrients);
- Diatoms respond rapidly and predictably to changes in water quality conditions.

The correlation that can be found between diatom distribution and water quality depends on the gradient that exists along the length of a river. In most instances pH, conductivity and nutrients could explain the variance in the distribution. Other variables of interest can possibly be investigated by constraining variables that have a known effect on the axes of ordination. If other variables can still explain a considerable part of the remaining variance, its influence on diatom distribution can be assessed (ter Braak and Šmilauer, 1998).

On a few occasions, river sites were sampled where the water quality conditions were considerably different from up and downstream sites. The diatom assemblages at these sites were also considerably different. These samples had to be classified as outliers as they would obscure the trends detectable with the multivariate analysis of the data sets. However, the information contained in the assemblage composition of these outlier sites, remains valuable. Only when these circumstances can be observed repeatedly, can this information become useful for the development of indicator values.

The technique of weighted-averaging and calibration has provided optimum values and tolerance ranges for individual diatoms species, specified for the habitat of origin. With this knowledge on the autecology of common diatoms, the analysis of (spatial or temporal) shifts in assemblage composition provides insight into the causes of such changes. The data in this study have shown that changes in conductivity, nitrogen (nitrite/nitrate and ammonium), pH and phosphorus can be successfully inferred from the diatoms with a lower degree of variation than monthly monitoring of water chemistry. This is the result of the integration effects that changes in water quality conditions have on diatom assemblage composition.

The data sets used for the development of these models were not large enough to make reasonable comparisons between optimum values for taxa observed across regional boundaries. Indicator values based on the Swartkops dataset showed high r^2_{jack} and low RMSE, where the models based on the Olifants River data set performed less well. Few taxa that occurred in both rivers showed similar indicator values for pH, nitrite/nitrate or phosphate (the only variables for which models could be developed in both rivers). This is most probably a result of the relatively small amount of data on which the Olifants River model is based. It is probably also due to the fact that the Olifants was visited once whereas the Swartkops was sampled on a monthly basis during a two-year period, along a strong and persistent pollution gradient. Patterns in species distribution were observed repeatedly, increasing the performance of the calibration models.

So far, the lack of commonly accepted, standardised protocols for monitoring with diatom assemblages has limited the use of this group in South African rivers. In addition, the presently obscure state of diatom taxonomy in South Africa made the use of this group unfavourable. With the development of a species identification database during this study at the University of Port Elizabeth, the identification of benthic diatoms that have previously been observed in South African rivers will be facilitated. The methods for field collection of diatom assemblages and processing techniques used during this study are straightforward and uncomplicated. The use of diatoms for water quality monitoring therefore has the potential to become accessible for local and national water authorities.

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INTRODUCTION

Prof. G C Bate undertook this study as the recipient of Grant K5/814 from the Water Research Commission. Mr. J. S. van der Molen collected the river samples, undertook the multivariate analyses of the data and reported those findings. Mr. van der Molen used the study with the intention of submitting the data in fulfilment of the requirements for the PhD degree of the University of Port Elizabeth. The section of the report prepared by Mr van der Molen is largely a statistical interpretation of the data. The first section of the report concentrates less on multivariate analyses and more on water quality and the manner in which diatom dominance is able to interpret water quality. The raw data from which the analyses were made is provided in Appendix A.

Prof. G C Bate retired from the Department of Botany at UPE at the end of 1998. Although still active as a research associate, the project was officially transferred to Dr. J. B. Adams.

What is required for practical purposes is that the diatoms, found in a water body, indicate the chemical quality of that water body. To do this, the water quality data, produced by chemical analysis, is assumed to be an absolute value. This is not true because the quality of the water varies considerably from time to time depending upon conditions. So, the fact that the diatoms do not relate directly to a measured water quality is probably due as much to the water analysis as to the diatoms. What this project sets out to evaluate, is how well diatoms can reflect water quality and whether it will be possible, knowing the difficulties associated with taxonomic identification, to apply diatoms as tools in water quality resolution.

The main findings are that the van Dam *et al.* (1994) data set from the Netherlands cannot be transposed directly to South African conditions. The discussion deals with some aspects of this problem. A recommendation is that because diatoms appear very suitable biomonitors of water quality, a full data set for South African conditions needs to be produced.

AIMS AND HOW THE PROJECT ADDRESSED THE AIMS

The project was sub-divided into two parts. The title of the first part was "The preparation of a river water diatom identification database for use in South Africa". The Title of the second part was "The use of diatoms in the assessment of water quality". An early hypothesis was that the database from the Netherlands would be suitable for use in South Africa. For that reason, the aims in the first part were:

To produce a genus identification database consisting of all 238 genera described by Round *et al.* (1991). This was completed.

To obtain literature on the descriptions of all the 948 taxa of the Netherlands database. Because the results of this study showed that the Netherlands database was not entirely suitable for use in South Africa, descriptions were not confined to the Netherlands taxa.

To produce a database and an identification system containing all the 948 diatom species used by van Dam et al (1994) to determine water quality in the Netherlands. For the reasons stated in 2 above this was not considered relevant to the study.

To construct identification systems for each genus of the Netherlands database. For the reasons stated above this was not considered relevant to the study as the data took form. Instead, the identification system was confined to all the genera as described in Round et al. (1990) because this is the latest text and it is in English.

Run a workshop for interested persons to test the system. A workshop has been run on two occasions for the staff of the CSIR (Durban).

The aims in the second part were:

To survey the benthic diatom flora of identified river systems and to relate the dominant taxa to the chemical water quality in those rivers. This has been achieved for selected South African rivers

To determine the extent to which the diatom database developed in the Netherlands is relevant to South African rivers and their water quality.

In the first part, a MS Excel spreadsheet was prepared from descriptions of each of the known diatom genera in Round et al. (1990). In the spreadsheet, all the possible characteristics (i.e. raphe, araphid, striae number, shape, etc., were positioned across the page. Each of the possible genera were positioned down the LHS of the page and in each appropriate cell the genus was awarded a 1 if the characteristic applied or left blank if the characteristic did not apply.

A visit was then made to the University of Bristol, to Professor F.E. Round (senior author of the definitive text "The Diatoms") and, over a period of three days, each of the characteristics was checked. The table was then taken into a MS Access database system where a series of forms were produced, one for each genus. The MS Access was made available to the CCWR in Durban who placed it on their web site.

This database is available to anyone interested in using it. They can be accessed either from the CCWR web site or, by arrangement and a small charge to cover the cost can be supplied as an MS Access database or as a MS Excel spreadsheet.

The aims in the second part (literature) were achieved using Inter-library loans through the University of Port Elizabeth. Some of the aims of the second part very largely fell away as the project progressed. The number of taxa found was so small that the use of a species ID system was deemed to be more difficult for the potential user than to present each of the dominant taxa in visual format. These taxa are presented as plates in an Appendix at the end of this report.

LITERATURE REVIEW

Rivers in South Africa

In South Africa, rivers can be roughly distinguished in four groups: perennial, seasonal in summer rainfall area, seasonal in winter rainfall area and intermittent rivers (Allanson *et al.*, 1990). It is important to distinguish between seasonal rivers in summer and winter rainfall areas as the biological activity peaks during summer and the impact of no flow conditions during summer could be more extreme. In the eastern regions of the country relatively short river systems (e.g. the Tugela) discharge a combined 58% of the South African Mean Annual Runoff (MAR=51.5 x 10^9 m^3) into the Indian Ocean. Some 22% of the South African MAR is transported by the Orange-Vaal system, which drains more than half of the surface area of the country. Rivers of the southern and western coastal regions carry the rest of the MAR (Davies and Day, 1998). The regulation and abstraction of river water by humankind has a large effect on natural flow patterns in most South African rivers. Formerly perennial rivers have become seasonal. In other systems, (such as the Fish River, which receives water from the Orange River system as part of an inter catchment transfer scheme) regulations have turned seasonal rivers into perennial rivers (Allanson *et al.*, 1990).

Water quality issues in South African rivers

The need for good quality water in South Africa is increasing and most rivers in South Africa have therefore been modified to enhance their use for irrigation, industrial and drinking water purposes. The return flow from irrigated agricultural lands and sewage purification works has increased the total suspended solids (TDS) in many rivers. Due to inappropriate agricultural practices, erosion has become a problem and has increased the already naturally high turbidity of many rivers. The sediments causing this turbidity are being trapped in man-made dams. Topsoil from the upper Orange River catchment for instance, is being trapped in the Gariep Dam (designed capacity 56 x 10^9 m^3) and adds an estimated 120 mm per year to the lake bottom (Davies and Day, 1998). In the province of Mpumalanga, mining operations are the cause of acidic effluents into some of the rivers (e.g. Olifants). Mineral ores and coal contain large amounts of sulphur which, when oxidised, forms sulphuric acid. All the electricity for national use (and some for export) is being generated in this area by coal-fired power stations. As a result, acid rain has been reported in this area. Slimes dams, made up of gold-mine waste containing heavy metals, arsenic and cyanides, are often located and designed in such a way that leachate has a direct effect on ground and river water quality. Eutrophication, caused mainly by sewage effluents, run-off from informal settlements and agriculture, has many unwanted effects such as the abundant growth of macrophytes. These effects become more apparent once the river water has been dammed. The cyanobacterium *Microcystis aeruginosa* can cause toxic blooms under such circumstances (Davies and Day, 1998).

Biological monitors in use in South Africa

In 1996, the National Biomonitoring Programme for Aquatic Ecosystems (NBPAE) was initiated by the Department of Water Affairs and Forestry (DWAF), the Water Research Commission (WRC) and the Department of Environmental Affairs and Tourism (DEAT). The objective is to design a monitoring programme to monitor the health of aquatic ecosystems throughout the country and to provide information that can be used by water resource managers to manage water systems (Hohls, 1996). Currently, an array of biological indices is being tested for practical use and interpretation. These indices are the South African Scoring System version 4 (SASS4, based on macroinvertebrates), the Index of Biotic Integrity (IBI, based on fish) and the Riparian Vegetation Index (RVI). A suite of secondary indices is also used to interpret the biological indices. These include Habitat assessment indices, the Hydrological Index, the Water Quality Index (WQI) and Geomorphological indices. The use of benthic diatoms has briefly been considered, but the lack of expertise in South Africa made a diatom index unsuitable for use (Uys *et al.*, 1996).

The water chemistry of many of the regulated rivers in South Africa is monitored by the DWAF. However, the chemistry at any given time is a mere "snapshot" of the water quality. The temporal variation of most water quality variables is usually high in lotic environments (France and Peters, 1992; Chambers *et al.*, 1992; Cattaneo and Prairie, 1995). Biological monitors are beneficial if they can accurately assess the water quality with a lower degree of variability than can the "snap-shot" sampling of specific water quality variables (Stevenson and Pan, 1999).

Dr. Mark Chutter is the leader in the use of macroinvertebrates as biological indicators of river health in South African rivers. Species have been identified with distinct levels of tolerance for organic pollution. From this the South African Scoring System (SASS, recently upgraded to SASS4) was developed. SASS4 was developed to assess general river health (Chutter, 1998). Attempts have been made to find a direct correlation between SASS4 results and water quality variables. So far, however, this has been unsuccessful (e.g. Cilliers, 1999). There is therefore, still place for a biological indicator that can be indicative of specific water quality variables.

Diatom research in South Africa

In South African river systems, diatoms have been studied extensively since the early 1950's (e.g. Cholnoky, 1953; Cholnoky, 1968; Archibald, 1983) and efforts have been made to relate diatom associations to water quality (e.g. Archibald, 1972; Schoeman, 1979). A large number of papers have been produced, mainly by B.J. Cholnoky, R.E.M. Archibald and F.R. Schoeman, all former employees of the Council for Scientific and Industrial Research (CSIR) in Pretoria. They have described a wide range of diatom species occurring in rivers throughout South Africa (e.g. Cholnoky, 1960; Archibald, 1983; Schoeman and Archibald, 1986). Their studies indicate that some species are endemic to this region, but the most abundant species are also common in other parts of the world. The taxonomic value of their work on diatoms in South Africa has been tremendous. Many of the papers were published internationally and Dr Archibald and Dr Schoeman have confirmed the identification of some of the known diatom species from South Africa by studying type slides from several European and a North American diatom collections (e.g. Archibald and Schoeman, 1984).

Diatoms in river systems

The most common benthic algae in freshwater habitats are blue green algae (Cyanophyta), green algae (Chlorophyta), diatoms (Bacillariophyta) and red algae (Rhodophyta). Most other divisions of algae can also occur in the freshwater benthic habitats. Benthic algae occur in unicellular, colonial or filamentous growth forms. The concepts that are discussed in this overview apply to most algae divisions in stream benthic habitats. However, the particular focus is on stream benthic diatoms. No attempts are being made to give a full account of the conceptual frameworks for benthic algal ecology.

Most motile benthic diatoms are unicellular and move by means of their raphe (e.g. *Navicula*). Their orientation is prostrate (e.g. *Achnanthes*), apically attached (e.g. *Synedra*) or stalked (e.g. *Cymbella* or *Gomphonema*). Prostrate diatoms are able to withstand flow (in the low velocity boundary layer around the object to which the diatoms are attached) and are most resistant to grazing. However, prostrate diatoms are easily overgrown by other benthic algae. Apically attached diatoms stand erect on substrata in slow currents. Stalked diatoms take longer to manifest true growth during community development. They can overgrow prostrate and apically attached diatoms, out competing them for light and nutrients (McCormick, 1996). Motile diatoms can move through the periphyton matrix formed by other growth forms. The existence of different growth forms in epibenthic diatom communities is most apparent in the succession of diatom species on introduced substrata, or after a disturbance event. During the initial stage of colonisation, bacteria and fungi are believed to be conspicuous constituents of the benthic community. They precondition the surface for early diatom colonisation (Korte and Blinn, 1983). The first diatoms to colonise are prostrate species, closely attached to the surface. An important factor in the initial stage of development is the immigration of diatom cells originating from upstream sites. Especially, motile species are known to resuspend easily into the water column and migrate, as metaphyton or tychoplankton (Wetzel, 1996), downstream. These migrating species contribute significantly to the early colonisation of newly immersed surfaces (Hudon and Bourget, 1987). In the following stage of succession larger species, often apically attached or stalked, become more apparent in the benthic community (Steinman and McIntire, 1986). Depending on the local growth conditions (stream velocity and light conditions), a stratified community is formed and loosely attached diatoms are predominant (intermediate current, high light conditions). Under high current and low light conditions a largely unstratified community, dominated by adnate species, is formed (Hudon and Bourget, 1983).

Benthic diatoms occur in four major and distinct habitats: (1) aquatic plant surfaces supporting the *epiphyton*; (2) stone surfaces supporting the *epilithon*; (3) sand surfaces supporting the *epipsammon* and (4) the *epipelon*, mobile taxa growing among deposited inorganic and organic sediment particles (Round, 1991). Throughout this document terms will be used which perhaps need some explaining. The term 'periphyton' is used for all microscopic algae, bacteria and fungi on or associated with substrata. 'Benthic algae' refers to all periphytic algae including the macro algae. 'Benthic diatoms' include all epiphytic, epilithic, epipsammic and epipelic diatom taxa. The term 'assemblage' is used for the benthic diatoms that form part of the benthic algal community.

Niche of diatoms in river systems

Benthic algae play a pivotal role in nutrient cycling processes in streams (also referred to as nutrient spiralling [e.g. Mulholland, 1985]). Sources of nutrients that are utilised are substratum and stream water nutrients. Nutrient transformation and remineralisation are other important functions of stream benthic algae (Mulholland, 1996). The total supply of nutrients can be increased via fixation of atmospheric forms, e.g. endosymbionts in the diatoms *Rhopalodia gibba* and *Epithemia turgida* have been shown to fix atmospheric nitrogen (DeYoe *et al.*, 1992).

Community structure and function

Biomass, taxonomic composition or chemical composition can be used to assess community structure. Measurements of functional characteristics include productivity, respiration, nutrient uptake rates and enzyme activity. Biomass can be measured in many ways (e.g. ash free dry mass, chlorophyll *a* or cell density). Whichever method is most suitable depends on the hypotheses that are being tested and the number of samples that can be taken. As will be discussed in "the criteria for biological indicators", the taxonomic composition of the diatom assemblages is the preferred approach in biological monitoring. The taxonomic composition is most often assessed by the relative abundance of taxa in a sample. Diversity characteristics can be determined from these data, which in turn can be used as a comparative value for community change. Modern multivariate techniques are objective means of classifying species according to their tolerance to major environmental gradients (e.g. Agbeti, 1992).

The distribution of benthic algae in a stream is the result of a complex series of interactions between hydrological, water quality and biotic factors. The hydrological and water quality factors are a reflection of higher scale features of river catchments such as slope, land use and vegetation. In turn, these features are a result of geology, climate and human activities. Biotic factors, such as grazing by macroinvertebrates and fish, have an effect on the loss of biomass. Moreover, specific life forms are often targeted (e.g. stalked diatoms are a preferred food source for some macroinvertebrates above prostrate living taxa) and grazing can therefore affect the taxonomic composition of benthic communities (Steinman, 1996). Another biotic factor is the competition for resource supplies. When a periphyton mat develops to such an extent that prostrate taxa are overgrown by stalked or apically attached life forms, light and nutrients will become limiting for the under story algae (McCormick, 1996).

Temporal and spatial patterns

Short-term (days) differences in community composition are driven by immigration of cells, differences in growth rate between populations and loss processes such as death, emigration, sloughing and grazing. Long-term temporal patterns are (1) constant, (2) determined by cycles of accrual and sloughing or (3) seasonal. Microscale spatial differences exist between biomass and taxonomic composition on the various distinct habitats in streams (e.g. stones and sediment). Mesoscale differences are apparent between pool (lack of shear stress), run (enhanced nutrient mass transfer) and riffle habitats (most notably resulting in a gradient of substratum types). The river continuum concept (RCC, by Vannote *et al.*, 1980) suggests an increase in benthic algal biomass towards the middle reaches of a stream as shading by riparian vegetation decreases and streams widen. In the lower reaches, benthic algal biomass decreases again because of increased turbidity in the water column. Broad scale spatial differences result in inter catchment patterns. Differences in community composition among regions during periods of low flow may reflect regional differences in geology and land use and associated enrichment (Biggs, 1990, Biggs *et al.*, 1990). Poulin and Williams (1998) estimate that there are 10 million diatom species worldwide of which about 11 000 have been identified to date. Lange-Bertalot (1998) suggests that part of this species pool is cosmopolitan. These species become abundant where water systems are impacted by anthropogenic influences. Under ultra oligotrophic conditions in New Caledonia, a large proportion of the species pool is endemic to that island. Diatom autecology has been studied in various parts of the world and indices for the assessment of water quality have been developed (e.g. Prygiel and Coste, 1993; Kelly and Whitton, 1995). However, the need remains for the calibration of autecological data in specific regions (Van Dam *et al.*, 1994).

Factors affecting stream benthic diatoms

Light and temperature

Light is a fundamental requirement for benthic algae to photosynthesise inorganic compounds into living biomass. The benthic light environment is influenced by shading from riparian vegetation, attenuation by the water column and the periphyton matrix (prostrate diatom species are shaded by apically attached and stalked species) (McCormick, 1996). Temperature determines the rate at which biological and chemical processes occur. The ambient temperature of benthic algae is influenced directly by solar radiation or, more importantly, the temperature of the surrounding water. Individual diatom taxa have been reported to show preference for specific temperature ranges (DeNicola, 1996).

Nutrients

There are fundamental differences between nutrient uptake mechanisms for phytoplankton and benthic algae. Benthic algae are fixed in position and subject to flow velocities that are 10 to 100 000 times greater then the sinking rate of planktonic growth forms. Water motion alters the physico-chemical conditions near algal cells and therefore affects the movement of dissolved nutrients and gases. This indicates that benthic algae do not necessarily grow in a stable laminar layer where nutrient movement is solely by diffusion. Benthic algae, unlike phytoplankton, create mats on the substratum that are many cells thick. The nutrient dynamics within these mats creates the potential for these algae to be separated from the bulkwater nutrient source (not so much in streams, as currents disrupt the boundary layer to maintain a resource gradient across the interface of the periphyton matrix) (Borchardt, 1996).

The relationship between nutrients and benthic algal community structure is not well understood. Borchard (1996) gives an overview of various autecological studies on the response of some benthic algal taxa and concludes that there are conflicting responses of the same species to similar nutrient conditions. This suggests that factors other than nutrients are more important in determining species composition. However, various researchers have been able to successfully infer trophic conditions from the composition of benthic diatom assemblages (e.g. Van Dam *et al.*, 1994; Kelly and Whitton, 1995). Bennion (1994) showed a successful diatom-phosphorus transfer function for shallow, eutrophic ponds. This indicates that trophic conditions do have an influence on species composition, but that it is hard to distinguish specific nutrients causing the effect. Nutrient kinetic studies and multivariate statistics are promising approaches to study the effect of nutrients on benthic algal species composition (Borchard, 1996).

Substrata interaction

One of the physical influences of substrata on the development of benthic algal communities is the use of microtopography to provide shelter against shear stress. In the epipelon, a diurnal rhythm in the vertical migration through the upper layers of the sediment has been discovered. Diatoms migrate vertically down several centimetres through surface sediments at night and then return to the sediment surface to photosynthesise during daylight. It is generally believed that migration down into the sediments enables algae to have access to higher concentrations of nutrients that are more soluble in hypoxic or anaerobic conditions and, hence, more readily available (Round 1981). Epipelic algae regulate the release of nutrients from the sediment to the water column (Burkholder, 1996).

There are three hypotheses about how epiphytes can be influenced by their host. The first school of thought is that the substratum is inert and epiphytes use macrophytes merely as an advantageous location since they are elevated in the water column with greater access to light (Cattaneo and Kalff, 1979). Secondly, researchers have suggested that epiphytes have access to a second source of nutrients, via the host plant, as well as the water column (e.g. Burkholder and Wetzel, 1990). Thirdly, there are signs that epiphytes and their host plant compete for nutrient sources and that allelopathic substances are released to inhibit epiphyte growth (Burkholder, 1996).

Physical disturbance

Disturbance is a key factor, determining pattern and process in freshwater benthic algal communities, but the nature of the influence is complex and discrete categories of effects are hard to distinguish. Three types of disturbance have been identified by Peterson (1996) to which benthic algae in fresh waters are commonly exposed: scour, emersion and light deprivation. Scouring of benthic algae is a result of increased flow velocities. The resistance to scour of a community is a function of the developmental stage of the algal matrix (Peterson and Stevenson, 1992). Desiccation, as result of a drop in the water level, has a serious effect on the succession of benthic algal communities. Some diatom taxa have, however, been reported to be able to resist long-term desiccation and could serve as a source to re-establish benthic algal communities after prolonged periods of drought (Peterson, 1996). Light deprivation can be the result of overgrowth of prostrate cells by stalked or apically attached cells during algal mat development. A more catastrophic event is the burial of attached algae as a result of the redeposition of scoured sediments after substratum mobilising spates (Peterson, 1996).

Use of benthic diatoms for water quality assessment

To evaluate the usefulness of a taxonomic group for the assessment of the ecosystem status, certain criteria should be taken into account. Cairns *et al.* (1993) proposed a list of attributes for biological indicators. These attributes are evaluated for algae in general by McCormick and Cairns (1994). This list of attributes will be discussed specifically for stream benthic diatoms. According to Cairns *et al.* (1993) a biological indicator should be:

1. Biologically relevant, i.e. important in ecosystem functioning;
2. Socially relevant i.e. of obvious value to those involved in decision making processes;
3. Broadly applicable to many stressors and sites;
4. Sensitive to stressors, preferably without an all or nothing response or excessive natural variability;
5. Measurable, in that the indicator can be identified and quantified using an accepted procedure, with known accuracy;
6. Interpretable i.e. capable of distinguishing impacted from natural conditions;
7. Capable of continuity of measurement through time and space;
8. Applicable on an appropriate spatial and temporal scale;
9. Not redundant i.e. it should supply additional information to that given by other measures used in a monitoring programme;
10. Integrative in time, summarising information from other possible indicators that cannot be feasibly measured;
11. Anticipatory i.e. providing an early warning system;
12. Timely in that information is provided rapidly, before unacceptable damage occurs;
13. Diagnostic of the particular stressor causing the problem;
14. Cost effective;
15. One for which historical information exists to detect long term trends in ecosystem condition;
16. Non-destructive to the ecosystem.

No single biological indicator will possess all these criteria, which stresses the need for the use of various components of the ecosystem to assess its status. The part that stream benthic diatoms can play in a biological monitoring programme is discussed below.

Biologically and socially relevant

Diatoms are important in river and stream ecosystems as they play a fundamental role in food webs (Lamberti, 1996) and biogeochemical cycles (Mulholland, 1996). The social relevance of diatoms is illustrated by the fact that certain taxa can be the source of nuisance algal problems, such as taste and odour impairment of drinking water, clogging water filters and toxic blooms (Palmer (1962) in Stevenson and Pan, 1999).

Broadly applicable

Diatoms occur from the head to the mouth in a variety of habitats (Round, 1991). They have a cosmopolitan distribution and are indicative for a wide range of environmental conditions, such as acidification effects (e.g. Charles 1985), salinity (e.g. Fritz 1991) and organic enrichment (Agbeti, 1992).

Sensitive to stressors

Some diatoms are sensitive to certain stressors where others are tolerant (e.g. Krammer and Lange-Bertalot, 1986). Therefore, the best approach is to analyse complete assemblages to even out erratic behaviour of a few populations (Stevenson and Pan, 1999).

Measurable

Changes in species composition of diatom assemblages tend to be the most sensitive response to environmental change (Van Dam, 1982). Other structural (e.g. biomass) and functional (e.g. metabolic rate) characteristics are also likely to change because of environmental stress. However, benthic communities are able to adapt rapidly by changing species composition, restoring previous biomass and metabolic rates. The structural analysis of the taxonomic composition of diatom assemblages is therefore the most promising approach for river water quality monitoring (Stevenson and Pan, 1999). Diatom species are relatively easy to distinguish compared to other algae, due to their unique morphological features. Other algae may need to be cultured for identification or need to show reproductive structures (Stevenson and Pan, 1999). Diatom taxa are well documented and diatom taxonomy is studied the world over with an active international research society specifically focused on this phylum of algae.

Interpretable

A biological indicator is suitable when a reference exists against which to gauge the condition of interest. With knowledge about the location of potential sources of impact, it will be possible to select suitable reference and test sites. A survey of benthic diatoms should be established in such a way that the data collected can be translated into information useful for management purposes. Spatial and temporal variation in community structure can mask the impact that has been studied. From the perspective of a monitoring biologist, there are two types of factors affecting ecological processes. These are noise and control variables. The noise variables are hard to control in most field conditions. Control variables are those that are controllable by the sampler (e.g. sampling technique, habitat selected for sampling). The reduction of variance in the sampling procedure increases the sensitivity of a potential diatom index. Depending on the objective of a study, variables can be considered 'noise' or 'control'. If for instance, the epilithic diatom flora gets smothered with *Cladophora* because of an increased nutrient input and the objectives are solely to distil the effects of nutrient status on the diatom assemblages, the impact on the epilithic diatoms is regarded as a noise factor. On the other hand, the overall effect on the epilithic diatom assemblages is an indication of the change in river health (Kelly *et al.*, 1998).

Continuity through time and space

Although it is likely that seasonal changes occur in diatom assemblages (Biggs, 1996), they are present throughout the year. Once the seasonal variation is known, diatoms can become reliable indicator organisms (McCormick, 1994).

Appropriate temporal and spatial scale

Benthic diatoms are attached and they will therefore integrate the water quality of the particular site. Because of the short generation time of diatoms, individual populations respond rapidly to environmental change. It takes about two to three weeks before this is reflected to a measurable extent in the assemblage composition (Round, 1991; Kelly *et al.*, 1998).

Anticipatory

Benthic diatoms are suitable early warning organisms due to their short generation time. Information supplied by a biological indicator should have a high signal to noise ratio, which reduces false signals. Metabolic changes have been recorded in algae, which are likely to have an effect on the community composition. There are limitations however: the trophic position of algae limits their ability to predict the impact of chemicals that biomagnify (i.e. accumulate in the organs of organisms high-up in the food chain). This is again an argument for the use of a suite of bio-indicators to properly assess the status of an ecosystem (McCormick, 1994).

Timely

Diatoms can be collected in a much shorter time than fish and macroinvertebrates. Seining and electro-shocking to collect fish are time consuming and may not provide a representative sample of the fish community. Protocols for macroinvertebrate sampling are sensitive to habitat differences. In addition to the SASS4, a habitat integrity score is taken into account, but it is often difficult to interpret this in the assessment of the status of the river. Laboratory processing time for diatom samples are comparable to that for macroinvertebrates but longer than for fish (McCormick, 1994).

Redundancy

Diatoms respond rapidly to varying nutrient conditions and provide sensitive and reliable indications of trophic conditions. Herbicides also target the diatom assemblages because of their phytotoxic properties (Kosinsky, 1984 in McCormick, 1994). Because they tend to be sensitive to different types of environmental changes, algae and aquatic animals provide complementary information regarding ecosystem condition.

Integrative

Changes in the algal community integrate shifts in biomass and feeding efficiency of higher trophic levels and the effects of fluctuating nutrient conditions. Their integral role in ecosystem energetics and biogeochemical cycling enables algae to provide a relatively unique composite picture of ecosystem conditions (McCormick, 1994).

Diagnostic

Ideally, diagnostic information should be derived from experiments under environmentally realistic conditions (Cox, 1993). However, the translation of this knowledge into the field is difficult. Modern multivariate techniques prove to be objective means for classifying species according to their tolerance to major environmental gradients (e.g. Agbeti, 1992).

Cost-effective

The cost of the collection and analysis of diatom samples is comparable to that of macroinvertebrates. The information contained in diatom samples is high due to the large number of species encountered, compared to that for e.g. ichthyofauna (McCormick, 1994).

Historical database (to detect trends)

Diatoms accumulated in sediments are excellent indicators of historic environmental conditions in lentic systems (e.g. Fritz *et al.*, 1999) but it is hard to use the same approach in lotic systems where sediments are repeatedly disrupted and resuspended, e.g. by flooding. Diatoms are, however, ideal organisms for permanent mounts that can be kept indefinitely in organised collections as a source of reference material.

Non destructive

Sampling of diatoms does not result in perceptible environmental impact. Sampling of higher organisms may however impact adversely on indigenous populations, particularly if those are rare or threatened species.

International use of diatoms to monitor water quality

The assessment of water quality conditions in freshwater habitats with benthic diatoms has a long history. Diatoms are used as bioindicators in Europe (Kelly *et al.*, 1998; Prygiel *et al.*, 1999a), North America (Stevenson & Pan, 1999; Lowe & Pan, 1996), South America (Lobo *et al.*, 1998; Loez and Topalian, 1999), Australia (John, 1998; Chessman *et al.*, 1999) Asia (Lobo, 1995; Juttner *et al.*, 1996, Rothfritz *et al.*, 1997) and

Africa (e.g. Schoeman, 1979; Pieterse and van Zyl, 1988; Gasse *et al.*, 1995). Some of these approaches are focussed on inferring past hydrochemical characteristics in lakes (e.g. Fritz *et al.*, 1991; Gasse *et al.*, 1995), while others are designed to monitor present day conditions in rivers and streams (e.g. Prygiel and Coste, 1999).

In Europe some 20 different methods using benthic diatoms to assess river water quality have been developed. The methods differ in their objectives from the assessment of general water quality to specific water quality components. A task group is presently developing normalisation evaluation methods concerning the biological quality of watercourses (Prygiel *et al.*, 1999b). The methods used throughout Europe fall into four categories: Saprobic level evaluation methods, methods for evaluation of general water quality, evaluation of trophic levels and the assessment of ecological spectra. The saprobic level evaluation method is based on the classification of diatom taxa according to the resistance, sensitivity or indifference to pollution (e.g. Lange-Bertalot, 1979). In Austria, this method has been the basis of a diatom index that is the only index routinely applied on a national scale in Europe (Prygiel *et al.*, 1999b). General water quality evaluation methods target water quality components such as BOD, COD, phosphorus and nitrogen. The most applied method in this category was originally developed by Coste and Leynaud (1974) and later upgraded by Descy and Coste (1991). The system works on the basis of a grid comprising four groups of species characteristic for clean water (G1) to polluted waters (G4). Seven sub-groups of species have a wider tolerance, but are broadly representative of clean acidic or alkaline waters (SG1) to the (SG4) group, which occurs in slightly saline waters (Figure1) The combination of group and subgroup scores results in a value between 1 (high pollution) and 10 (pristine). A commercial computer software package (Omnidia) is available to process results (Lecointe *et al.*, 1993).

Sub-Groups	Group 1: *Achnanthes exilis*; *Achnanthes minutissima* et var.; *Denticula tenuis* var. *crassula*; *Diatoma hiemale* var. *mesodon*; *Meridion circulare* et var.	Group 2: *Cocconeis pediculus*; *Cymbella ventricosa*; *Diatoma vulgare*; *Nitzschia dissipata*; *Fragilaria construens* et var.	Group 3: *Fragilaria intermedia* (et *vaucheriae*); *Fragilaria pinnata*; *Nitzschia acicularis*; *Nitzschia linearis*; *Rhoicosphenia curvata*	Group 4: *Navicula seminulum*; *Nitzschia amphibia*; *Nitzschia frustulum* et var.; *Nitzschia kuetzingiana*; *Nitzschia palea*
Achnanthes affinis *Achnanthes linearis* et var. *Cymbella microcephala* *Cymbella sinuata* *Navicula tridentula fo parallela*	10	9	8	7
Amphipleura pellucida *Cymbella affinis* *Gomphonema constrictum* var. *capitata* *Gomphonema intricatum* et var. *pumila* *Fragilaria capucina* et var.	9	8	7	6
Cymbella lanceolata *Cymbella prostrata* *Cyrosigma attenuatum* *Cyrosigma spencerii* var. *nodifera* *Navicula gracilis*	8	7	6	5
Cymbella cistula *Gomphonema olivaceum* et var. *Navicula cryptocephala* var. *interm.* *Navicula pupula* et var. *Surirella ovata*	7	6	5	4
Cymbella tumida *Navicula gregaria* *Navicula viridula* et var. *Nitzschia filiformis* *Synedra pulchella*	6	5	4	3
Diatoma elongatum et var. *Gomphonema abbreviatum* *Gomphonema parvulum* et var. *Navicula accomoda* *Navicula gothlandica*	5	4	3	2
Navicula mutica et var. *Navicula neoventricosa* *Navicula vaucheriae* *Nitzschia clausii* *Synedra affinis*	4	3	2	1

Figure 1. Twofold entry grid from Coste and Leynaud (1974).

One of the methods developed for the evaluation of trophic levels in watercourses, is the Trophic Diatom Index (TDI) by Kelly and Whitton (1995) based on investigations in England and Scotland. The selection criteria of the 86 epilithic taxa (species and/or genus level) used in this index, were easy identification and high indicator value. Each taxon is given a sensitivity value (1-5) and an indicator value (1-3). The resulting TDI value ranges from 1 (very low nutrient concentrations) to 5 (very high nutrient concentrations). Classifications based on ecological spectra of individual species (autecology) are developed by various researchers for specific water quality components (e.g. ter Braak and Van Dam, 1989; Van Dam *et al.*, 1994). The largest number of applications of autecological spectra concerns paleolimnological studies in lakes. These methods are based on the development of transfer functions between the composition of diatom assemblages and specific water quality variables. This methodology can also be applied successfully in lotic environments, as shown by Pan *et al.* (1996) and also this study. With this approach optimum values and tolerance ranges are given for individual taxa, from which specific water quality conditions can be inferred.

Artificial substrata

Artificial substrata can be useful when the objectives call for precise assessments in streams with highly variable habitat conditions (specific habitat does not occur consistently throughout the river). Benthic algal communities on artificial substrata do not always reflect those on natural substrata. However, when the objectives are to detect changes in water quality, rather than to assess the effects on natural communities of periphyton, the consistent use of one type of substrate becomes beneficial (Stevenson and Pan, 1999). The two largest drawbacks of the use of artificial substrata are that sampling sites have to be visited twice (once to place the substrata and once to collect) and that artificial substrata are often subject to deliberate removal. The types of substrata used, range from unglazed tiles to glass slides. More recently, lengths of polypropylene rope (frayed at the ends) have been suggested as artificial substrata, simulating submerged macrophytes (see Kelly *et al.*, 1998).

Analysis of assemblages

Ordination, clustering and community similarity indices are three approaches to assess variation in species composition among communities. In ordination, sites are arranged along axes according to species composition. Sites with similar species composition are plotted closely together in the ordination diagram (a low dimensional representation of the species data). The axes are theoretical variables that can best explain the species distribution. In canonical correspondence analysis (CCA) the axes are constrained to be linear combinations of environmental variables. CCA is a powerful technique for detecting patterns of species distribution related to associated physico-chemical parameters (ter Braak and Verdonschot, 1995). For this reason it is widely used in different areas ranging from community ecology to management (Birks *et al.*, 1994).

GENERAL METHODS

The data from which the statistical section of this report is taken were submitted as a thesis by J S van der Molen. The abbreviated diatom names are used throughout this report. Appendix B of this report contains the abbreviated diatom names and corresponding species names of the diatoms referred to in this report. The abbreviated names were deemed easier for ecologists who are not specifically trained in diatom taxonomy.

Since the objectives of this report were to relate diatom species to water quality, the data set were analysed to provide a direct relationship between the two; presumably, this relationship is cause and effect. The main data sets were those from the Eastern Cape, the Western Cape, the Olifants River system, Mpumalanga and a seasonal data set from the Swartkops River, Port Elizabeth. These were analysed separately with the epilithic diatoms separated from the epipelic diatoms in the first instance. Only simple statistics available on MS Excel are presented, namely n, mean, SD and CV% (calculated as the SD/Mean x 100), maximum and minimum to indicate the range of values applicable to each taxon.

The relevant data were separated by "cutting" non-relevant data from a single main table (Appendix A). Hence, in the case of the Swartkops River, all non-Swartkops River data were "cut" out. Then, in the case of the epipelic data, the epilithic data were "cut" out. When the dominant data were being analysed, all the non-dominant columns were "cut" out. In all cases the diatom data and water quality data were kept together. No data were "cut" and "pasted" from one area of a table to another. This was done to reduce the potential for error. Tables generated in Excel were subsequently imported directly into MSWord.

Throughout the project, methods of diatom collection and analyses were kept as consistent as possible. This section gives an outline of the methods used during the projects discussed later.

Site selection

The purpose of this project was to investigate the relationship between the occurrence of diatoms and specific water quality variables in a range of rivers in the Western and Eastern Cape and the upper part of the catchment of the Olifants River (Mpumalanga). Sites were selected from those regularly sampled by the Department of Water Affairs and Forestry (DWAF). For most of these sites a record of water quality already exists. The intention was to sample a minimum of five sites in each river, ranging from the upper reaches of the catchment to just above the tidal head of the estuary. This was, however, not always possible since some of the sites regularly sampled by the DWAF did not meet these criteria. In such cases, sites from neighbouring catchments were combined to meet the requirements for the multivariate analyses of the data collected (see subsequent paragraphs).

Diatom collection and processing

The epipelon was sampled as described by Round (1981). Samples were taken in triplicate. A length of glass tube was drawn across the sediment and allowed to fill with a mixture of surface sediment and water. This mixture was stored in a plastic sample container (50 ml). In the laboratory, the sample was placed in a petri dish. The sediment was allowed to settle over night. The following morning the supernatant was drawn off and 4 cover slips (covering ca. 30% of the sediment surface) were placed on top of the wet sediment. On the afternoon of the same day the cover slips were carefully removed. In this way only living cells that had attached to the cover slips were sampled. Four cover slips from each sample were placed in 50 ml beakers, to which 2 ml of $KMnO_4$ (saturated) and 2 ml of HCl (10 M) was added. This mixture was heated on a hot plate until the solution went clear.

Epilithic diatom samples were collected in triplicate following the method described by Round (1993). Each stone was vigorously shaken in the water to remove loosely attached diatom cells. An area of 50 cm^2 was subsequently rubbed with a finger and the loosened mucilage washed into a sample bottle with demineralised water. In the laboratory a sub-sample was investigated using light microscopy to check for dead diatom cells. If the sub-sample contained a considerable number of dead cells, the sample was discarded from further analysis. The acceptable samples were transferred to centrifuge tubes (15 ml) and the sample containers rinsed with 0.1 M HCl to remove any cells attached to the walls of the sample container. This was added to the centrifuge tubes. The samples were centrifuged (2000 rpm, 10 min) and the supernatant poured off. $KMnO_4$ (2 ml saturated) and HCl (2 ml, 10 M) were added and the tubes heated until the solutions went clear.

All acid cleaned samples were washed with distilled water using 5 consecutive spins (2000 rpm, 10 minutes). Stubs, to be viewed under a Scanning Electron Microscope (SEM), were made by placing a drop of the diatom 'digest' on to filter paper (HTTP millipore, 0.4 mm). The filter paper was dried and fixed to a SEM stub using double-sided tape. The stub was subsequently sputter coated with gold in an Edwards Sputter Coater S150B (2 minutes, 20 mA). Permanent light microscopy slides were made with a few drops of diatom 'digest', placed onto a cover slip and allowed to dry in air. When completely dry a small amount of Naphrax® mounting medium (Northern Biological Supplies, U.K.) was dotted onto a glass microscopy slide and the cover slip placed over it. Air trapped under the slide and the Naphrax was dispersed by heating the slide on a hot plate (approx. 60° C). The Naphrax was allowed to dry. Each slide was eventually sealed around the edge of the coverslip with Bioseal[R] to prevent ageing of the Naphrax. The slides were logged and stored in a slide library, to form a permanent record.

Diatom identification and enumeration

Diatom frustules were examined under a Zeiss Axioplan light microscope with Differential Interference Contrast (DIC) optics. Using a television camera (JVC KY-F3), images of the dominant species were visualised using the AnalySIS image analysis programme (©1999, Soft Imaging System GmbH). If these images did not provide enough detail for species identification a sample was prepared for viewing in a Scanning Electron Microscope (SEM, Philips XL 30). The light and SE microscope images were catalogued according to river and genus. Information regarding habitat, site of origin, taxonomic name, authority and source of reference was saved with each image.

A minimum of 200 valves was counted in each sample using 1000x magnification. The nomenclature of Krammer & Lange-Bertalot (1986-91) was used with a few exceptions associated with some taxonomic revisions suggested by Round *et al.* (1990). Other taxonomic works consulted included Archibald (1983), Hustedt (1930), Lange-Bertalot & Krammer (1989), Simonsen (1987) and various articles by R.E.M. Archibald, B.J. Cholnoky and F.R. Schoeman (e.g. Cholnoky, 1960; Schoeman and Archibald, 1976).

Water quality analyses

The water samples (250 ml) were preserved with $HgCl_2$ (8 mg/l) and analysed at the laboratories of the Institute for Water Quality Studies, Department of Water Affairs and Forestry, Pretoria, South Africa (National Laboratory Accreditation Service, Accredited Laboratory No. T0073). The samples were analysed for NH_4, NO_2+NO_3, F, alkalinity as $CaCO_3$, Na, Mg, Si, PO_4, SO_4, Cl, K, Ca and total dissolved solids (TDS). In situ dissolved oxygen (WTW, Oxi 330), electrical conductivity (YSI model 30 conductivity meter), pH (UniFet 100 pH meter) and temperature (read from the conductivity meter) were measured.

Data analyses

For each sample the relative abundance of species, effective number of occurrences (Hill's N_2, ter Braak and Šmilauer, 1998), Shannon diversity (H', $\log_{10}$-based) and evenness (J') (Zar, 1996) were determined. Initially the relative abundance of individual diatom species that constituted over 1% of an assemblage on at least one occasion was used in further analyses.

Prior to the statistical analyses, the distribution of the water quality data was analysed for normality (Statistica v.5.1, 1998). Where the data showed a skewed distribution the data were $\log_e$-transformed. Where zero values occurred $\log_e(x+1)$ was used (Jager and Looman, 1995).

Detrended Correspondence analysis (DCA, in CANOCO for Windows, version 4.0, 1997) was used to determine the major patterns of diatom species distribution. This analysis was used to detect patterns in species distribution resulting from spatial or temporal forces, or habitat specificity.

N_2, H' and J' were compared between seasons in a three-way multivariate analysis of variance (MANOVA, habitat nested in site, site nested in season). N_2, H' and J' were also compared between sampling sessions for each habitat (epilithon and epipelon) with a Tukey test for unequal sample sizes. The assumptions of ANOVA were checked in each case using protocols recommended by Fry (1993). Analyses were performed in Statistica (v.5.1, 1998).

The measured water quality variables were ranked on the basis of the goodness of fit for each separate variable on the species distribution. The method used was Forward Selection as supplied in the multivariate statistical package CANOCO for Windows (version 4.0, 1997). The significance of each variable was tested with a Monte Carlo test (999 permutations). This method uses the 'eigenvalue' as a measure of niche separation. In the first step of Forward Selection, an eigenvalue is calculated for each and every water quality variable as the only environmental variable influencing the species distribution (marginal effect). The statistical significance of the effect of every variable is tested by a Monte Carlo permutation test (ter Braak and Verdonschot, 1995). At the end of the first step of the Forward Selection, the best variable is selected. One by one the subsequent variables are added to the analysis. After each addition, the conditional effect of that variable is again tested for significance with a Monte Carlo permutation test. These steps proceed until the addition of an environmental variable does not result in a significant increase of the goodness of fit (eigenvalue). The number of water quality variables (Q) that can be selected is limited to the number of sites sampled (S) minus 2 (Q = S-2).

The water quality variables selected by forward selection were used in the Canonical Correspondence Analysis (CCA). This ordination technique was used to identify patterns in species distribution that corresponded with patterns in the distribution of the measured water quality variables. The results of each CCA was plotted as a two dimensional graph where the species names were placed according to their similarity in distribution to other species and their correlation to the water quality variables used in the analyses. The water quality variables were plotted as arrows originating from the centre of the graph. The origin represents the mean value of each separate variable and the direction of the arrow line represents an increase in the value of the particular variable. This means that the opposite direction of each solid line represents lower values than the average of the variable.

The ordination diagrams were plotted with CANODRAW (v. 3.1, 1997). Only those species with a cumulative fit (first and second axes) >20% and a weighted average of >5% were plotted (Šmilauer, 1992).

Diatom-based calibration methods

Weighted-averaging regression and calibration models for inferring selected water quality variables were developed using CALIBRATE (v. 0.82, 1997). The optimum concentrations and tolerances of individual species were calculated with weighted averaging. A species' optimum for a water quality variable is the average of all the values for the samples in which the species occurred, weighted by its relative abundance (ter Braak and van Dam, 1989). The species optima can be used to infer water quality conditions from diatom distribution data by calculating the weighted average of the optima of all the species present. In this way the environmental conditions can be reconstructed, based on the composition of either epilithic or epipelic diatom assemblages.

The prediction errors of the models were simulated by cross-validation. This method ('Jack-knifing' or 'leave-one-out') predicts the diatom-inferred value for a water quality variable at a site. This is done by using the species optima estimated from all sites, except the inferred site. Each site is thereby given a predicted water quality value that can be compared with the observed water quality value. The strength of the relationship between the predicted and observed values is expressed as a coefficient of determination (r^2). The prediction errors are accumulated to a 'Jack-knifed' root mean square of the errors of prediction (RMSE). A model is performing well when a high r^2 is observed in combination with a low RMSE (ter Braak and Juggins, 1993).

RESULTS

Epilithic and epipelic diatoms were sampled from 16 rivers during the course of this study. The details regarding the rivers, number of sites, number of epilithic and epipelic samples taken, together with the number of diatom taxa reported from each site is given in Table 1.

Table 1. Epilithic and epipelic samples taken from rivers in the Eastern and Western Cape and Mpumalanga, showing the number of sites and number of taxa identified from each site.

River	River sites		Taxa reported	
	Epilithon	Epipelon	Epilithon	Epipelon
Buffalo	5	0	11	0
Nahoon	4	0	11	0
Gamtoos	8	9	11	20
Sundays	4	3	12	16
Swartkops	25	26	10	21
Eerste	6	2	12	7
Palmiet	3	4	9	12
Bot	1	1	6	14
Houhoek	0	1	0	7
Bedeke	1	1	6	10
Brandwag	1	1	9	9
Moord	1	1	10	7
Grootbrak	2	0	7	0
Keurbooms	5	2	11	10
Seneke	0	1	0	7
Olifants	47	75	23	40
TOTAL	113	127	148	180

The total of 148 epilithic and 180 epipelic diatoms does not tell the correct story regarding the total number of taxa that are involved because many of the epipelic taxa are the same as those from the epilithon. There were only 102 species identified from all sites and these came from 31 genera. This indicates that one of the biggest problems foreseen against the use of diatoms as indicators of water quality, i.e. identification, is not a problem at all. With approximately two new genera from each river, it is possible to estimate that we will end up with about 70 genera and 200 species if another 25 rivers are sampled. This assumes a linear relationship between new sites and new taxa. In reality the number of overlaps is likely to increase with each new river. It should thus be easy to document all the required information to enable future workers to rapidly identify the taxa found. Only two genera may require a system to enable species identification. These are *Navicula* and *Nitzschia.* However, these two genera accounted for only 24 and 16 species respectively.

Buffalo and Nahoon Rivers: epilithon

From the rivers near East London, the Buffalo and Nahoon, samples were taken from eleven sites. The data set (Appendix A), however, reflects only nine sites. The sites BR2 and NR5 are excluded as they only had epipelic data available.

The taxon ACHNMINU was dominant at three of the nine sites, BR1, BR3 and NR1. Since all three of these sites are near the source of the river, the conclusion is that ACHNMINU is indicative of water that has not been heavily affected by urban and industrial influences. The water quality data for these sites in the Buffalo and Nahoon rivers are shown in Table 2. ACHNSUAT was found at two sites NR2 and NR3, while GONEPARV was found at BR6 and NR4. ACHNSUAT may also be indicative of fairly clean water while GONEPARV being far down stream would seem to indicate polluted water. Two other taxa were dominant at BR4 and BR5. These were NAVIGREG and NAVIPERM that were found between the Laing and Bridle Drift dams.

Table 2. Water quality indicated by ACHNMINU for three sites from two rivers (Buffalo and Nahoon) in the Eastern Cape. Water quality units were $mg.l^{-1}$ except for electrical conductivity (EC - $mS.m^{-1}$), alkalinity (expressed as $CaCO_3$ $mg.l^{-1}$) and pH.

Details	Sites			Statistical data				
ACHNMINU	BR1	BR3	NR1	Mean	SD	CV%	Max	Min
Dominance (%)	69.51	64.87	95.07					
Water Quality								
Ca++				27.67	21.22	76.70	45.00	4.00
Cl^-				110.33	88.26	80.00	176.00	10.00
EC				63.77	49.16	77.09	101.20	8.10
F^-				0.18	0.13	68.63	0.30	0.05
K^+				2.40	1.71	71.08	3.80	0.50
Mg^{++}				19.00	14.18	74.62	30.00	3.00
Na^+				84.00	67.67	80.56	134.00	7.00
NH_4^+				0.28	0.04	140.13	0.74	0.02
NO_2+NO_3^-				1.03	1.54	150.47	2.81	0.10
pH				8.19	0.34	4.12	8.42	7.80
$PO4^{---}$				0.17	0.27	156.73	0.49	0.01
SiO_2^-				6.80	0.82	12.04	7.50	5.90
SO_4^{--}				22.33	19.14	85.70	40.00	2.00
Alkalinity				142.67	114.38	80.17	248.00	21.00
TDS				445.33	347.10	77.94	716.00	54.00

Swartkops River: epipelon

The data for the Swartkops River showed that the diatom NAVIGREG was dominant at certain sites in the epipelon. The data for those sites are shown in Table 3. Note: these data are only for those sites where NAVIGREG was dominant. The data in Table 4 show the water quality where NAVIGREG was not the dominant, indeed where it was absent or present only at less than 10% of the total diatom population. Under these circumstances, one would expect the data in Table 4 to be rather different to those in Table 3. Table 5 presents the comparison between the maximum (Max) and minimum (Min) water quality variables for these two data sets.

These data indicate that when NAVIGREG is the dominant diatom, the concentrations of Cl^-, EC, Mg^{++}, Na^+, NH_4^-, NO_2+NO_3^-, PO_4^{---}, SiO2 and SO_4^{--} will be low, i.e. it is an indicator of better quality water than when it is present in only small numbers. It seems to be less sensitive to Ca++, F^+, K^+, pH, alkalinity and TDS although more data are required to verify the latter two.

Table 3. Water quality for NAVIGREG where it occurred in the epipelon of the Swartkops River as the dominant diatom (> 10% of the total counts) for 21 sites.

Water quality	Mean	SD	CV%	Max	Min
Ca++ (mg.l^{-1})	16.95	13.75	81.11	62.00	3.00
Cl^- (mg.l^{-1})	218.43	170.93	78.26	698.00	40.00
EC (mS.m-1)	93.83	73.06	77.86	299.00	17.60
F^- (mg.l^{-1})	0.13	0.08	65.73	0.30	0.00
K^+ (mg.l^{-1})	19.15	42.24	220.57	190.40	0.70
Mg^{++} (mg.l^{-1})	21.19	15.44	72.87	63.00	4.00
Na^+ (mg.l^{-1})	135.38	110.86	81.89	471.00	25.00
NH_4^+ (mg.l^{-1})	0.06	0.16	257.73	0.70	0.00
NO_2^-+NO_3^-	0.13	0.20	159.61	0.85	0.00
pH	7.45	0.60	8.01	8.99	6.89
PO_4^{---} (mg.l^{-1})	0.03	0.02	74.30	0.08	0.01
SiO_2 (mg.l^{-1})	2.07	0.80	38.56	3.20	0.00
SO_4^{--} (mg.l^{-1})	47.33	35.47	74.93	127.00	5.00
Alkalinity	91.19	116.05	127.26	530.00	21.00
TDS (mg.l^{-1})	570.57	512.15	89.76	2258.00	104.00

Table 4. Water quality for NAVIGREG where it occurred in the epipelon of the Swartkops River at less than 10% of the total counts (n = 48).

Water quality	Mean	SD	CV%	Max	Min
Ca^{++} ($mg.l^{-1}$)	42.19	25.59	60.67	90.00	2.00
Cl^{-} ($mg.l^{-1}$)	675.08	425.33	63.00	1577.00	40.00
EC (mS.m-1)	271.21	175.18	64.59	903.00	17.30
F^{-} ($mg.l^{-1}$)	0.22	0.11	48.69	0.40	0.00
K^{+} ($mg.l^{-1}$)	30.40	47.62	156.62	242.60	0.60
Mg++ ($mg.l^{-1}$)	56.06	34.48	61.50	129.00	3.00
Na^{+} ($mg.l^{-1}$)	411.79	256.75	62.35	899.00	24.00
NH_4^{+} ($mg.l^{-1}$)	0.21	0.62	302.18	3.81	0.00
$NO_2^{-}+NO_3^{-}$ ($mg.l^{-1}$)	0.81	1.33	164.49	6.22	0.00
PH	7.65	0.55	7.18	9.00	6.81
PO4--- ($mg.l^{-1}$)	1.21	1.74	143.19	6.97	0.01
SiO_2 ($mg.l^{-1}$)	2.65	1.48	55.91	8.90	0.50
SO4-- ($mg.l^{-1}$)	140.67	103.97	73.91	514.00	5.00
Alkalinity	181.04	152.96	84.49	851.00	7.00
TDS ($mg.l^{-1}$)	1584.60	979.89	61.84	3380.00	95.00

River: Swartkops

habitat: epipelon

Slide	1081	1084	1089	1092	1095	1102	1105	1110	1113	1116	1118	1154	1157	1161	1164	1167	1170	1185	1188	1192	1195	1198	1201	1211	1214
Station	F09	E09	D09	C09	B09	F10	E10	D10	C10	B10	A10	F11	E11	D11	C11	B11	A11	F12	E12	D12	C12	B12	A12	F13	E13
Water quality																									
Ca^{2+} ($mg.l^{-1}$)	26	50	15	12	7	41	47	24	20	10	3	50	53	40	23	10	3	57	75	42	24	9	3	45	47
Cl^- ($mg.l^{-1}$)	392	809	211	154	99	676	745	319	248	140	40	861	985	680	259	124	40	922	1285	617	257	116	43	752	891
Conductivity ($mS.m^{-1}$)	183.5	336	98.1	76.8	47	247	277	136.7	108.8	57.7	17.6	311	367	252	124.3	51.6	17.5	355	485	249	130.3	50.4	18.2	289	341
F^- ($mg.l^{-1}$)	0.2	0.2	0.1	0.1	0	0.3	0.2	0.2	0.1	0.1	0	0.3	0.3	0.2	0.2	0.1	0	0.3	0.3	0.2	0.1	0.1	0	0.2	0.2
K^+ ($mg.l^{-1}$)	14.2	14	12.8	14.3	1.5	21.2	17.3	20	28.9	1.8	0.7	22.3	24.4	28.3	47	1.9	0.8	24.8	26.1	33.3	56.6	1.9	0.7	19.3	19.4
Mg^{2+} ($mg.l^{-1}$)	34	62	18	14	8	51	60	31	23	13	4	62	82	59	26	13	3	73	105	55	26	12	4	63	77
Na^+ ($mg.l^{-1}$)	261	495	122	95	61	396	434	198	152	85	25	519	610	393	169	73	25	555	759	362	167	67	25	443	520
NH_4^+ ($mg.l^{-1}$)	0	0	0	0	0	0	1.99	0.65	0	0	0	0	0.24	3.08	0	0.04	0	0.22	0.07	0.25	0	0	0	0.04	0
NO_2^-+NO_3^- ($mg.l^{-1}$)	0.43	2.34	0.33	0.09	0	1.01	5.21	0.21	0.1	0.17	0.08	2.86	0.93	0.53	0.07	0.1	0.06	2.05	1.8	0.85	0	0.07	0	1.06	1.14
pH	7.23	7.64	7.32	7.24	7.06	7.57	7.84	7.96	7.34	7.09	7.2	7.64	8.26	8.19	7.8	7.12	7.01	7.38	7.79	8.62	7.86	7.18	7.27	7.82	8.44
PO_4^{3-} ($mg.l^{-1}$)	1.095	0.696	0.034	0.017	0.007	1.326	3.952	0.035	0.013	0.012	0.012	2.457	0.138	0.15	0.009	0.007	0.039	3.216	0.154	0.049	0.013	0.038	0.006	1.412	0.085
SiO_2 ($mg.l^{-1}$)	3.3	3.6	3.1	3.3	3	1.8	3.5	3	3.2	3.2	3	1.8	1.1	1.3	2.4	2.4	2.7	2.5	1.5	1.9	1.9	2.1	2.5	1.1	0.9
SO_4^{2-} ($mg.l^{-1}$)	84	194	40	28	22	113	134	72	47	34	5	170	182	118	47	27	7	206	239	124	52	28	9	162	180
Alkalinity (as $CaCO_3$ in $mg.l^{-1}$)	117	154	79	77	32	171	165	120	135	42	21	182	235	189	180	43	18	198	270	198	197	40	14	153	167
TDS ($mg.l^{-1}$)	959	1825	517	411	237	1514	1677	812	684	335	104	1928	2229	1555	792	302	101	2098	2827	1480	824	284	102	1680	1943

River: Swartkops

habitat: epipelon

Slide	1218	1221	1224	1227	1238	1253	1245	1248	1251	1254	1265	1268	1272	1275	1278	1281	1295	1298	1302	1305	1308	1311	1323	1326
Station	D13	C13	B13	A13	F14	E14	D14	C14	B14	A14	F15	E15	D15	C15	B15	A15	F16	E16	D16	C16	B16	A16	F17	E17
ACHNENGE	13.22	0.76	0.63	0.81	4.28	2.00	10.32	0.83	1.20	0.00	3.67	2.16	7.36	9.82	4.57	0.28	6.58	0.15	15.17	5.39	0.64	0.60	2.11	0.16
ACHNEXIG	0.96	3.70	0.33	0.00	0.32	0.15	0.32	1.67	1.40	0.00	0.96	0.00	2.65	4.45	4.19	0.00	0.45	0.00	2.33	2.46	4.20	0.00	0.33	0.16
ACHNHUNG	0.00	0.61	0.00	0.16	0.33	0.00	0.33	12.79	0.00	0.00	0.64	0.00	0.00	1.44	0.00	0.00	0.00	0.00	1.59	0.94	0.17	0.00	0.66	0.63
ACHNMINU	0.64	1.37	3.08	10.29	0.83	0.15	0.00	3.03	8.68	5.35	0.48	0.00	0.00	1.44	11.85	13.44	0.00	0.00	0.00	0.84	9.15	9.44	0.00	0.00
AMRACOFF	0.64	0.00	0.00	0.00	0.16	0.16	0.32	0.00	0.00	0.00	0.00	0.98	1.55	0.00	0.00	0.00	0.00	0.16	1.99	0.00	0.00	0.00	0.17	0.00
AMRASUBT	0.00	0.00	0.00	0.00	2.45	0.00	0.00	0.00	0.00	0.00	17.07	2.99	0.31	0.00	0.00	0.00	19.26	1.39	0.23	0.19	0.00	0.00	5.72	2.28
BALAPARA	0.00	4.48	0.00	0.00	12.62	0.00	0.48	4.18	0.00	0.00	6.06	0.00	0.00	2.88	0.49	0.32	6.19	0.00	0.00	1.92	0.16	0.00	20.38	0.16

Water quality data for NAVIHESI, the epipelic diatom in the Swartkops River that was dominant most often after NAVIGREG, is shown in Table 7. Table 8 shows a comparison of the water quality indications for the epipelic diatoms NAVIGREG and NAVIHESI where they were the dominant component of the diatom population.

The diatoms appear to respond to the maximum water quality values rather than to the minimum values. The maximum values for Ca, Cl, EC, K, Mg, Na, pH, SO_4, alkalinity and TDS were all much lower where NAVIHESI was dominant (Table 8). From this, it appears that NAVIHESI occurs in even cleaner water than does NAVIGREG. It is not, therefore, surprising to note that on every occasion that NAVIHESI was dominant, it was found at site A, closest to the source of the Swartkops River.

Table 6. The sites and month of the year in the Swartkops River where the diatom NAVIGREG was identified as the dominant.

	SITES					
MONTH	**A**	**B**	**C**	**D**	**E**	**F**
SEPT		B09				
OCT	A10	B10				
NOV		B11				
DEC		B12		D12		
JAN		B13	C13	D13		
FEB		B14	C14	D14		
MAR		B15	C15			
APR		B16	C16			
MAY		B17				
JUN		B18				
JUL		B19				
AUG		B20				
SEP		B21				

Table 7. Water quality for NAVIHESI, the diatom that was dominant most often after NAVIGREG, but where it occurred as the dominant diatom in the epipelon of the Swartkops River.

	Mean	SD	CV%	Max	Min
% Dominance	31.68	5.01	15.82	38.96	25.89
Water quality					
Ca^{++} ($mg.l^{-1}$)	3.00	0.53	17.82	4.00	2.00
Cl^{-} ($mg.l^{-1}$)	45.75	4.17	9.11	51.00	40.00
EC (mS.m-1)	18.98	1.53	8.07	21.21	17.30
F^{-} ($mg.l^{-1}$)	0.05	0.05	106.90	0.10	0.00
K^{+} ($mg.l^{-1}$)	0.73	0.07	9.75	0.80	0.60
Mg++ ($mg.l^{-1}$)	4.00	0.53	13.36	5.00	3.00
Na^{+} ($mg.l^{-1}$)	27.13	2.17	7.99	30.00	24.00
NH_4^{+} ($mg.l^{-1}$)	0.01	0.02	282.84	0.07	0.00
NO_2^{-}+NO_3^{-} ($mg.l^{-1}$)	0.02	0.03	138.87	0.06	0.00
pH	7.22	0.15	2.07	7.40	7.00
PO_4^{---} ($mg.l^{-1}$)	0.03	0.02	57.50	0.06	0.01
SiO_2^{-} ($mg.l^{-1}$)	2.48	0.37	14.77	2.90	2.00
SO_4^{--} ($mg.l^{-1}$)	6.50	3.07	47.24	10.00	0.00
Alkalinity	15.50	4.41	28.44	22.00	9.00
TDS ($mg.l^{-1}$)	106.88	8.90	8.33	122.00	95.00

Table 8. Comparison of the water quality indications for the epipelic diatoms NAVIGREG and NAVIHESI where they were the dominant component of the diatom population.

Water quality	NAVIGREG as dominant		NAVIHESI as dominant	
	Max	Min	Max	Min
Ca^{++} ($mg.l^{-1}$)	62.00	3.00	4.00	2.00
Cl^{-} ($mg.l^{-1}$)	698.00	40.00	51.00	40.00
EC ($mS.m^{-1}$)	299.00	17.60	21.21	17.30
F^{-} ($mg.l^{-1}$)	0.30	0.00	0.10	0.00
K^{+} ($mg.l^{-1}$)	190.40	0.70	0.80	0.60
Mg^{++} ($mg.l^{-1}$)	63.00	4.00	5.00	3.00
Na^{+} ($mg.l^{-1}$)	471.00	25.00	30.00	24.00
NH_4^{+} ($mg.l^{-1}$)	0.70	0.00	0.07	0.00
NO_2^{-}+NO_3^{-} ($mg.l^{-1}$)	0.35	0.00	0.06	0.00
pH	8.99	6.89	7.40	7.00
PO_4^{---} ($mg.l^{-1}$)	0.08	0.01	0.06	0.01
SiO_2^{-} ($mg.l^{-1}$)	3.20	0.00	2.90	2.00
SO_4^{--} ($mg.l^{-1}$)	127.00	5.00	10.00	0.00
Alkalinity	530.00	21.00	22.00	9.00
TDS ($mg.l^{-1}$)	2258.00	104.00	122.00	95.00

NAVIGREG was dominant in the epipelon on 21 occasions in the Swartkops River and occurred mostly at site B. NAVIHESI was dominant on 10 occasions and was only found at site A. FRAGELLI was dominant on 7 occasions and the water quality data associated with it as the dominant are shown in Table 9.

By comparison with NAVIGREG that was dominant in water with a slightly lower quality than NAVIHESI, the diatom FRAGELLI was dominant in water with a greater maximum value of Cl^-, PO_4^{--}, SiO_2 and SO_4^-. FRAGELLI was the dominant diatom at site F on 4 occasions and site C on 3 occasions. Site F was the site most likely to be heavily polluted, but site C is quite high up the river. The reason for its presence at site C needs to be clarified.

Swartkops epilithon

The data in Tables 10 and 11 show that in the cleaner water of the Swartkops (see TDS Table 10), ACHNMINU is the dominant epilithic diatom. In the epipelon of the cleaner Swartkops River water, NAVIGREG was the dominant diatom. ACHMINU was only the dominant epilithic diatom at either of the sites A or B, i.e. in the upper reaches of the Swartkops. In the more polluted water ACHNMINU was found at frequency levels of less than 10% (Table 11). In many instances, it was absent from the epilithic diatom flora altogether. For example it was never found at Site C, only once at site D and then at 0.16% of the cells. At site E, it occurred only once and then as only 2.84% of the epilithic diatom flora.

NITZFRUS was the epilithic diatom that occurred with the second most frequency. It was dominant at sites C and D on one occasion each and Site E on 8 occasions. This diatom is clearly an indicator of polluted sites on epilithic habitats. Table 12 shows the water quality for this taxon.

Table 9. Water quality for FRAGELLI where it occurred in the epipelon of the Swartkops River as the most dominant diatom (n = 7).

	Mean	SD	CV%	Max	Min
FRAGELLI	26.91	11.43	42.47	46.79	13.29
Water quality					
Ca^{++} ($mg.l^{-1}$)	34.43	17.39	50.50	60.00	12.00
Cl^{-} ($mg.l^{-1}$)	504.00	304.23	60.36	930.00	154.00
EC (mS.m-1)	205.03	106.14	51.77	356.80	76.80
F^{-} ($mg.l^{-1}$)	0.23	0.11	48.68	0.40	0.10
K^{+} ($mg.l^{-1}$)	25.51	14.41	56.48	56.60	14.20
Mg^{++} ($mg.l^{-1}$)	41.00	20.66	50.38	69.00	14.00
Na^{+} ($mg.l^{-1}$)	315.71	188.44	59.69	563.00	95.00
NH_4^{+} ($mg.l^{-1}$)	0.01	0.03	264.58	0.08	0.00
NO_2^{-}+NO_3^{-} ($mg.l^{-1}$)	0.23	0.38	167.63	1.01	0.00
pH	7.39	0.33	4.42	7.86	7.00
PO_4^{---} ($mg.l^{-1}$)	1.82	2.37	130.54	5.97	0.01
SiO_2^{-} ($mg.l^{-1}$)	2.87	1.48	51.37	5.80	1.50
SO_4^{--} ($mg.l^{-1}$)	119.29	92.23	77.32	285.00	28.00
Alkalinity	154.14	51.35	33.32	209.00	77.00
TDS ($mg.l^{-1}$)	1234.57	668.49	54.15	2118.00	411.00

Table 10. Water quality of the 21 sites in the Swartkops River where ACHNMINU was the dominant epilithic species.

EPILITHON	Mean	SD	CV%	Max	Min
ACHNMINU %	42.35	12.00	28.34	67.58	20.76
Water Quality					
Ca^{++} ($mg.l^{-1}$)	6.62	4.17	62.93	16.00	2.00
Cl^{-} ($mg.l^{-1}$)	89.14	53.08	59.55	234.00	35.00
EC ($mS.m^{-1}$)	37.56	22.49	59.89	100.90	17.30
F^{-} ($mg.l^{-1}$)	0.08	0.07	83.96	0.20	0.00
K^{+} ($mg.l^{-1}$)	1.35	0.67	49.59	2.40	0.60
Mg^{++} ($mg.l^{-1}$)	8.62	5.63	65.27	24.00	3.00
Na^{+} ($mg.l^{-1}$)	53.52	32.11	59.98	147.00	24.00
NH_4^{+} ($mg.l^{-1}$)	0.01	0.02	218.93	0.07	0.00
NO_2^{-}+NO_3^{-} ($mg.l^{-1}$)	0.06	0.10	158.65	0.45	0.00
pH	7.17	0.16	2.29	7.48	6.89
PO_4^{---} ($mg.l^{-1}$)	0.03	0.02	70.94	0.08	0.01
SiO_2^{-} ($mg.l^{-1}$)	2.43	0.49	20.15	3.20	1.20
SO_4^{--} ($mg.l^{-1}$)	19.48	16.79	86.19	77.00	0.00
Alkalinity ($mg.l^{-1}$)	26.62	13.04	48.99	51.00	7.00
TDS ($mg.l^{-1}$)	211.90	125.99	59.45	566.00	95.00

Table 11. Water quality of the 21 sites in the Swartkops River where ACHNMINU occurred at a frequency of less than 10% as an epilithic species.

Water Quality	Mean	STD	CV%	Max	Min
Ca^{++} ($mg.l^{-1}$)	52.73	18.55	35.18	88.00	3.00
Cl^{-} ($mg.l^{-1}$)	910.09	344.86	37.89	1577.00	40.00
EC ($mS.m^{-1}$)	423.93	203.24	47.94	843.00	17.50
F^{-} ($mg.l^{-1}$)	0.28	0.09	33.26	0.40	0.00
K^{+} ($mg.l^{-1}$)	22.53	8.42	37.36	47.00	0.80
Mg^{++} ($mg.l^{-1}$)	73.41	27.55	37.53	129.00	3.00
Na^{+} ($mg.l^{-1}$)	555.45	201.81	36.33	899.00	25.00
NH_4^{-} ($mg.l^{-1}$)	0.39	0.83	211.09	3.08	0.00
$NO_2^{-}+NO_3^{-}$ ($mg.l^{-1}$)	1.37	1.71	125.30	6.22	0.00
pH	7.90	0.74	9.37	9.18	6.81
PO_4^{---} ($mg.l^{-1}$)	2.08	2.15	103.55	6.97	0.01
SiO_2^{-} ($mg.l^{-1}$)	2.62	1.26	48.04	5.80	0.60
SO_4^{--} ($mg.l^{-1}$)	198.00	100.08	50.55	514.00	7.00
Alkalinity	194.59	53.41	27.45	295.00	18.00
TDS ($mg.l^{-1}$)	2062.55	729.18	35.35	3380.00	101.00

Table 12. Water quality for NITZFRUS in the Swartkops River where it occurred as the dominant epilithic diatom (n = 10).

Water Quality	Mean	SD	CV%	Max	Min
Ca^{++} ($mg.l^{-1}$)	55.70	19.71	35.38	88.00	23.00
Cl^- ($mg.l^{-1}$)	965.00	371.84	38.53	1577.00	259.00
EC ($mS.m^{-1}$)	495.41	251.16	50.70	843.00	124.30
F^- ($mg.l^{-1}$)	0.29	0.09	30.19	0.40	0.20
K^+ ($mg.l^{-1}$)	27.01	8.72	32.30	47.00	17.10
Mg^{++} ($mg.l^{-1}$)	79.90	28.77	36.00	129.00	26.00
Na^+ ($mg.l^{-1}$)	581.40	216.80	37.29	899.00	169.00
NH_4^- ($mg.l^{-1}$)	0.83	1.10	132.66	3.08	0.00
NO_2^-+NO_3^- ($mg.l^{-1}$)	1.69	1.55	92.18	5.21	0.07
pH	8.25	0.38	4.61	8.87	7.76
PO_4^{---} ($mg.l^{-1}$)	1.24	1.52	122.28	3.95	0.01
SiO_2^- ($mg.l^{-1}$)	2.54	1.28	50.53	4.70	1.00
SO_4^{--} ($mg.l^{-1}$)	212.90	127.69	59.98	514.00	47.00
Alkalinity (in $mg.l^{-1}$)	217.40	46.04	21.18	295.00	163.00
TDS ($mg.l^{-1}$)	2199.50	773.95	35.19	3380.00	792.00

These latter data indicate generally polluted waters. Figure 1 shows the frequency at which NITZFRUS occurred at an abundance of less than 10%. It mainly occurred at low abundance in clean water, confirming the indication that it is an indicator of polluted water when it occurs as the epilithic dominant.

Comparison Olifants : Buffalo/ Nahoon

In order to assess the accuracy of the diatom ACHNMINU to determine water quality, the data collected from different rivers, different habitats, in different seasons and in different years were compared. These data are shown in Table 13. Bearing in mind the potential variability of the water quality, the max/min comparisons for EC, NH_4^+ and NO_2^-+NO_3^- and PO_4^{---} shown in Table 13 were very good. F^-, K^+ and TDS were good. The comparisons for Ca^{++}, alkalinity, Mg^{+} and Na^{+} were fair. Cl^{-}, however, was not good, nor were SiO_2^{-} or SO_4^{--}.

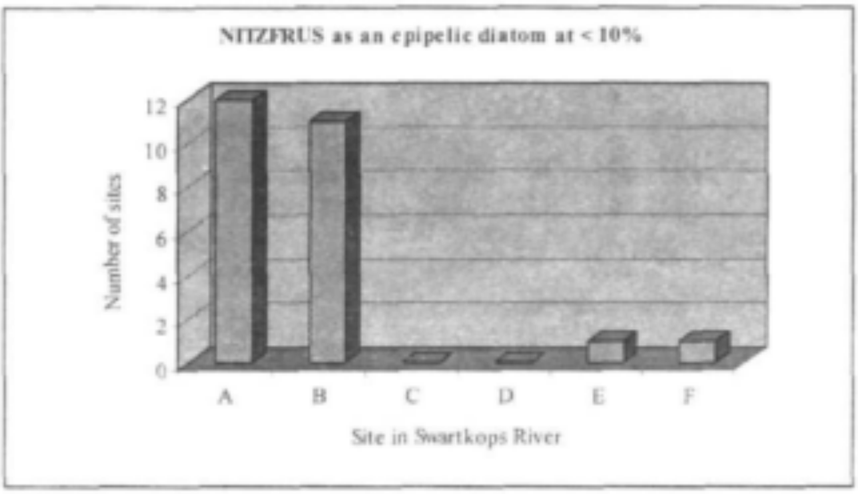

Figure 2. The number of occasions that NITZFRUS occurred at a frequency of less than 10 % at sites in the Swartkops River.

It was not possible to compare the epipelon from the Olifants River with the epipelon from the Buffalo and Nahoon Rivers, because there were no data for the latter rivers. However, the data in Table 13 show that ACHNMINU indicates some characteristics of water quality regardless of the habitat from which it comes.

The epilithic diatom ACHNMINU occurred as the dominant species at 19 sites in the Olifants River. The level of dominance ranged from 93% to 34%. When these values were compared, it was clear that a high level of dominance did not improve the capability of the diatom species to relate to any of the water qualities measured. Hence, if a diatom is dominant, it will indicate the nature of the habitat and one that is dominant at 95% will not assess the habitat more accurately than one that is dominant at (say) 30%. Professor Round, from the University of Bristol, maintained that he could determine dominance in some samples within three microscope frames. Experience shows that this is indeed sometimes possible. This finding will simplify counting strategies in samples that have overwhelming dominance. However, preparation between samples should be equivalent. There were almost no gradients in the Olifants River from site O1 to O11. The only obvious gradient occurred with alkalinity that decreased from O1 to O11. Surprisingly, pH did not follow the same trend.

Table 13. Comparison of the water quality found in the ACHNMINU epipelon of the Olifants River with ACHNMINU epilithon of the Buffalo and Nahoon Rivers. Samples were taken at different times of the year in different years.

ACHNMINU										
	EPIPELON River: Olifants					EPILITHON River: Buffalo/Nahoon				
Site	Ave	SD	CV	Max	Min	Ave	SD	CV	Max	Min
Ca^{++} ($mg.l^{-1}$)	42.8	24.2	56.6	94.0	15.0	27.7	21.22	76.7	45	4
Cl^{-} ($mg.l^{-1}$)	8.63	16.2	188	40.0	0.0	110.3	88.26	80	176	10
EC ($mS.m^{-1}$)	51.4	30.8	59.9	109.4	21.6	63.8	49.16	77.09	101.2	8.1
F^{-} ($mg.l^{-1}$)	0.3	0.11	35.6	0.5	0.2	0.2	0.126	68.63	0.3	0.05
K^{+} ($mg.l^{-1}$)	4.63	3.01	65.1	9.8	1.7	2.4	1.706	71.08	3.8	0.5
Mg^{++} ($mg.l^{-1}$)	19.5	19.4	99.4	66.0	6.0	19.0	14.18	74.62	30	3
Na^{+} ($mg.l^{-1}$)	33.3	25.6	77	74.0	9.0	84.0	67.67	80.56	134	7
NH_4^{+} ($mg.l^{-1}$)	0.04	0.09	236	0.3	0.0	0.3	0.397	140.1	0.74	0.02
NO_2^{-}+NO_3^{-} ($mg.l^{-1}$)	1.93	1.97	102	4.8	0.1	1.0	1.545	150.5	2.81	0.1
pH	7.97	0.61	7.69	9.4	7.4	8.2	0.337	4.119	8.42	7.8
PO_4^{---} ($mg.l^{-1}$)	0.08	0.17	220	0.5	0.0	0.2	0.271	156.7	0.486	0.01
SiO_2^{-} ($mg.l^{-1}$)	1.99	0.98	49.1	3.5	0.5	6.8	0.819	12.04	7.5	5.9
SO_4^{--} ($mg.l^{-1}$)	171	151	88.3	479.0	23.0	22.3	19.14	85.7	40	2
Alk ($mg.l^{-1}$)	53.8	27.6	51.4	110.0	31.0	142.7	114.4	80.17	248	21
TDS ($mg.l^{-1}$)	364	223	61.3	832.0	170.0	445.3	347.1	77.94	716	54

The ACHNMINU data for the 43 sites across all rivers where it was dominant, are interesting in that the data are not normally distributed. They are skewed to the low values with only a few very high values. The possibility must exist that the few very high values represent errors of analysis. In the case of the Olifants River, the mineral element analysis values are used to illustrate this point. The mean value of any data set can be assessed with regard to its variability using the standard deviation (SD). One measure of whether a datum point belongs to a set of data is called Chauvenet's Criterion. According to this test, if any value within a data set is more than 3 SD's away from the mean, then that value should be rejected. In the case of the Olifants River data, site W1 which is the uppermost site in the Wilge River, fails the test because the values for Ca^{++}, Cl^{-}, EC, Mg^{++}, Na^{+}, SO_4^{--}, Alkalinity and TDS were all greater than the mean + (SD x 3). The dominant diatom at this site was ACHNMINU, which is an indicator of Class 1 water (see later). It is clear, therefore, that the analysis of the water at site W1 should be rejected.

The value of TDS ($mg.l^{-1}$) is, on average, 6.5 times greater than the value of electrical conductivity. This was tested using the water analysis data and the results showed that on average the value is indeed 6.5 taking all the data together, but that it varied for different rivers. These results are shown in Table 14.

Table 14. The ratio of TDS/EC for six rivers in South Africa.

River	Ratio TDS/EC
Swartkops River	5.9
Olifants River	7.5
Buffalo River	6.7
Nahoon River	6.8
Gamtoos River	6.5
Sundays River	6.8

In order to indicate what the different diatoms are indicating in terms of water quality, it was necessary to construct water quality classes from the available water quality analyses. This was done for each of the attributes that were analysed by DWAF for all the rivers in this study. Class 1 water is considered to be that water having the lowest content of each of the attributes while Class 5 water was considered to be that water having the highest content of each of the attributes. Class 3 water was given artificial values that were the average of the highest and the lowest, while Class 2 was the average of 1 and 3. Class 4 water had values for each attribute that were the average of Class 3 and Class 5 water. The content of each attribute in each of the classes is presented in Table 15.

Table 15. The values of mineral elements for each of five water classes from all the river water analysed during this study.

Attribute	Class 1	Class 2	Class 3	Class 4	Class 5
Ca^{2+} ($mg.l^{-1}$)	1.00	126.75	252.50	378.25	504.00
Cl^- ($mg.l^{-1}$)	0.00	1711.00	3422.00	5133.00	6844.00
EC ($mS.m^{-1}$)	5.50	498.88	992.25	1485.63	1979.00
F^- ($mg.l^{-1}$)	0.00	0.13	0.25	0.38	0.50
K^+ ($mg.l^{-1}$)	0.15	60.61	121.08	181.54	242.00
Mg^{2+} ($mg.l^{-1}$)	1.00	173.25	345.50	517.75	690.00
Na^+ ($mg.l^{-1}$)	6.00	915.75	1825.50	2735.25	3645.00
NH_4^+ ($mg.l^{-1}$)	0.00	0.95	1.91	2.86	3.81
NO_3^- ($mg.l^{-1}$)	0.00	6.07	12.14	18.20	24.27
pH	4.90	6.07	7.24	8.40	9.57
PO_4^{3-} ($mg.l^{-1}$)	0.00	1.74	3.48	5.22	6.97
SiO_2 ($mg.l^{-1}$)	0.00	2.23	4.45	6.68	8.90
SO_4^{2-} ($mg.l^{-1}$)	0.00	528.50	1057.00	1585.50	2114.00
Alkalinity ($mg.l^{-1}$)	6.00	217.25	428.50	639.75	851.00
TDS ($mg.l^{-1}$)	34.00	3560.25	7086.50	10612.75	14139.00

To apply these values to a diatom taxon, the average of the rivers in which the diatom was dominant was assessed with respect to these classes. For each attribute, the diatom is considered to be a Class 1 type if the value of the attribute was less than half the value between Class 1 and Class 2, i.e. in the case of Ca^{++}, if a diatom was dominant in water with a Ca^{++} value of between 1.00 and 63.37 $mg.l^{-1}$. It would be a Class 2 water indicator if the water had between 63.38 and 189.62 $mg.l^{-1}$ Ca^{++}.

Table 16 shows the water class indications for the dominant diatom taxa from this study.

Table 16. Water class indications for the dominant diatom taxa from the present study.

	n	Ca^{2+}	Cl^-	EC	F^-	K^+	Mg^{2+}	Na^+	NH_4^+	NO_3^-	pH	PO_4^{3-}	SiO_2	SO_4^{2-}	Alk	TDS
ACHNMINU	43	1	1	1	3	1	1	1	1	1	4	1	2	1	1	1
NAVIGREG	27	1	1	1	2	1	1	1	1	1	3	1	3	1	1	1
NITZFRUS	13	2	2	2	4	1	2	2	1	1	4	2	2	2	2	2
NAVIHESI	12	1	1	1	1	1	1	1	1	1	3	1	2	1	1	1
FRAGELLI	9	1	1	1	3	1	1	1	1	1	3	3	2	1	2	1
ACHNOBLO	8	1	1	1	2	1	1	1	1	1	2	1	2	1	1	1
ACHNSUAT	7	1	1	1	4	1	1	1	1	1	3	1	4	1	2	1
FALATERA	6	1	2	2	4	1	1	2	2	1	3	2	2	1	2	2
NAVIPHYL	5	1	2	2	4	1	1	2	1	1	4	1	2	2	2	2
NITZPALE	5	1	1	1	3	1	1	1	3	2	3	2	2	1	2	1
NAVICAPI	4	1	1	1	3	1	1	1	1	1	4	1	2	1	2	1
DIATVULG	4	1	1	4	4	1	1	1	1	1	4	1	2	1	2	1
ACHNABUN	3	1	1	1	2	1	1	1	1	1	3	1	2	1	1	1
BALAPARA	3	1	1	1	3	2	1	1	1	1	4	2	2	1	2	1
CCNEPLAC	3	1	1	1	3	1	1	1	1	2	3	2	2	1	1	1
DINEPUEL	3	1	1	1	3	1	1	1	1	1	4	1	2	1	2	1
GONEPARV	3	1	1	1	2	1	1	1	1	1	3	1	3	1	1	1
NAVIPSHA	3	2	1	2	3	4	1	2	1	1	4	1	3	1	4	2
NITZPACE	3	1	1	1	3	1	1	1	1	1	4	1	2	1	2	1
ACHNEXIG	1	1	1	1	2	2	1	1	1	1	3	1	2	1	2	1
AMRASUBT	2	1	2	2	4	1	1	2	1	1	3	3	2	1	2	2
EUTUFALA	2	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1
EUTIINCI	1			1					1	1	1	1				
EUTITENE	1			1					1	1	1	1				
NAVIFRUG	2	1	1	1	4	1	1	1	1	3	3	3	3	1	1	1
NAVITELO	2			1					1	1	1	1				
NITZDESE	2	1	2	2	4	1	2	2	2	1	4	2	2	1	2	2
NITZFONT	2	5	5	4	4	1	5	5	1	1	4	1	1	5	2	5
NITZGRAF	2	1	1	1	4	1	1	1	1	1	4	1	2	1	1	1
SYNETABU	2	2	2	2	4	1	2	2	1	2	4	1	1	2	2	2
AMROPEDI	1	2	1	1	5	1	1	1	1	1	4	1	2	1	2	1
CALOSCHU	1	1	1	1	4	1	1	1	1	1	4	1	3	1	2	1
CYCLMENI	1	1	1	1	3	1	1	1	1	1	4	1	3	1	2	1
ENTOALAT	1	1	1	2	3	1	1	1	1	1	3	2	1	1	2	
EUTITRIN	1			1					1	1	1	1				
FALEUMPA	1	1	2	2	4	1	1	2	1	1	2	2	2	1	2	2
FRUSROST	1			1					1	1	1	1				
GONECLEV	1			1					1	1	2	1				

MAGLELLI	1	1	1	1	1	1	1	1	1	1	3	1	2	1	1	1
NAVICIle	1	2	2	2	3	2	2	2	1	1	4	1	2	1	2	2
NAVICONF	1	1	1	2	4	1	1	2	1	1	3	5	2	1	2	2
NAVICRCE	1			1					1	3	3	4				
NAVICRex	1	2	1	1	3	1	3	1	1	1	4	1	2	4	3	2
NAVIMENI	1	1	1	1	3	1	1	1	1	1	4	2	2	1	2	1
NAVIMOLL	1	1	1	1	5	1	1	1	2	1	4	1	4	1	2	1
NAVIPUPU	1			1					4	1	3	2				
NITZCAPI	1	1	1	2	3	1	1	2	2	1	4	1	1	1	2	2
NITZDISS	1	1	1	1	4	1	1	1	1	2	4	1	1	2	1	1
NITZDIST	1	1	1	1	2	1	1	1	1	1	3	1	4	1	1	1
NITZELal	1	1	1	2	3	1	1	2	1	1	4	2	2	1	2	1
NITZGRAC	1	2	1	1	5	1	1	1	1	1	4	1	1	2	2	1
NITZLIte	1			3							4					
PINNBRAU	1			1					1	1	2	1				
PLACSP01	1	1	1	1	4	1	1	2	1	1	4	2	2	1	2	1

MULTIVARIATE ANALYSIS AND INTERPRETATIONS

SEASONAL STUDY OF EPILITHIC AND EPIPELIC DIATOMS AS WATER QUALITY INDICATORS ALONG A POLLUTION GRADIENT IN THE SWARTKOPS RIVER.

Introduction

The objectives of this study were to assess the temporal patterns in the distribution of diatom assemblages in two distinct microhabitats and their relationship with water quality in the Swartkops River. Indicator values of diatom taxa for specific water quality variables were estimated and tested with weighted-averaging regression and calibration models. A comparison was made of the performance of the models developed for epilithic and epipelic diatom taxa. Finally, the variability of water quality sampling and diatom inferred water quality assessment was compared.

The study area.

The main part of the catchment of the Swartkops River lies in the "Groot Winterhoek Mountains" (Figure 3). The total catchment area is ca. 1354 km^2 with a mean annual run-off of 84.2 x 10^6 m^3. The largest obstruction to river flow in the catchment is the Groendal Dam. This reservoir has a storage capacity of ca. 12 x 10^6 m^3, which is 45% of the mean annual run-off from that part of the catchment. The Elands River is the largest tributary to the Swartkops and has two small dams in its catchment. These dams tend to have little effect on the river flow (Baird *et al.*, 1986). The part of the Swartkops River that was studied is a 2^{nd} to 3^{rd} order stream (Strahler method in Gordon *et al.*, 1992) based on a 1:250 000 scale map. The climate in the catchment is largely warm temperate with all months between 10-22° C and all months at least 60 mm of rain (Köpke, 1988).

Six sites were selected along the river that were regularly sampled as part of a monitoring programme run by the Department of Water Affairs and Forestry (DWAF). The locations of the sites are given in Table 17. Figure 3 illustrates the catchment area.

The water quality of the Swartkops River is severely impacted by several anthropogenic sources (Baird, 1986; Mackay, 1993; Binning, 1999). There is a persistent gradient of water quality, ranging from virtually pristine conditions just upstream from the town of Uitenhage (Sites A and B), to heavily degraded water quality just 20 km downstream (Sites C-F). The sources of impact include: a wool processing factory, three sewerage treatment works, run-off from informal settlements and discharges from light industries (e.g. leather tanning).

The sampling sites were visited monthly between May 1997 and April 1999. The conductivity, dissolved oxygen, pH and temperature were assessed as described in the section on methods. Between April 1998 and April 1999 the full suite of major inorganic water quality variables was analysed by the DWAF. The epipelon was sampled at each site when suitable patches of sediment had accumulated at the site. Where possible, the epilithon was also sampled (Table 17).

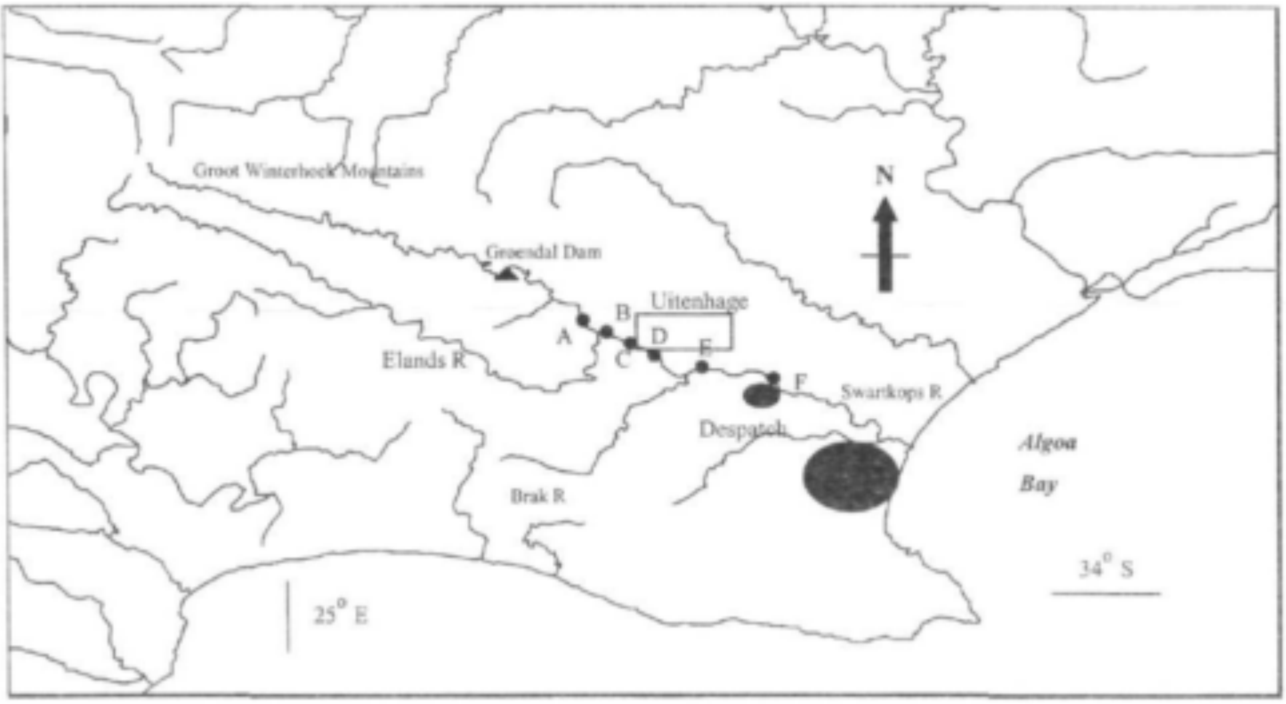

Figure 3. Catchment of the Swartkops River.

Table 17. Name and location of 6 sampling sites in the Swartkops River sampled between March 1997 and April 1999.

Site	Name	Location		Number of samples	
		South	East	epilithon	epipelon
A	Springfontein	33°44'10.5"	25°19'11.3"	21	13
B	Bulmer drift	33°45'07.6"	25°20'33.4"	21	14
C	Gubb & Ingg's	33°45'51.2"	25°22'32.9"	2	21
D	Niven Bridge	33°46'19.5"	25°23'16.5"	9	14
E	Nic Claasen Bridge / Brak River	33°47'33.1"	25°24'48.4"	21	21
F	Despatch Bridge	33°47'25.2"	25°29'18.6"	11	21

RESULTS

Physico-chemical conditions

River flow (measured at site D) was generally below 1 $m^3.s^{-1}$ (Figure 4). The physical conditions at the sampling sites were such that the flow velocity seldom exceeded an estimated 0.3 $m.s^{-1}$. Zero flow conditions were recorded on several occasions during the two years of the survey.

The water quality variables showed a clear gradient between the two reference sites, A-B, and the impacted sites downstream, C-F (Table 18). Nutrient concentrations were particularly high at sites E and F due to discharge by several sewerage treatment works upstream. Just upstream of site F, the river was covered by thick mats of water hyacinth (*Eichhornia crassipes* (Mart.) Solms-Laub), which is alien to this region. It appeared that the hyacinths removed a large portion of the nitrogen from the water column, but phosphate concentrations remained high (maximum of 6.0 $mg.l^{-1}$ on 12 March 1999).

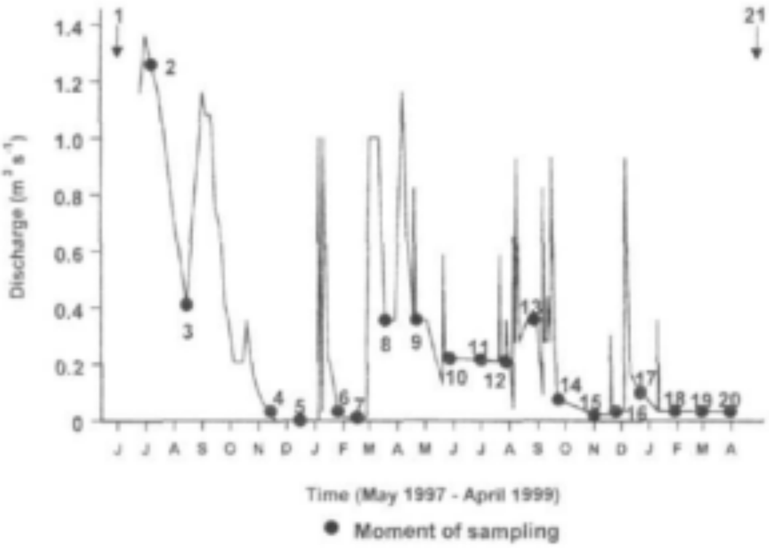

Figure 4. Discharge (m^3 s^{-1}) at site D between June 1997 and April 1999. Numbers indicate consecutive sampling sessions. No flow data available for sessions 1 and 21.

Table 18. Summary of water quality variables measured at sites A-F in the Swartkops River between 23 April 1998 and 30 April 1999. The values are geometric means (with SD) except for pH (metric mean, SD).

	Alkalinity (as $CaCO_3$ in $mg.l^{-1}$)	Ca^{2+} ($mg.l^{-1}$)	Cl^- ($mg.l^{-1}$)	Conductivity ($mS.m^{-1}$)	K^+ ($mg.l^{-1}$)	Mg^{2+} ($mg.l^{-1}$)	Na^+ ($mg.l^{-1}$)	NH_4^+ ($mg.l^{-1}$)	NO_2^- $+NO_3^-$ ($mg.l^{-1}$)	pH	PO_4^{3-} ($mg.l^{-1}$)	SiO_2 ($mg.l^{-1}$)	SO_4^{2-} ($mg.l^{-1}$)	TDS ($mg.l^{-1}$)
A	15.15	2.88	44.00	18.84	0.73	3.96	27.02	< 0.04	0.07	7.28	0.02	2.48	7.76	106.29
	(4.68)	(0.49)	(4.62)	(1.54)	(0.08)	(0.58)	(1.89)	*	(0.03)	(0.18)	(0.01)	(0.34)	(2.98)	(7.66)
B	37.93	10.02	129.64	53.58	1.96	12.70	76.44	< 0.04	0.11	7.08	0.02	2.24	26.78	305.95
	(7.34)	(2.81)	(39.20)	(16.70)	(0.45)	(4.31)	(24.42)	*	(0.13)	(0.14)	(0.02)	(0.59)	(15.71)	(92.27)
C	218.40	30.82	358.22	167.75	58.21	35.41	232.13	0.16	0.08	7.91	0.04	2.24	68.18	1060.50
	(249.65)	(24.59)	(281.12)	(127.06)	(82.38)	(25.65)	(193.22)	(0.20)	(0.02)	(0.44)	(0.30)	(2.17)	(37.47)	(940.87)
D	159.73	37.45	573.02	225.53	25.46	51.38	339.30	0.69	0.40	8.12	0.10	1.87	112.60	1345.68
	(66.89)	(19.02)	(308.77)	(108.20)	(8.72)	(25.43)	(179.06)	(1.36)	(0.40)	(0.58)	(0.24)	(1.46)	(72.58)	(670.81)
E	205.23	58.09	1027.88	403.52	21.81	84.18	621.07	0.23	1.76	8.02	0.61	2.06	216.48	2304.16
	(45.47)	(15.32)	(278.71)	(165.03)	(5.41)	(21.89)	(158.19)	(0.79)	(1.73)	(0.29)	(1.31)	(1.32)	(99.29)	(585.02)
F	175.92	46.93	769.97	294.54	20.44	60.06	479.05	0.08	0.72	7.22	2.36	2.41	163.36	1769.94
	(26.14)	(9.37)	(154.96)	(51.10)	(2.90)	(11.00)	(94.31)	(0.07)	(0.97)	(0.32)	(2.01)	(1.14)	(49.10)	(339.79)
	Anova													
F	12.4	29.5	43.0	36.4	11.3	39.3	42.0	3.8	3.0	16.7	20.5	1.1	27.8	33.0
P	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.004	0.02	<0.001	<0.001	0.4	<0.001	<0.001

Diatom species distribution

A MANOVA was conducted to determine the variation in the diatom species distribution as a result of seasonal influences. Season did not have an influence on the effective number of species (N_2), species diversity (H') or species evenness (J', Table 19).

Table 19. Three way nested MANOVA of effective number of species (N_2), species diversity (H') and species evenness (J'). Sites nested in season, habitats nested in sites.

	MS effect	MS error	F	p
N_2	2.23	7.57	0.29	0.83
H'	0.03	0.03	1.29	0.28
J'	0.02	0.01	2.07	0.10

In the ordination diagram (DCA) of sampling stations (Figure 4), samples taken at stations A and B have been placed on the right section and the impacted stations (C-F) on the left. A separation is also visible along the second (vertical) axis between epilithic and epipelic assemblages. This indicates that both spatial forces and habitat differences have a profound effect on diatom assemblage composition. The differences induced by habitat are less than those induced by spatial forces, since the eigenvalue of the second axis is considerably lower than the first axis.

The mean N_2, H' and J' were significantly higher in the epipelon than in the epilithon (Table 20). For this reason the two habitats were analysed separately for correlation with water quality variables.

Table 20. Mean effective number of species (N_2), mean species diversity (H') and mean species evenness (J').

	N_2	H'	J'
epilithon	4.26	0.77	0.65
epipelon	7.52	1.02	0.75
F	223.5	411.4	179.8
p	0.001	0.001	0.001

A post hoc analysis (Tukey test for unequal n) of species diversity (H') between sampling sessions, showed that the H' of the epipelic assemblages was significantly lower during the 3rd sampling session (August 1997) (Table 21). This coincided with high discharge rates before the time of sampling (Figure 3). The same post hoc analysis did not result in significant differences in species diversity between sampling sessions for epilithic assemblages.

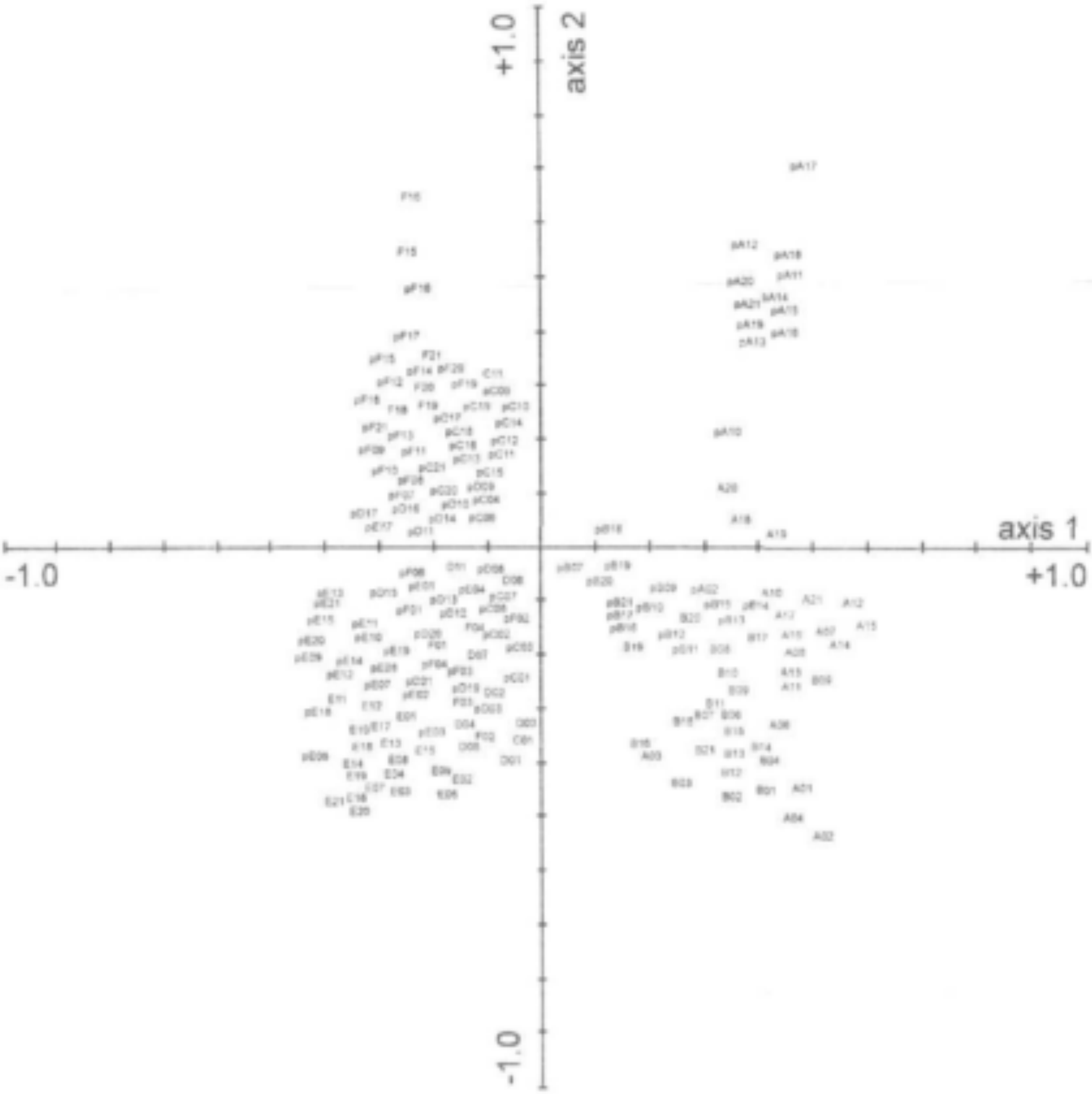

Figure 5. DCA ordination diagram of 190 samples from 6 sites (A-F) in the Swartkops River. A 'p' indicates a sample from the epipelon, all other samples from epilithon. Numbers are consecutive sampling times between May 1997 and April 1999. Eigenvalues: axis 1: 0.624; axis 2: 0.229.

Table 21. Probabilities for significant differences between sampling sessions. Two-way MANOVA, Tukey test for unequal n. Sites nested in sampling sessions. Significant differences are boxed.

Sampling session	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Mean H'	1.12	0.86	0.68	1.01	1.15	1.06	1.03	1.17	1.03	0.99	1.06	1.05	1.01	1.04	1.10	1.04	1.07	1.10	0.99	0.96	0.98
1	1.00																				
2	0.43	1.00																			
3	[illegible]	0.81	1.00																		
4	1.00	0.95	[illegible]	1.00																	
5	1.00	[illegible]	[illegible]	0.95	1.00																
6	1.00	0.62	[illegible]	1.00	0.98	1.00															
7	1.00	0.90	[illegible]	1.00	0.65	1.00	1.00														
8	1.00	[illegible]	[illegible]	0.87	1.00	0.90	0.32	1.00													
9	1.00	0.86	[illegible]	1.00	0.75	1.00	1.00	0.33	1.00												
10	1.00	0.99	[illegible]	1.00	0.19	1.00	1.00	[illegible]	1.00	1.00											
11	1.00	0.63	[illegible]	1.00	0.98	1.00	1.00	0.78	1.00	0.98	1.00										
12	1.00	0.72	[illegible]	1.00	0.94	1.00	1.00	0.64	1.00	1.00	1.00	1.00									
13	1.00	0.97	[illegible]	1.00	0.37	1.00	1.00	0.08	1.00	1.00	1.00	1.00	1.00								
14	1.00	0.80	[illegible]	1.00	0.85	1.00	1.00	0.46	1.00	1.00	1.00	1.00	1.00	1.00							
15	1.00	0.24	[illegible]	1.00	1.00	1.00	0.99	1.00	0.99	0.38	1.00	1.00	0.51	0.98	1.00						
16	1.00	0.81	[illegible]	1.00	0.84	1.00	1.00	0.45	1.00	1.00	1.00	1.00	1.00	1.00	0.98	1.00					
17	1.00	0.54	[illegible]	1.00	0.99	1.00	1.00	0.89	1.00	0.94	1.00	1.00	0.99	1.00	1.00	1.00	1.00				
18	1.00	0.25	[illegible]	1.00	1.00	1.00	0.99	1.00	0.99	0.42	1.00	1.00	0.72	1.00	1.00	0.99	1.00	1.00			
19	1.00	0.99	[illegible]	1.00	0.14	1.00	1.00	[illegible]	1.00	1.00	0.92	0.98	1.00	1.00	0.15	1.00	0.82	0.32	1.00		
20	0.99	1.00	0.07	1.00	[illegible]	0.92	1.00	[illegible]	0.99	1.00	0.45	0.64	1.00	0.83	[illegible]	0.85	0.32	0.06	1.00	1.00	
21	1.00	1.00	[illegible]	1.00	0.10	0.99	1.00	[illegible]	1.00	1.00	0.84	0.94	1.00	0.99	0.10	0.99	0.72	0.24	1.00	1.00	1.00

Diatom species distribution in relation to water quality variables

All water quality variables, except pH, showed a skewed distribution. $Log_e(x+1)$ transformation successfully removed the skewness. The water quality variables that correlated with the distribution of epilithic and epipelic diatom species were identified with forward selection (Table 22). The variables Ca, Cl, Conductivity, K, Mg, Na, SO_4, alkalinity and TDS were strongly correlated with each other ($r>0.85$). Therefore, this group of ions was represented by conductivity. The aim of this ordination analysis was to investigate the correlation between water quality and diatom species distribution, regardless of the time of sampling. Therefore, sampling months were used as co-variables, to rule out any possible influence of seasonal variation. Five water quality variables had a significant effect on the species distribution ($p \leq 0.03$). The most important one was conductivity, which explained 21.7% (epilithon) and 20.2% (epipelon) of the variation in the species composition.

Table 22. Ranking of water quality variables in importance by their conditional effects on the species distribution in epilithon and epipelon as obtained by forward selection. λ_a = increase in eigenvalue; p = significance level of addition (Monte Carlo permutation test). Any possible seasonal variation is partialled out by taking the month class variables as covariables.

	epilithon		epipelon	
Variable	λ_a	p	λ_a	p
Conductivity	0.66	0.001	0.52	0.001
NO_2+NO_3	0.26	0.001	0.12	0.001
PO_4	0.14	0.001	0.11	0.001
pH	0.1	0.002	0.05	0.003
SiO_2	0.07	0.037	0.04	0.025

Epilithon

The cumulative percentage of variance explained by the environmental variables is 49% (Table 23). This indicates that the selected environmental variables explain almost half of the diatom species distribution. The first two axes (used in the ordination diagrams - Figures 6 and 7) represent 41.4% of the variance in the species composition and 81.9% of the species-environment relationship (Table 23).

Table 23. Summary of ordination of epilithic diatom species by CCA.

	Axis 1	Axis 2	Axis 3	Axis 4	Total inertia
Eigenvalues	0.682	0.324	0.12	0.063	3.04
Species-environment correlations	0.986	0.906	0.89	0.760	
Cumulative percentage variance					
of species data	28.1	41.4	46.4	49.0	
of species-environment relation	55.5	81.9	91.6	96.8	
Sum of all unconstrained eigenvalues					2.428
Sum of all canonical eigenvalues					1.228

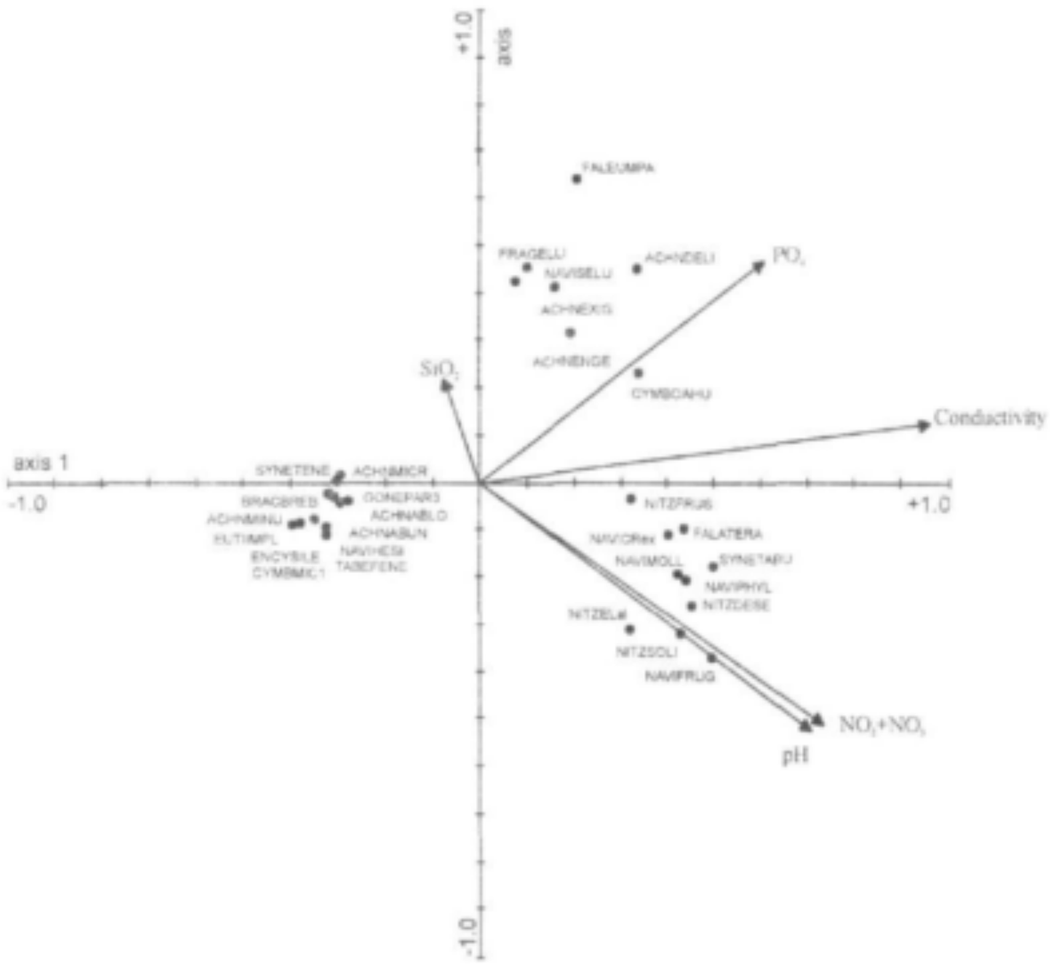

Figure 6. Ordination diagram of epilithic diatom species and their correlation with selected water quality variables. Species acronyms are explained in the Appendix. See also Table 23.

Figure 6 shows the ordination of the epilithic taxa. Conductivity is strongly correlated with the first axis. A separation is clearly visible along the first axis between species dominating the upstream sites A and B (on the left), and the impacted sites E and F (on the right, Figure 7). *Achnanthes engelbrechtii* (ACHNENGE), *A. delicatula* (ACHNDELI) and *Cymbella oahueinsis* (CYMBOAHU) are indicators of a high concentration of phosphate. *Achnanthes abundans* (ACHNABUN) dominates where conductivity and phosphate is lower than the mean observed conductivity and phosphate concentrations (Figure 6).

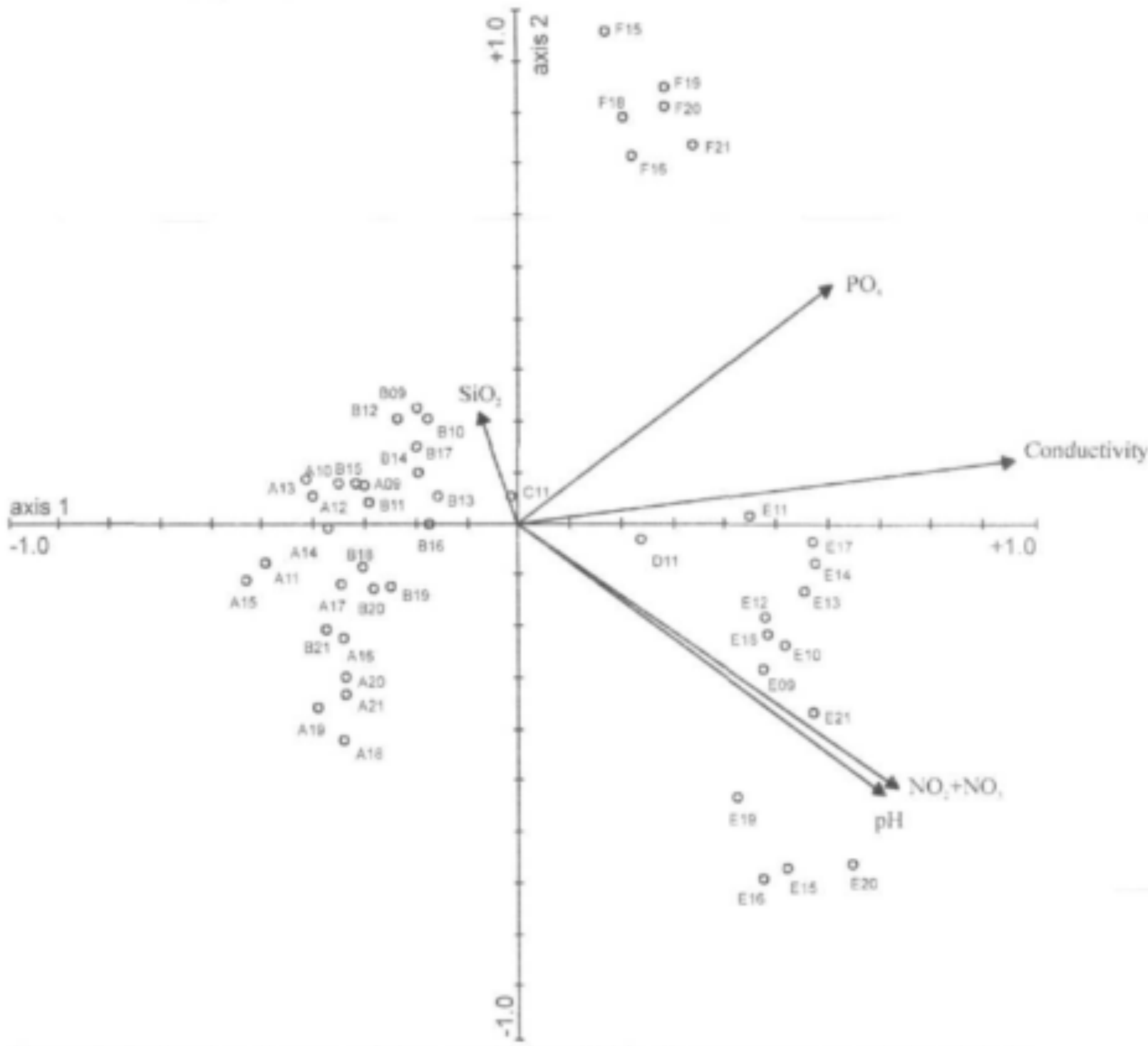

Figure 7. Ordination diagram of sites at which epilithic diatoms were sampled and their correlation with selected water quality variables. See Table 23.

Epipelon

A summary of the ordination of the epipelic diatoms is given in Table 24. The cumulative percentage of variance explained by the environmental variables is 35.9%. This indicates that other (unmeasured) environmental variables also have an important effect on the diatom species distribution. The first two axes (used in the ordination diagram, Figure 4.6) represent 29.3% of the variance in the species composition and 78.7% of the species-environment relationship (Table 24).

Table 24. Summary of ordination of epipelic diatom species by CCA.

	Axis 1	Axis 2	Axis 3	Axis 4	Total inertia
Eigenvalues	0.527	0.132	0.104	0.046	2.573
Species-environment correlations	0.946	0.817	0.765	0.631	
Cumulative percentage variance					
of species data	23.4	29.3	33.9	35.9	
of species-environment relation	62.9	78.7	91.1	96.5	
Sum of all unconstrained eigenvalues					2.252
Sum of all canonical eigenvalues					0.838

Figure 8 shows the ordination of the epipelic taxa and their correlation with the selected water quality variables. Conductivity is strongly correlated with the first axis. Just like in the epilithon, the taxa *Achnanthes engelbrechtii* (ACHNENGE), *A. delicatula* (ACHNDELI) were dominant in the epipelon at sites with high concentrations of phosphate. However, unlike in the epilithon, the distribution of *Cymbella oahuensis* (CYMBOAHU) is more correlated with pH and nitrite/nitrate. Along the second axis (nutrient and pH gradient) a separation is visible between sites F and a group formed by C, D and E (Figure 9).

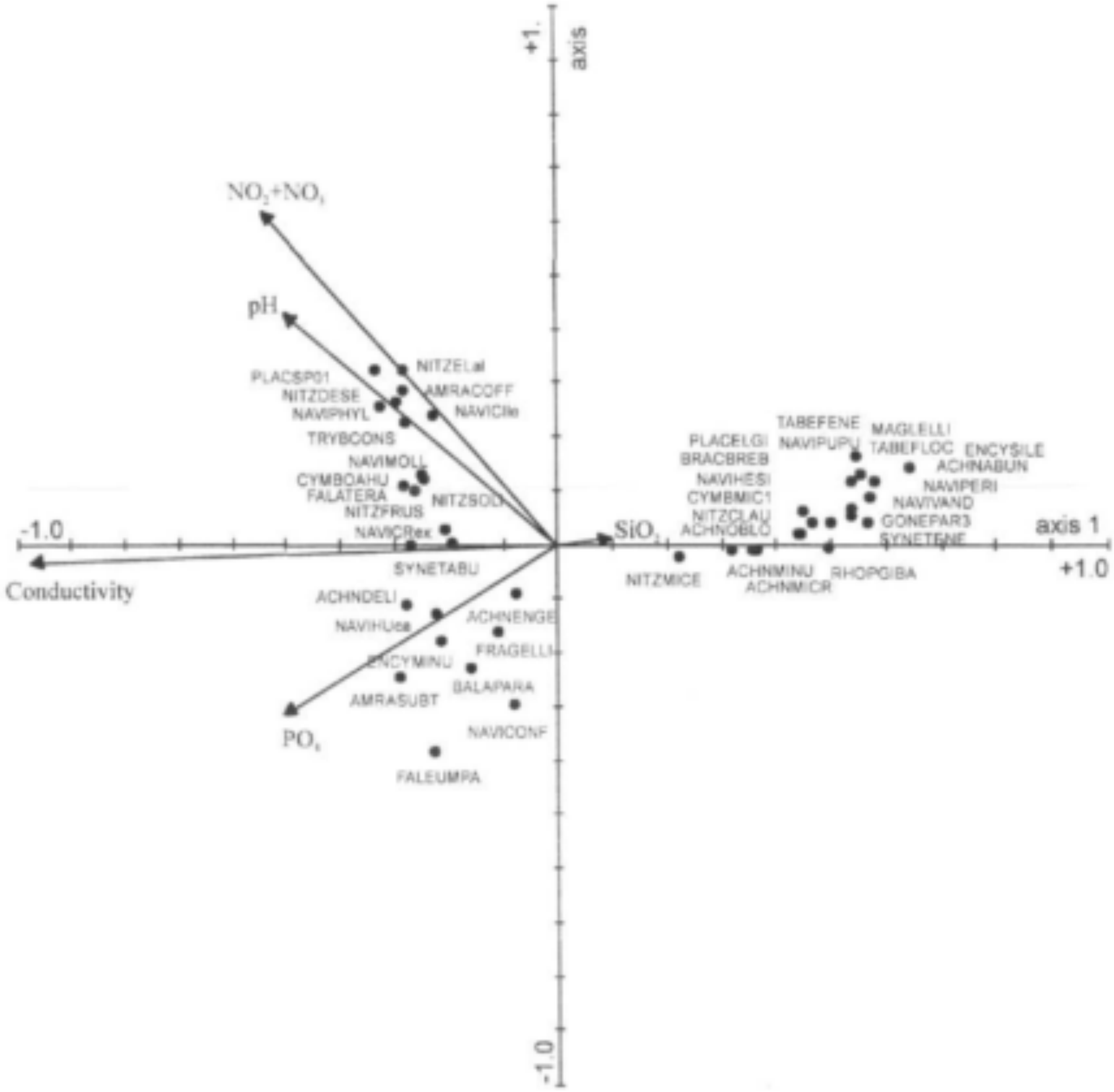

Figure 8. Ordination diagram of epipelic taxa and their correlation with selected water quality variables. Species acronyms are explained in the Appendix. See also Table 24.

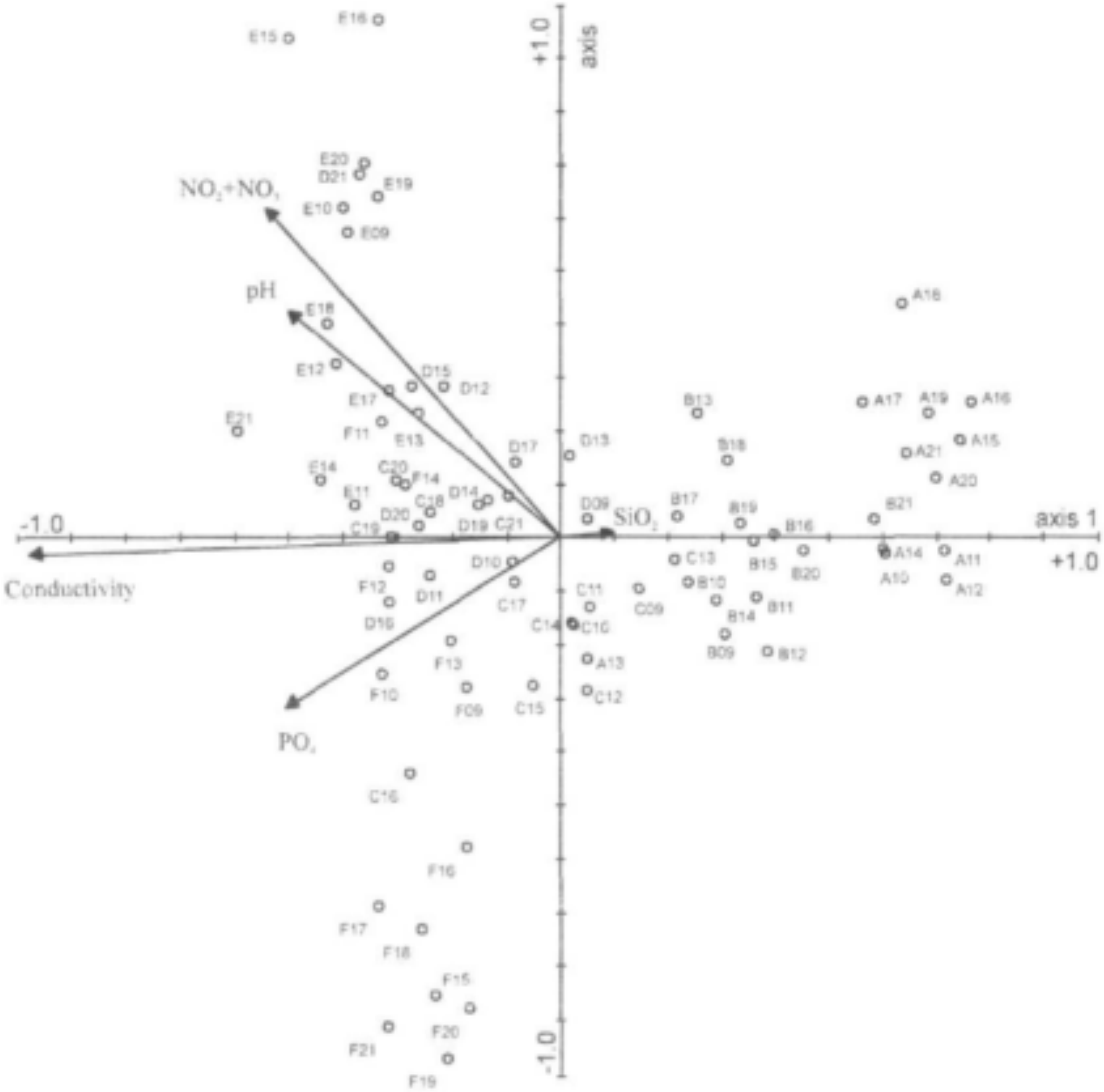

Figure 9. Ordination diagram of sites at which epipelic taxa were sampled and their correlation with selected water quality variables. See Table 24.

Weighted-averaging regression and calibration

Weighted-averaging calibration models were developed for the water quality variables that were selected with forward selection (Table 22). For epilithic assemblages the models for conductivity, nitrite/nitrate and pH yielded the strongest correlation between observed and predicted values (Table 25). The models based on epipelic diatoms performed well only for conductivity.

Table 25. Performance indication of calibration models based on epilithic and epipelic diatoms in the Swartkops River. RMSE = root mean square error. r^2 = coefficient of determination of regression (inverse deshrinking) between observed and diatom-inferred values. RMSE and r^2 in parentheses derived from jackknifing. WA: weighted averaging. WA (tol): weighted averaging with tolerance down weighting.

	Epilithon (n=47 sites)				Epipelon (n=76 sites)			
	WA		WA(tol)		WA		WA(tol)	
	RMSE	r^2	RMSE	r^2	RMSE	r^2	RMSE	r^2
Conductivity	0.36	0.93	0.26	0.96	0.40	0.86	0.41	0.86
	(0.40)	(0.91)	(0.32)	(0.95)	(0.43)	(0.84)	(0.46)	(0.82)
NO_2+NO_3	0.26	0.75	0.25	0.77	0.33	0.51	0.29	0.60
	(0.30)	(0.66)	(0.38)	(0.49)	(0.35)	(0.44)	(0.37)	(0.40)
PO_4	0.37	0.66	0.29	0.80	0.43	0.44	0.41	0.48
	(0.43)	(0.56)	(0.47)	(0.49)	(0.47)	(0.35)	(0.53)	(0.22)
pH	0.30	0.77	0.29	0.78	0.41	0.43	0.40	0.47
	(0.35)	(0.69)	(0.38)	(0.64)	(0.44)	(0.34)	(0.43)	(0.37)
SiO_2	0.19	0.49	0.18	0.57	0.30	0.31	0.30	0.30
	(0.26)	(0.12)	(0.26)	(0.13)	(0.37)	(0.04)	(0.39)	(0.04)

Tolerance-downweighted WA resulted in slightly higher r^2 for most variables in the ordinary WA models, but resulted in higher RMSE and lower r^2 under cross-validation (jackknifing) (Table 25). The ordinary WA is therefore the most appropriate method.

To illustrate the performance of the models, the observed values of each water quality variable can be plotted against the predicted (Jackknifed) value at each site. In the theoretical event that both observed and predicted values are the same, the points would be plotted on a 1:1 line. Figure 10 illustrates the correlation between predicted and observed values of the water quality variables for which indicator values were inferred, based on epilithic and epipelic taxa.

Weighted-average optima and tolerances for diatom species in the epilithon and epipelon are listed in Table 26. For each species the maximum relative abundance (Max) and the number of effective occurrences (N_2) in the epilithon and epipelon are also listed. Optima of species with a low Max and N_2 are to be interpreted with caution. These species were included in the model since the RMSE increased when rare species (maximum relative abundance between 1% and 5%) were omitted. The tolerance values for each species are a measure of the ecological amplitude (Ter Braak and Looman, 1995).

Variability in observed and diatom inferred water quality assessment

The temporal variability of water quality variables can be assessed with a coefficient of variation, CV (Sokal and Rohlf, 1981). The CV is the standard deviation expressed as a percentage of the mean. When the CV of the observed water quality variables is plotted against the CV of the diatom-inferred variables, it is possible to visualise which method assesses a water quality variable with the lowest variability (Figure 11 a and b). The diatom inferred values had a significantly lower variability than the observed values ($n = 31$, $p < 0.02$). The CV's of nitrite/nitrate and phosphate are an order of magnitude higher than for the other variables.

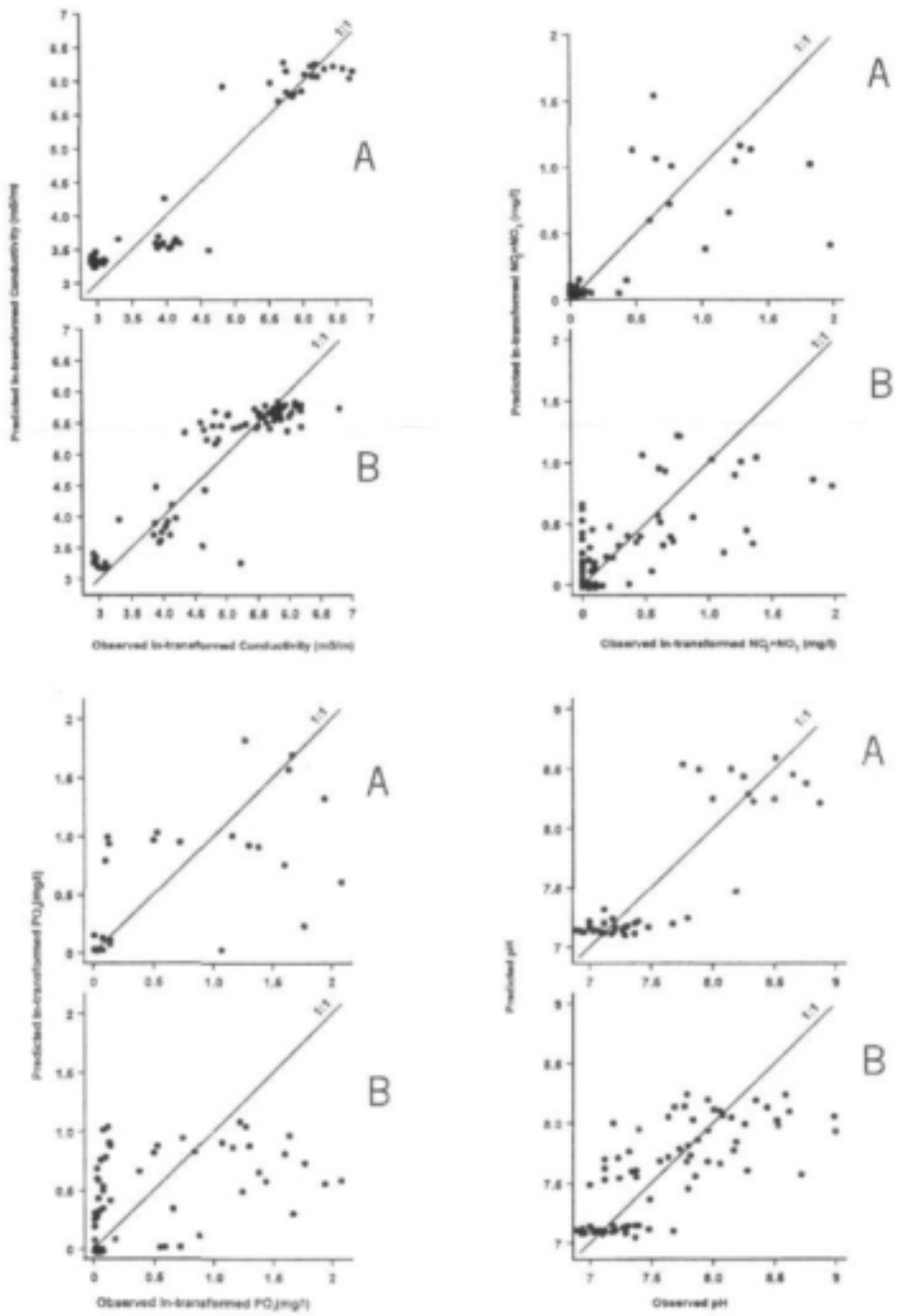

Figure 10. Correlation between observed and diatom inferred (predicted) values for conductivity, NO_2+NO_3, PO_4 and pH. A: based on epilithic taxa. B: based on epipelic taxa

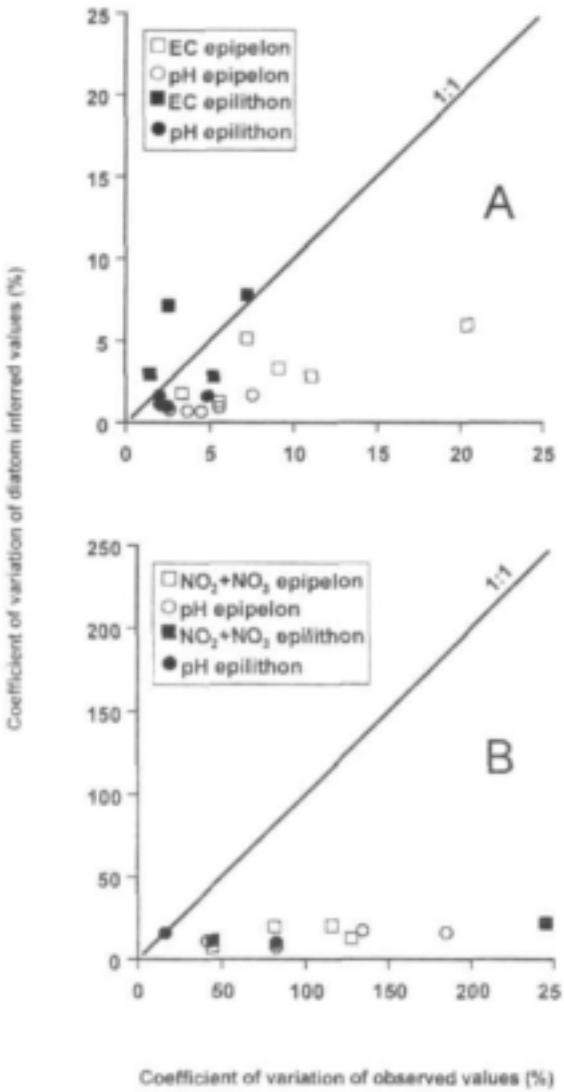

Figure 11. Coefficient of variation (%) of observed vs. diatom inferred water quality values. A: variables EC (conductivity) and pH in epilithon and epipelon. B: variables NO_2+NO_3 and PO_4 in epilithon and epipelon. Note the difference in scale.

Table 26. The maximum percent abundance (max), effective number of occurrences (Hill's N_2) and optima and tolerances for WA transfer functions for conductivity (mS/m), NO_2+NO_3 (mg l^{-1}), PO_4 (mg l^{-1}) and pH for diatom species in epilithon and epipelon in the Swartkops River. * represent zero abundance in respective habitat.

	epilithon										epipelon									
	Max	N_2	Conductivity		NO_2+NO_3		PO_4		pH		Max	N_2	Conductivity		NO_2+NO_3		PO_4		pH	
Acronym			Opt	Tol	Opt	Tol	Opt	Tol	Opt	Tol			Opt	Tol	Opt	Tol	Opt	Tol	Opt	Tol
ACHNABUN	33.6	18.5	24.48	0.67	0.05	0.09	0.028	0.017	7.3	0.2	8.6	21.1	32.98	1.22	0.04	0.07	0.078	0.327	7.2	0.2
ACHNAMOE	5.6	1.9	339.19	0.04	*	1.12	3.114	0.299	6.9	0.2	1.6	7.2	235.70	0.90	0.65	0.60	1.307	0.921	7.4	0.5
ACHNDELI	12.7	10.3	386.84	0.68	0.43	0.73	2.763	1.109	7.5	0.7	7.3	24.6	309.23	0.64	0.80	0.87	1.695	1.056	7.6	0.6
ACHNENGE	46.5	16.3	228.87	1.68	0.29	0.55	1.595	1.328	7.5	0.7	15.2	52.3	171.31	1.31	0.34	0.55	0.580	0.914	7.7	0.6
ACHNENla	*	*	*	*	*	*	*	*	*	*	3.8	9.1	240.87	0.54	0.28	0.37	1.058	1.039	7.5	0.5
ACHNEXIG	7.4	11.0	206.02	1.27	0.19	0.56	2.040	1.412	7.2	0.5	11.9	41.2	123.29	1.31	0.20	0.40	0.408	0.863	7.5	0.6
ACHNHUNG	*	*	*	*	*	*	*	*	*	*	12.8	23.3	223.51	0.90	0.25	0.44	0.504	0.686	7.8	0.5
ACHNMICR	21.0	21.6	35.17	0.80	0.07	0.11	0.026	0.020	7.2	0.2	7.4	21.4	48.05	1.14	0.10	0.14	0.052	0.219	7.2	0.3
ACHNMINU	67.6	26.4	33.53	0.91	0.08	0.28	0.042	0.135	7.2	0.2	13.4	36.2	51.24	1.58	0.09	0.22	0.139	0.473	7.3	0.4
ACHNABLO	35.4	24.3	34.32	0.89	0.07	0.12	0.026	0.020	7.2	0.2	9.1	31.3	54.92	1.28	0.09	0.17	0.074	0.270	7.3	0.4
AMRACOFF	3.4	5.2	584.64	0.57	0.95	0.39	0.298	0.354	8.4	0.3	17.5	14.0	311.65	0.77	0.84	0.69	0.375	0.590	8.0	0.5
AMRAHELE	15.4	1.9	338.92	0.04	*	1.14	3.089	0.299	6.9	0.2	6.9	7.9	312.12	0.23	0.65	0.70	2.143	0.734	7.3	0.4
AMRANORM	*	*	*	*	*	*	*	*	*	*	4.2	14.1	110.23	2.12	0.14	0.39	0.860	1.019	7.2	0.3
AMRASUBT	*	*	*	*	*	*	*	*	*	*	19.3	15.4	336.61	0.44	0.59	0.90	2.192	0.889	7.4	0.6
BALAPARA	*	*	*	*	*	*	*	*	*	*	20.4	23.5	208.60	0.74	0.37	0.55	0.937	0.941	7.5	0.5
BRACBREB	10.9	22.4	37.44	0.98	0.07	0.14	0.030	0.022	7.2	0.3	13.9	21.8	39.32	1.00	0.06	0.11	0.036	0.090	7.2	0.2
CCNEPLAC	1.8	6.1	283.06	1.43	0.19	0.48	2.663	1.391	7.2	0.5	2.1	18.5	277.27	1.00	0.50	0.78	0.897	1.095	7.8	0.6
CYMBMIC1	14.2	19.2	25.64	0.83	0.05	0.14	0.030	0.022	7.3	0.2	7.2	17.7	29.38	1.23	0.04	0.11	0.054	0.230	7.2	0.2
CYMBOAHU	4.8	12.5	390.08	0.92	0.71	0.87	1.375	1.119	7.8	0.8	11.5	19.4	294.30	0.69	0.95	0.90	1.121	0.974	7.8	0.6
DINEELLI	2.1	5.3	54.07	0.66	0.06	0.06	0.017	0.009	7.2	0.3	6.3	18.0	73.17	1.09	0.10	0.15	0.045	0.099	7.3	0.5
DINEPUEL	*	*	*	*	*	*	*	*	*	*	22.0	27.1	176.22	0.79	0.33	0.47	0.517	0.757	7.7	0.6
ENCYMINU	1.1	4.2	395.63	0.65	1.27	1.38	1.179	1.245	8.0	0.6	6.0	19.4	236.82	0.75	0.54	0.65	1.356	1.050	7.5	0.5
ENCYSILE	1.5	12.6	24.79	0.93	0.03	0.04	0.105	0.430	7.2	0.2	2.8	12.4	26.01	1.07	0.02	0.04	0.027	0.015	7.3	0.2
ENTOALAT	1.4	1.6	580.32	0.96	1.17	1.07	0.858	2.942	7.9	1.0	20.9	14.1	327.26	0.30	1.04	0.67	1.249	0.994	7.7	0.5
EUTIIMPL	9.6	8.1	20.03	0.39	0.04	0.04	0.027	0.017	7.2	0.2	1.1	10.1	35.17	1.36	0.03	0.05	0.148	0.548	7.3	0.2
FALATERA	6.8	12.3	405.99	0.87	1.46	0.84	1.402	0.988	8.0	0.6	39.7	39.4	283.35	0.75	0.83	0.78	0.850	0.829	7.8	0.5
FALEUMPA	29.4	7.8	267.24	0.93	0.06	0.34	3.163	1.018	7.1	0.4	6.3	15.8	259.84	0.50	0.28	0.49	1.755	1.231	7.5	0.6
FRAGELLI	31.0	10.3	163.96	1.98	0.08	0.19	1.853	1.549	7.2	0.4	46.8	37.4	183.45	1.14	0.34	0.56	0.770	1.027	7.6	0.5
GONEACUM	*	*	*	*	*	*	*	*	*	*	1.8	10.1	45.06	2.54	0.05	0.10	0.186	0.528	7.4	0.4
GONEPAR1	2.6	15.8	156.20	2.65	0.73	0.75	0.587	0.822	7.8	0.7	3.4	34.7	161.41	1.66	0.66	0.79	0.677	0.895	7.6	0.5
GONEPAR3	4.1	16.0	27.13	0.69	0.04	0.07	0.027	0.020	7.2	0.2	3.9	15.9	38.75	1.50	0.11	0.29	0.101	0.357	7.2	0.2
GYROACUM	*	*	*	*	*	*	*	*	*	*	6.1	28.4	90.11	1.70	0.12	0.32	0.218	0.553	7.4	0.5

	epilithon										epipelon									
	Max	N_2	Conductivity		NO_2+NO_3		PO_4		pH		Max	N_2	Conductivity		NO_2+NO_3		PO_4		pH	
Acronym			Opt	Tol	Opt	Tol	Opt	Tol	Opt	Tol			Opt	Tol	Opt	Tol	Opt	Tol	Opt	Tol
MAGLELda	*	*	*	*	*	*	*	*	*	*	4.3	3.9	17.76	0.05	0.07	0.05	0.027	0.019	7.3	0.1
MAGLELLI	1.6	3.7	17.62	0.02	0.07	0.05	0.017	0.012	7.2	0.1	16.2	9.7	22.98	0.84	0.04	0.04	0.024	0.013	7.3	0.2
NAVICIle	1.9	4.2	271.63	1.53	1.23	0.86	1.369	0.979	8.0	0.5	45.9	19.6	263.07	1.19	0.74	0.72	0.689	0.720	7.8	0.5
NAVICLOA	1.9	2.6	21.10	0.04	0.01	0.03	0.023	0.005	7.5	0.3	1.3	6.6	19.87	0.09	0.03	0.04	0.032	0.016	7.4	0.2
NAVICONF	4.5	3.6	115.45	1.89	0.04	0.04	0.786	1.799	7.5	0.5	32.2	17.6	184.29	1.20	0.13	0.38	1.128	1.427	7.5	0.5
NAVICRCE	*	*	*	*	*	*	*	*	*	*	1.3	6.4	169.14	0.74	0.24	0.26	0.325	0.844	7.9	0.6
NAVICRex	6.8	11.8	365.61	1.20	1.31	0.80	1.052	0.974	8.1	0.6	12.3	49.1	238.39	1.01	0.49	0.67	0.682	0.867	7.8	0.5
NAVIFRUG	19.0	5.0	377.99	0.59	2.30	0.70	2.298	0.633	8.2	0.6	*	*	*	*	*	*	*	*	*	*
NAVIGREG	15.5	15.8	60.58	0.83	0.10	0.15	0.070	0.309	7.2	0.4	72.0	48.9	102.02	1.45	0.21	0.36	0.226	0.556	7.5	0.6
NAVILEPT	47.5	17.8	25.78	0.74	0.03	0.05	0.067	0.327	7.3	0.2	39.0	19.6	29.54	1.06	0.05	0.12	0.036	0.118	7.2	0.2
NAVIHUca	1.4	2.0	780.88	0.10	1.38	0.30	0.145	0.007	8.2	0.1	14.0	23.3	254.39	0.69	0.68	0.63	1.085	0.886	7.6	0.5
NAVIMOLL	21.5	10.9	388.36	1.70	1.34	0.82	0.568	0.736	8.4	0.6	1.1	23.9	279.11	0.84	0.84	0.70	0.879	0.756	7.8	0.5
NAVIPERI	*	*	*	*	*	*	*	*	*	*	2.7	10.3	25.29	1.04	0.05	0.08	0.025	0.018	7.2	0.2
NAVIPHYL	43.1	11.9	431.81	1.52	1.52	0.72	0.643	0.810	8.3	0.6	36.6	21.6	345.09	0.72	1.23	0.72	0.825	0.866	8.0	0.5
NAVIPSHA	*	*	*	*	*	*	*	*	*	*	32.5	13.6	173.69	1.27	0.13	0.30	0.256	0.404	7.8	0.6
NAVIPUPU	*	*	*	*	*	*	*	*	*	*	6.7	12.4	29.89	1.38	0.05	0.10	0.039	0.082	7.3	0.2
NAVISCHR	1.3	3.3	171.57	3.62	0.42	0.34	0.105	0.068	7.8	0.6	1.8	12.3	173.83	0.66	0.48	0.51	0.398	0.693	7.8	0.5
NAVISELU	12.1	7.1	150.88	2.46	0.07	0.22	1.395	1.383	7.2	0.4	11.2	23.9	130.62	1.15	0.17	0.35	0.249	0.612	7.7	0.5
NAVITELO	1.0	4.4	324.94	2.75	0.56	0.43	0.299	0.793	8.0	0.9	20.7	13.4	196.22	0.70	0.24	0.47	0.516	0.848	7.7	0.4
NAVIVAND	*	*	*	*	*	*	*	*	*	*	13.0	12.3	33.09	1.54	0.04	0.09	0.031	0.026	7.3	0.3
NAVIVIli	*	*	*	*	*	*	*	*	*	*	4.7	23.3	200.42	0.78	0.20	0.43	0.442	0.760	7.9	0.5
NAVIVIro	4.1	3.0	120.97	2.25	0.29	0.26	0.209	0.729	7.8	0.6	14.8	30.8	105.39	1.53	0.20	0.35	0.247	0.717	7.6	0.6
NITZCAPI	*	*	*	*	*	*	*	*	*	*	27.8	18.0	293.21	0.72	0.62	0.59	0.504	0.644	8.0	0.6
NITZCLAU	3.2	2.7	50.26	0.47	0.05	0.08	0.025	0.006	7.0	0.2	4.2	12.3	38.78	1.07	0.03	0.04	0.028	0.017	7.1	0.2
NITZDESE	17.9	13.9	415.13	0.86	1.80	0.77	1.226	0.809	8.2	0.5	28.6	27.9	314.42	0.80	1.24	0.80	0.954	0.804	7.9	0.5
NITZELal	68.6	10.0	227.35	2.33	1.47	0.95	0.960	0.722	8.1	0.6	8.4	18.0	321.50	0.59	1.23	0.67	0.805	0.701	8.0	0.5
NITZFILI	7.5	5.6	122.52	1.31	0.23	0.30	0.169	0.396	7.6	0.7	8.2	33.3	145.22	1.11	0.22	0.40	0.366	0.762	7.6	0.6
NITZFONT	6.2	21.7	111.21	2.89	0.50	0.78	0.404	0.803	7.5	0.7	6.6	36.1	143.42	1.88	0.61	0.75	0.423	0.667	7.6	0.6
NITZFRUS	79.7	25.2	296.05	1.75	0.87	0.83	1.141	1.052	7.9	0.7	26.5	47.5	241.23	0.81	0.65	0.72	0.719	0.863	7.8	0.5
NITZGRAC	3.3	6.0	128.30	2.28	0.88	1.64	0.707	1.118	7.6	0.8	11.5	28.7	155.90	1.17	0.37	0.56	0.233	0.548	7.8	0.6
NITZMICE	9.8	19.5	66.11	2.03	0.05	0.12	0.598	1.257	7.1	0.3	11.7	40.0	76.18	2.08	0.13	0.35	0.262	0.681	7.4	0.5
NITZNANA	*	*	*	*	*	*	*	*	*	*	1.8	8.8	90.86	1.20	0.05	0.05	0.094	0.215	7.5	0.5
NITZPALE	25.6	16.1	144.59	2.34	0.71	0.98	0.854	1.074	7.5	0.6	35.6	49.3	149.40	1.74	0.37	0.55	0.384	0.673	7.7	0.6
NITZPACE	5.1	8.8	117.47	1.96	0.36	0.83	0.483	0.890	7.6	0.6	14.3	30.6	103.44	1.65	0.16	0.34	0.192	0.583	7.6	0.5
NITZPAAE	1.4	2.6	387.23	0.25	2.20	0.97	1.680	0.779	8.3	0.5	7.5	12.2	101.80	2.16	0.33	0.55	0.290	0.629	7.8	0.6

	epilithon										epipelon									
	Max	N_2	Conductivity		NO_2+NO_3		PO_4		pH		Max	N_2	Conductivity		NO_2+NO_3		PO_4		pH	
Acronym			Opt	Tol	Opt	Tol	Opt	Tol	Opt	Tol			Opt	Tol	Opt	Tol	Opt	Tol	Opt	Tol
NITZRECT	*	*	*	*	*	*	*	*	*	*	6.5	4.8	138.09	1.00	0.18	0.21	0.126	0.397	7.7	0.7
NITZSIGM	*	*	*	*	*	*	*	*	*	*	2.7	13.4	238.99	0.84	0.27	0.54	1.064	1.160	7.7	0.7
NITZSOLI	13.2	8.7	351.83	1.14	1.74	0.87	1.164	0.698	8.3	0.6	15.6	31.2	287.07	0.75	0.62	0.74	0.653	0.734	8.0	0.5
PLACELGI	*	*	*	*	*	*	*	*	*	*	10.7	8.2	27.41	1.29	0.07	0.17	0.076	0.188	7.4	0.2
PLACSP01	*	*	*	*	*	*	*	*	*	*	21.6	14.0	317.78	0.75	1.59	0.81	1.096	0.796	7.9	0.4
RHOPGIBA	*	*	*	*	*	*	*	*	*	*	10.1	7.7	31.88	1.98	0.04	0.04	0.054	0.132	7.3	0.4
STNEPACH	*	*	*	*	*	*	*	*	*	*	1.4	9.6	25.49	1.02	0.05	0.09	0.026	0.017	7.3	0.2
SYNERUMP	5.1	5.5	133.09	3.54	0.81	0.83	0.239	0.296	7.6	0.5	*	*	*	*	*	*	*	*	*	*
SYNETABU	39.8	7.0	516.75	0.47	2.05	0.95	1.031	0.919	8.3	0.5	24.4	30.5	281.20	0.67	0.68	0.85	0.921	0.936	7.9	0.6
SYNETENE	6.5	17.6	31.81	0.80	0.07	0.10	0.025	0.017	7.2	0.2	2.8	15.2	40.14	1.59	0.07	0.21	0.077	0.272	7.3	0.3
SYNEULNA	21.7	4.8	47.55	0.73	0.11	0.10	0.021	0.029	7.2	0.2	5.5	24.8	75.39	1.96	0.10	0.23	0.299	0.706	7.5	0.5
TABEFENE	1.1	8.4	18.29	0.07	0.04	0.04	0.025	0.017	7.2	0.2	8.8	8.7	20.90	0.55	0.03	0.04	0.026	0.014	7.2	0.2
TABEFLOC	2.8	5.9	24.25	0.69	0.06	0.07	0.025	0.013	7.2	0.2	3.6	7.9	25.42	0.91	0.04	0.05	0.023	0.011	7.2	0.2
TRYBANGU	*	*	*	*	*	*	*	*	*	*	11.1	9.4	255.62	0.56	0.53	0.49	0.735	0.920	7.7	0.6
TRYBCONS	5.3	4.8	477.66	0.93	1.59	0.76	0.718	1.011	8.1	0.3	17.3	23.5	292.15	0.62	0.89	0.64	0.443	0.613	8.1	0.5
TRYBLEVI	*	*	*	*	*	*	*	*	*	*	1.4	16.9	137.80	1.13	0.42	0.54	0.330	0.631	7.6	0.5

Discussion

The range of water quality in which diatoms were studied in the Swartkops River was extensive. As a result, the composition of the diatom assemblages changed considerably over the length of the river. These assemblages remained relatively constant throughout the two years of the survey (a seasonal pattern in the diatom distribution data could not be found). This is not surprising for a region with low seasonal variation in temperature and rainfall (Stone, 1988). During relatively high flow conditions, water column nutrient concentrations tended to decrease. The stress on the assemblages as a result of these higher flow conditions was likely to be a nutrient stress rather than a physical stress (Biggs, 1995) since on only one occasion the species diversity was decreased significantly in the epipelon, possibly due to scouring.

Microhabitats were distinctly sampled during this study to investigate the within and between habitat variation of the assemblages along an environmental gradient. The variation in the epilithic diatom assemblages was better explained by the measured water quality variables than in the epipelon. Stones in rivers are generally associated with currents that provide the attached assemblages with a better nutrient exchange than the epipelon (Cattaneo *et al.*, 1997). Substrates from which epipelic diatoms were sampled are generally found at places in the river where sedimentation dominates. The sediment is enriched by seston deposition (Cattaneo *et al.*, 1997) and the sediment composition is therefore a reflection of the water quality over a longer period of time. Conductivity, pH and nutrients had a significant effect on the distribution of the epipelic diatoms, but the WA calibration and regression models only performed well for conductivity. The epipelic diatoms therefore seem to indicate general trends of enrichment (conductivity) but less specific for components that vary erratically (such as nutrients and pH). A similar observation has been made in the Olifants River where epilithic diatoms recovered more quickly downstream from a source of pollution than did the diatoms in the epipelon (see next section). Gaining or influent streams receive water from groundwater. Losing or effluent streams lose water into the ground. This has an effect on bottom dwelling biota. The Swartkops River is a gaining stream especially under low flow conditions (Maclear, 1996).

Conductivity was the most important water quality variable affecting the distribution of diatom taxa in the epilithon and the epipelon. Biggs (1995) suggested that conductivity could be used as a surrogate for enrichment because the major ions that it represents (as also shown in this study where variables Ca, Cl, conductivity, K, Mg, Na, SO_4, alkalinity and TDS were strongly correlated with each other) are not subject to the same rapid biological processes as nitrogen and phosphorus. Nitrogen and phosphorus can be taken up quickly by periphyton in shallow streams (e.g. Borchardt, 1996); therefore their concentrations in the water column do not reflect enrichment. Correlation between the taxonomic composition of periphyton and conductivity has been shown by other researchers (e.g. Biggs, 1990 and O'Connell *et al.*, 1997). Using epiphytic diatoms on *Cladophora* from the St. Lawrence River, Canada, O'Connell *et al.* (1997) developed a regression and calibration model for conductivity (jackknifed r^2 (r^2_{jack}) = 0.24). Pan and Stevenson (1996) reported an apparent r^2 of 0.65 (r^2_{jack} of 0.03) for their model based on epiphytic diatoms in western Kentucky wetlands, USA. The models developed for epilithic and epipelic diatom taxa in the Swartkops River performed considerably better (r^2_{jack} = 0.91 (epilithon); r^2_{jack} = 0.81 (epipelon)). This might be a result of the broader range of conductivity that was observed in the Swartkops River (reference and impacted sites were sampled) and the frequent intervals at which samples were taken.

Models for nitrite/nitrate, pH and phosphate performed reasonably with epilithic diatoms but poorly with epipelic diatoms. Upstream from station F, a patch of water hyacinth completely covered the water surface. Measurements up- and downstream from this patch indicated that the hyacinths removed large amounts of the nitrogen in the water column, but phosphate concentration remained high. This is an indication that the periphyton might have been nitrogen limited. The high values of phosphate could therefore have been a confusing factor in the model since the nitrogen limitation rather than the high levels of (redundant) phosphate affected the assemblage composition. The model for total phosphorus developed by Pan *et al.* (1996) for streams in the Atlantic Highland region, USA, showed poor performance (apparent r^2 = 0.63 and r^2_{jack} = 0.27). For phosphate this study showed an apparent r^2 of 0.66 and an r^2_{jack} of 0.56. The variation in nutrient concentration is often large (this study; Chambers *et al.*, 1992; France and Peters, 1992), much larger than for conductivity or pH (this study; Cattaneo and Prairie, 1995). Large variation is often given as the reason why regression calibration models perform poorly in cross-validation (e.g. Pan *et al.*, 1996; O'Connel, 1997).

The variation in diatom inferred water quality values, was lower than the variation in observed values. The correlation between inferred and observed values was significant for most variables. With this knowledge the suggestion is that diatoms are valuable indicators of water quality that are indicative of time-integrated water quality conditions in the Swartkops River.

EPILITHIC AND EPIPELIC DIATOMS IN RELATION TO WATER QUALITY IN THE UPPER OLIFANTS RIVER, MPUMALANGA.

Introduction

This section deals with the benthic diatom flora of the Olifants River catchment south of the Loskop dam in Mpumalanga, South Africa. Sampling was done in co-operation with the biomonitoring field survey of the National Aquatic Ecosystem Biomonitoring Programme (NAEBP). Although the diatoms are not part of the array of bioindicators used in this programme, the Water Research Commission is interested to know whether diatoms can be useful indicators of water quality. Ultimately it will be possible to compare conditions indicated by the diatoms with those indicated by the biomonitors that are currently in use within the National Aquatic Ecosystem Biomonitoring Programme.

The Study Area

The upper reaches of the Olifants River that were visited during this exercise, lie in a region with a large amount of industry (most of South African's electricity is produced in this region) and mining activities. These activities and the domestic effluents generated by the towns of Middelburg and Witbank have considerable effects on the water quality of the river (Davies and Day, 1998).

During two sampling sessions (22-26 June 1998 and 3-7 August 1998) four streams in the upper reaches of the Olifants River catchment were sampled. These streams were: the Olifants (11 sites), Klein Olifants (5 sites), Wilge (7 sites) and the Bronkhorstspruit (3 sites). The locations of these sites are given in Table 27. Figure 12 illustrates the positioning of the sites along the various streams.

At each site epipelic and epilithic diatoms were sampled, identified and enumerated according to the methods described in the relevant section. The surface area that was scraped from each stone, in order to collect epilithic samples, was kept constant (approximately 50 cm^2). At site O1 no epilithic samples could be taken, since the nature of the stream bead was such that no stones were present.

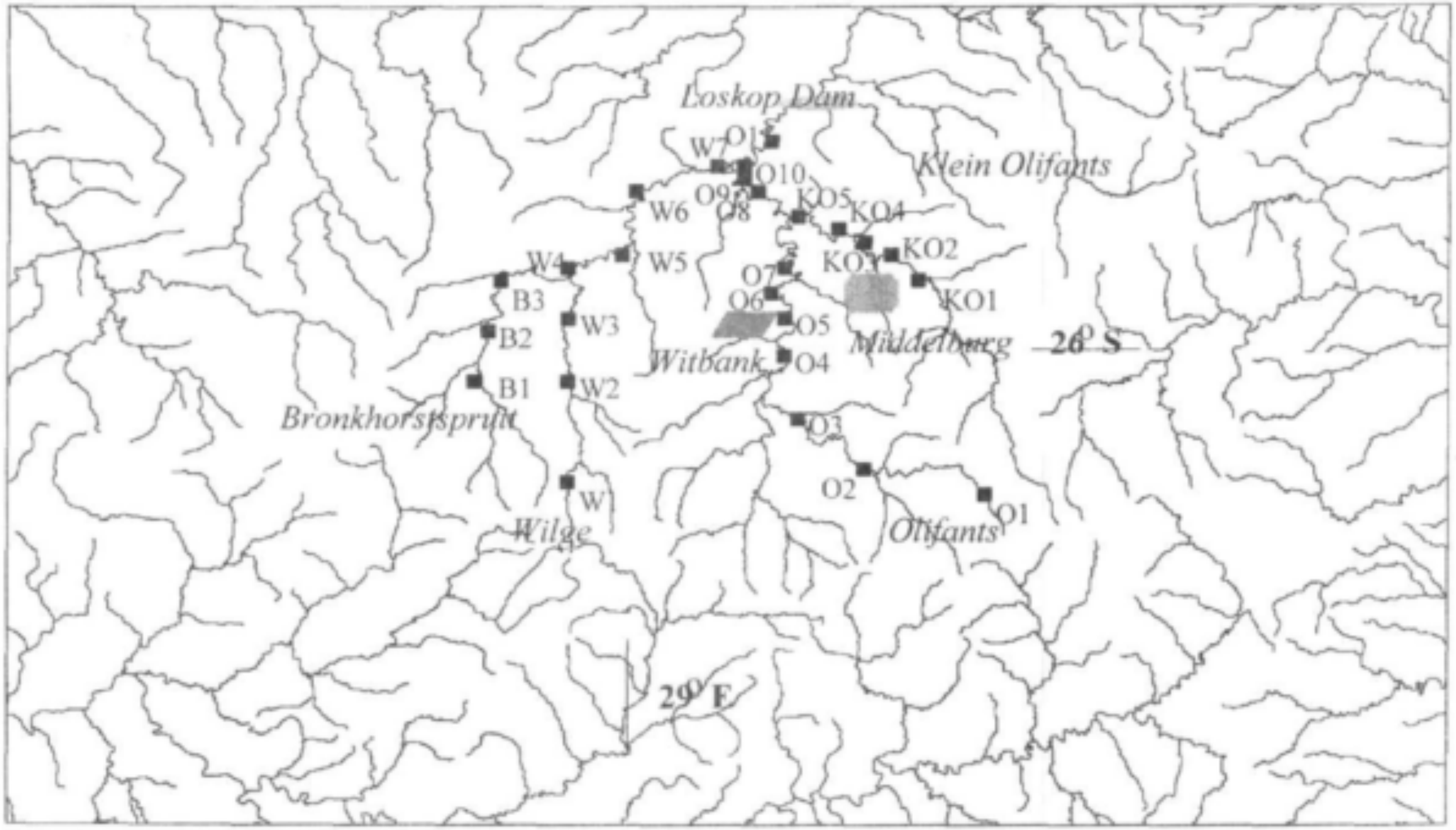

Figure 12. Catchment of the Olifants River south of the Loskop Dam. Sampling sites are indicated in the Olifants (O2-O11), Klein Olifants (KO1-KO5), Wilge (W1-W7) and Bronkhorst (B1-B3) Rivers.

Table 27. Name, location and date of sampling of 26 sites in the Olifants River catchment.

River	Site	Location (latitude, longitude)		Date of sampling
Olifants	O1	S: 26 ° 15 ' 40.6 "	E: 29 ° 41 ' 29.1 "	04-Aug-98
	O2	S: 26 ° 13 ' 11.5 "	E: 29 ° 27 ' 42.9 "	04-Aug-98
	O3	S: 26 ° 06 ' 20.2 "	E: 29 ° 19 ' 20.2 "	04-Aug-98
	O4	S: 25 ° 51 ' 13.4 "	E: 29 ° 17 ' 35.7 "	04-Aug-98
	O5	S: 25 ° 50 ' 28.6 "	E: 29 ° 15 ' 58.3 "	04-Aug-98
	O6	S: 25 ° 47 ' 0.7 "	E: 29 ° 18 ' 35.3 "	03-Aug-98
	O7	S: 25 ° 45 ' 37.5 "	E: 29 ° 19 ' 9.1 "	03-Aug-98
	O8	S: 25 ° 37 ' 24.6 "	E: 29 ° 13 ' 0.3 "	23-Jun-98
	O9	S: 25 ° 35 ' 47.7 "	E: 29 ° 12 ' 28.5 "	23-Jun-98
	O10	S: 25 ° 32 ' 58.0 "	E: 29 ° 13 ' 48.0 "	24-Jun-98
	O11	S: 25 ° 30 ' 54.2 "	E: 29 ° 15 ' 59.9 "	22-Jun-98
Klein Olifants	KO1	S: 25 ° 49 ' 1.4 "	E: 29 ° 35 ' 26.4 "	26-Jun-98
	KO2	S: 25 ° 46 ' 4.9 "	E: 29 ° 29 ' 21.6 "	25-Jun-98
	KO3	S: 25 ° 45 ' 0.7 "	E: 29 ° 27 ' 38.7 "	25-Jun-98
	KO4	S: 25 ° 43 ' 18.0 "	E: 29 ° 26 ' 7.2 "	25-Jun-98
	KO5	S: 25 ° 40 ' 25.7 "	E: 29 ° 19 ' 1.3 "	25-Jun-98
Wilge	W1	S: 26 ° 15 ' 40.6 "	E: 28 ° 50 ' 56.2 "	06-Aug-98
	W2	S: 25 ° 54 ' 7.2 "	E: 28 ° 51 ' 5.2 "	07-Aug-98
	W3	S: 25 ° 45 ' 12.5 "	E: 28 ° 57 ' 44.8 "	07-Aug-98
	W4	S: 26 ° 00 ' 52.3 "	E: 28 ° 52 ' 8.8 "	05-Aug-98
	W5	S: 25 ° 46 ' 50.2 "	E: 28 ° 53 ' 2.9 "	05-Aug-98
	W6	S: 25 ° 37 ' 12.6 "	E: 28 ° 59 ' 57.1 "	05-Aug-98
	W7	S: 25 ° 34 ' 48.1 "	E: 29 ° 9 ' 48.6 "	23-Jun-98
Bronkhorstspruit	B1	S: 26 ° 00 ' 36.3 "	E: 28 ° 40 ' 34.6 "	06-Aug-98
	B2	S: 25 ° 57 ' 9.8 "	E: 28 ° 41 ' 18.0 "	06-Aug-98
	B3	S: 25 ° 49 ' 33.2 "	E: 28 ° 43 ' 14.0 "	06-Aug-98

Results

At the 26 sites in the Olifants River catchment, a total of 46 diatom species were identified. In the epilithon 21 diatom species were found to constitute at least 5% of the diatom communities. In the epipelon this was the case for 40 species. A total of 15 species were found in either habitat. The Appendix lists the names and acronyms (according to Van Dam *et al.*, 1994) of each species.

Species distribution

Figures 13 and 14 illustrate the species distribution along sites of the streams under study in the Olifants River catchment (x-axis) in the epilithon and epipelon respectively. Along the y-axis the species are listed which were abundant at these sites. The height of each bar in the figure corresponds with the relative abundance of each species.

Epilithon

From Figure 13 it is apparent that *Achnanthes minutissima* (ACHNMINU) was common in the epilithon at all sites and most often dominant. *Achnanthes kryophila* (ACHNKRYO) and *Navicula frugalis* (NAVIFRUG) dominated the species composition at site O5. These species were not an important factor at any of the other sites and this in an indication that the conditions at site O5 were quite different.

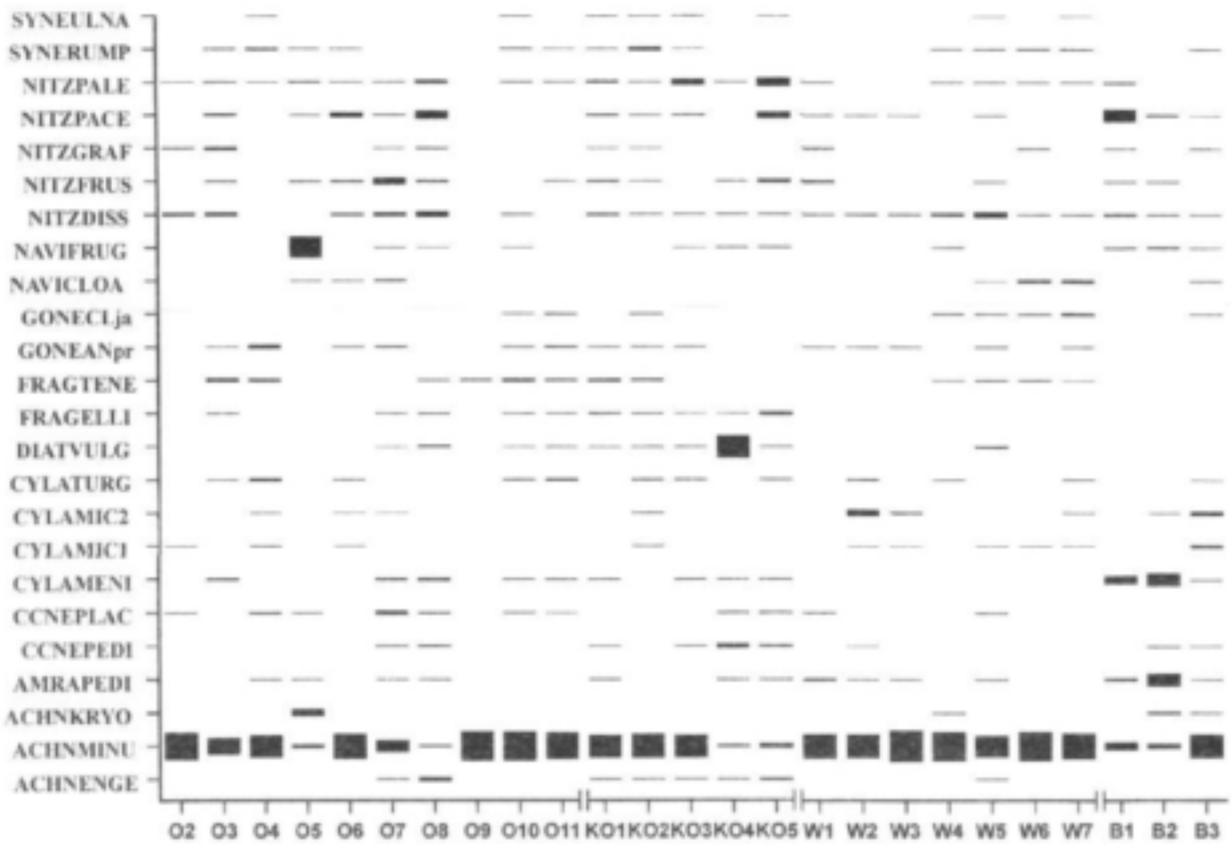

Figure 13. Distribution of epilithic diatoms along the length of the Olifants (O2-O11), Klein Olifants (KO1-KO5), Wilge (W1-W7) and Bronkhorst (B1-B3) Rivers.

Epipelon

The common species in the epipelon (Figure 14) were *Achnanthes minutissima* (ACHNMINU) (although not as dominant as in the epilithon), *Navicula capitatoradiata* (NAVICAPI), *Nitzschia palea* (NITZPALE) and *N. paleacea* (NITZPACE). Site W1 shows a high abundance of *Navicula peregrina* (NAVIPERI) and *N. riperia* (NAVIRIPE), which indicates that the conditions at these sites were quite different since these species are not abundant on any of the other sites.

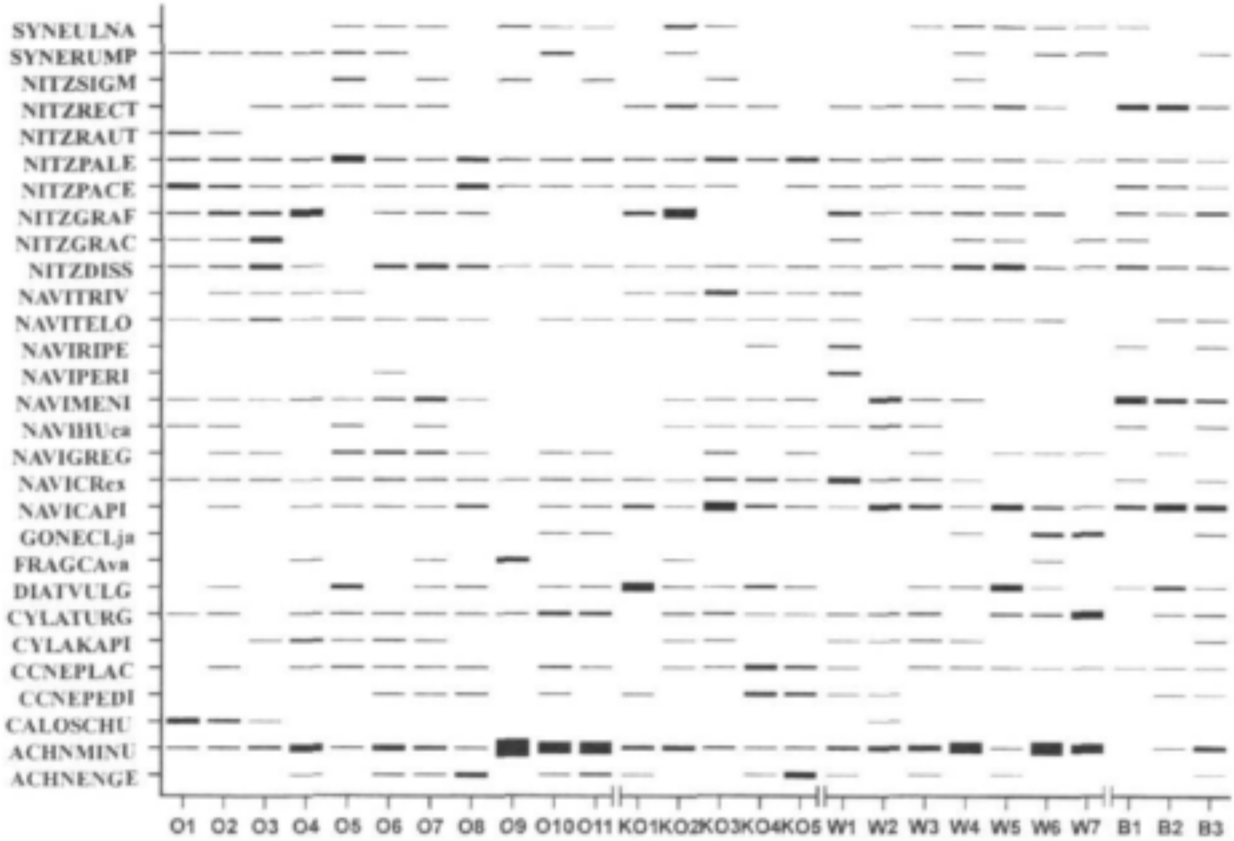

Figure 14. Distribution of epipelic diatoms along the length of the Olifants (O1-O11), Klein Olifants (KO1-KO5), Wilge (W1-W7) and Bronkhorst (B1-B3) Rivers.

DCA

A Detrended Correspondence Analysis (DCA) was conducted to investigate patterns of distribution of epilithic and epipelic diatom taxa. An initial DCA revealed that the epilithic assemblage at site O5 was an outlier. This sample is most probably an outlier because of the high concentrations of phosphate at this site (6.7 mg/l), a clear result from an upstream sewerage water outlet. The epilithic and epipelic assemblages at site O9 were outliers, most probably due to the inflow of water from the Klip River. The Klip River drains an area with heavy mining activity and is therefore low in pH: Site O9 shows a considerably lower pH than upstream sites (Table 28). A subsequent DCA was done on the dataset without these outliers (Figure 15).

What is most noticeable from Figure 15 is the separation between assemblages from the epilithon and epipelon at various sites. This is illustrated for several sites that are outlined in the figure. The distance between consecutive sites (e.g. W6 and W7) is often smaller than the distance between assemblages from separate habitats at the same site. This indicates that the habitat, rather than site differences determine the variation in assemblage composition. To determine distribution patterns between sites, the habitats should be analysed separately.

Water quality

Water quality variables were analysed by the DWAF. Unfortunately, no duplicate sampling results were supplied. The water quality along the length of the Olifants River and some of its tributaries was effected by various sources of nutrients (visible at sites O5 and KO4) and acid mine drainage (gradual decline of pH and alkalinity, especially at site O9).

Correlation between species distribution and water quality

The water quality variables that correlated with the distribution of epilithic and epipelic diatom species were identified with forward selection (Table 29). The variables Ca, Cl, conductivity, Mg, Na, SO_4 and TDS were strongly correlated with each other ($r > 0.85$) and were therefore represented by conductivity. In the epilithon three variables were significant ($p \leq 0.03$) with a fourth variable (phosphate) barely significant ($p \leq 0.1$) (Table 29). In the epipelon a series of six variables was found to correlate significantly with the species distribution ($p \leq 0.05$).

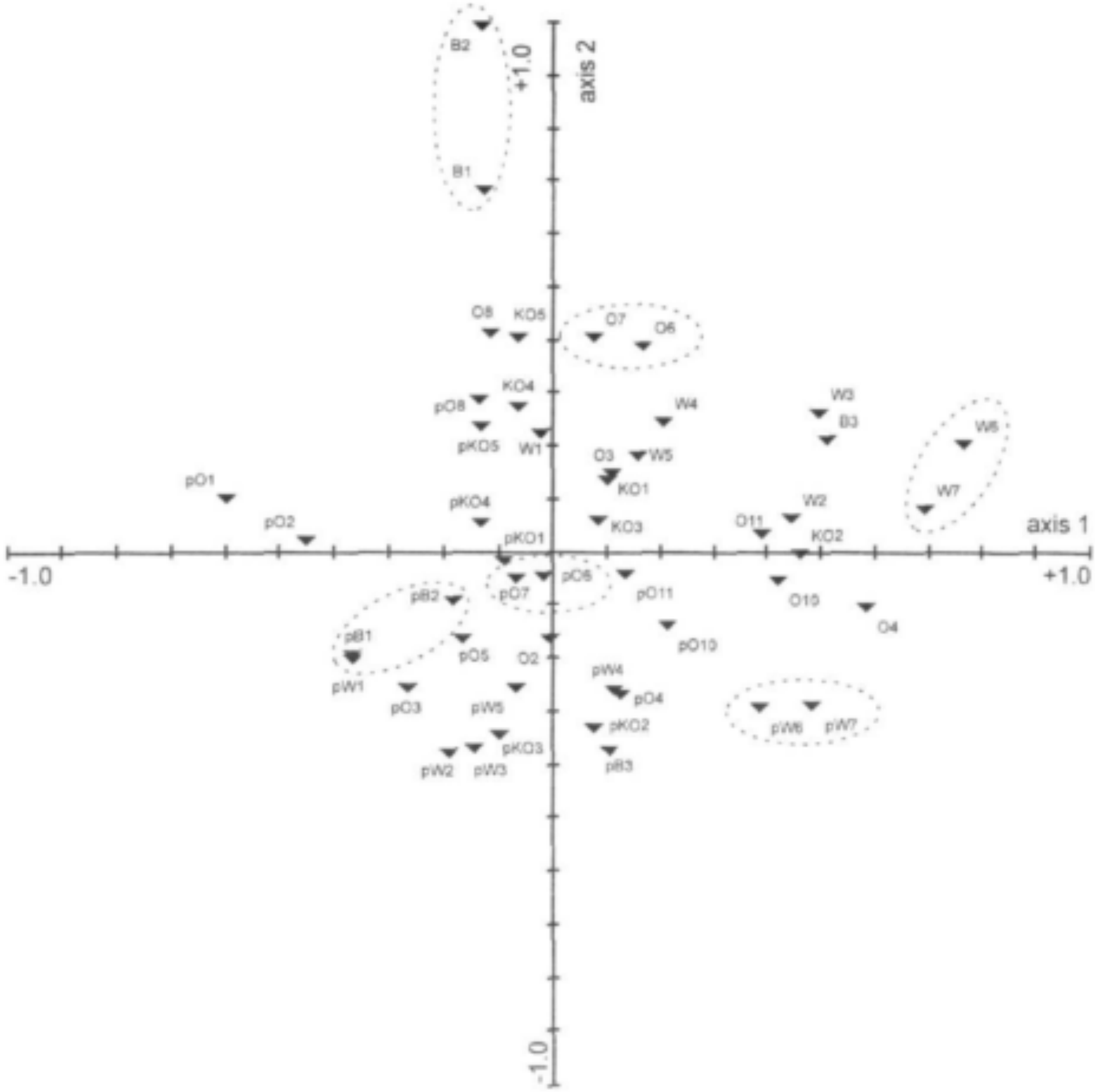

Figure 15. DCA ordination of sites in the catchment of the Olifants River. A 'p' indicates a sample from the epipelon, all other samples from epilithon. Eigenvalues: axis 1 = 0.32; axis 2 = 0.23.

Table 28. Water quality variables measured along the length of the Olifants (O1-O11), Klein Olifants (KO1-KO5), Wilge (W1-W7) and Bronkhorst (B1-B3) Rivers between 22 June 1998 and 7 August 1998.

Sites	Alkalinity (as $CaCO_3$ in $mg.l^{-1}$)	Ca^{2+} ($mg.l^{-1}$)	Cl^- ($mg.l^{-1}$)	Conductivity ($mS.m^{-1}$)	K^+ ($mg.l^{-1}$)	Mg^{2+} ($mg.l^{-1}$)	Na^+ ($mg.l^{-1}$)	NH_4^+ ($mg.l^{-1}$)	$NO_2^-+NO_3^-$ ($mg.l^{-1}$)	pH	PO_4^{3-} ($mg.l^{-1}$)	SiO_2 ($mg.l^{-1}$)	SO_4^{2-} ($mg.l^{-1}$)	TDS ($mg.l^{-1}$)
O1	166	26	39	43.7	2.7	16	45	0.06	0.15	8.79	0.040	4.5	24	356
O2	161	28	<25	40.9	4.4	18	33	<0.04	0.09	8.36	0.048	2.2	33	337
O3	149	112	44	138.5	7.6	85	77	<0.04	0.09	8.52	0.018	0.7	585	1094
O4	106	34	<25	43.7	4.9	20	25	0.05	0.12	7.99	0.005	0.5	106	337
O5	43	41	107	94.6	15.6	23	109	0.45	24.27	6.95	6.679	4.0	157	634
O6	58	94	40	109.4	9.8	66	49	<0.04	4.77	9.36	0.497	0.5	479	832
O7	51	79	40	96.6	8.4	53	43	<0.04	3.60	9.00	0.129	<0.4	398	701
O8	76	35	<25	45.7	6.5	18	28	<0.04	1.73	9.57	0.119	<0.4	130	335
O9	31	53	29	78.4	8.0	21	74	0.27	4.36	7.35	0.013	1.9	266	509
O10	32	47	<25	60.7	5.3	14	52	<0.04	3.38	7.74	0.012	1.8	205	399
O11	44	39	<25	54.4	5.2	14	49	<0.04	1.81	7.78	0.012	1.5	173	364
KO1	103	73	26	91.9	11.8	55	41	<0.04	0.26	8.37	0.008	<0.4	334	667
KO2	65	25	<25	36.2	4.9	17	16	0.10	0.23	8.17	0.014	1.7	93	245
KO3	78	30	<25	40.4	5.0	18	21	<0.04	0.08	9.08	0.007	0.9	111	295
KO4	131	51	47	74.3	15.1	21	68	<0.04	9.59	8.83	2.628	1.4	150	563
KO5	101	34	31	52.9	9.6	16	46	<0.04	2.92	8.97	1.337	<0.4	116	393
W1	358	168	222	299.0	3.8	255	196	<0.04	0.09	8.24	0.008	1.6	1240	2524
W2	129	34	<25	42.2	2.7	22	21	<0.04	0.22	7.72	0.008	3.9	82	333
W3	110	21	<25	26.5	1.7	16	9	0.05	0.41	8.21	0.013	3.5	24	217
W4	78	15	<25	21.6	2.6	12	12	<0.04	0.12	7.65	0.020	1.7	23	170
W5	62	12	<25	18.1	2.1	9	9	<0.04	0.09	8.07	0.000	1.2	21	137
W6	36	34	<25	27.6	2.2	6	9	<0.04	0.14	7.72	0.018	1.7	93	198
W7	41	39	<25	32.4	2.2	7	12	<0.04	0.42	7.92	0.032	3.3	103	222
B1	173	29	<25	39.9	10.8	20	22	0.06	0.15	8.05	1.100	2.6	17	333
B2	144	25	<25	31.6	5.8	18	14	<0.04	0.18	8.42	0.638	4.4	14	269
B3	113	19	<25	25.8	3.8	15	11	<0.04	0.16	7.85	0.007	2.1	15	214

Table 29. Ranking of water quality variables in importance by their conditional effects on the species distribution in epilithon and epipelon as obtained by forward selection. λ_a = increase in eigenvalue; p = significance level of addition (Monte Carlo permutation test).

Variable	λ_a	p
Epilithon		
pH	0.23	0.001
NH_4	0.16	0.036
alkalinity	0.15	0.011
PO_4	0.11	0.098
Epipelon		
alkalinity	0.22	0.001
NO_2+NO_3	0.16	0.005
NH_4	0.13	0.012
PO_4	0.13	0.003
conductivity	0.10	0.043
K	0.11	0.029

Epilithon

The cumulative percentage of variance explained by the environmental variables is 34%. This indicates that there are other (unmeasured) environmental variables that have an important effect on the diatom species distribution. The first two axes (used in the ordination diagram, Figure 16) represent 22.9% of the variance in the species composition and 53.4% in the species-environment relationship (Table 30).

Table 30. Summary of the ordination of epilithic diatom species by CCA.

	Axis 1	Axis 2	Axis 3	Axis 4	Total inertia
Eigenvalues	0.322	0.171	0.136	0.111	2.147
Species-environment correlations	0.928	0.907	0.911	0.915	
Cumulative percentage variance					
of species data	15.0	22.9	29.3	34.4	
of species-environment relation	34.9	53.4	68.1	80.1	
Sum of all unconstrained eigenvalues					2.147
Sum of all canonical eigenvalues					0.923

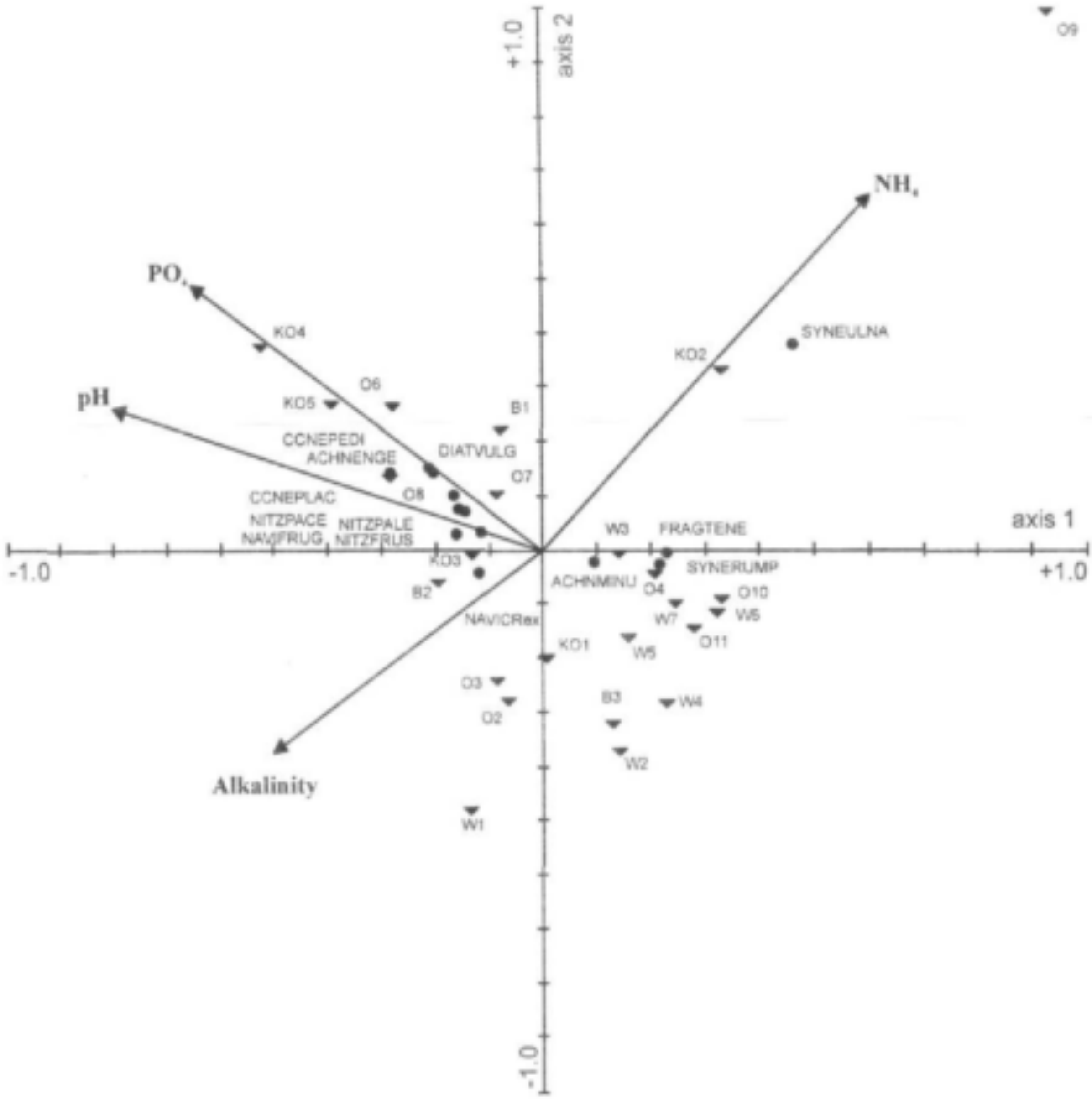

Figure 16. Ordination showing epilithic diatom species (circles), sites (triangles) and water quality variables (arrows) in the catchment of the Olifants River. See Table 30. Species acronyms given in the Appendix.

Along the alkalinity gradient, there is a general trend from upstream sites with naturally high alkalinity (in Wilge, Klein Olifants and Olifants Rivers) towards downstream sites where the influence of acidic sources becomes apparent. The position of site O9 (where the ammonium concentration was 0.27 mg l^{-1} and the pH had dropped sharply) is the consequence of the total dominance of *Achnanthes minutissima* (ACHNMINU) and low species diversity (see also Figure 13).

Epipelon

The cumulative percentage of variance explained by the environmental variables is similar to that in the epilithon (33.5%) (Table 31). The first two axes (used in the ordination diagram) represent 19.5% of the variance in the species composition and 46.8% in the species-environment relationship (Table 31).

Table 31. Summary of the ordination of epipelic diatom species by CCA.

	Axis 1	Axis 2	Axis 3	Axis 4	Total inertia
Eigenvalues	0.230	0.167	0.153	0.132	2.034
Species-environment correlation	0.944	0.903	0.913	0.898	
Cumulative percentage variance					
of species data	11.3	19.5	27.0	33.5	
of species-environment relation	27.1	46.8	64.9	80.4	
Sum of all unconstrained eigenvalues					2.034
Sum of all canonical eigenvalues					0.847

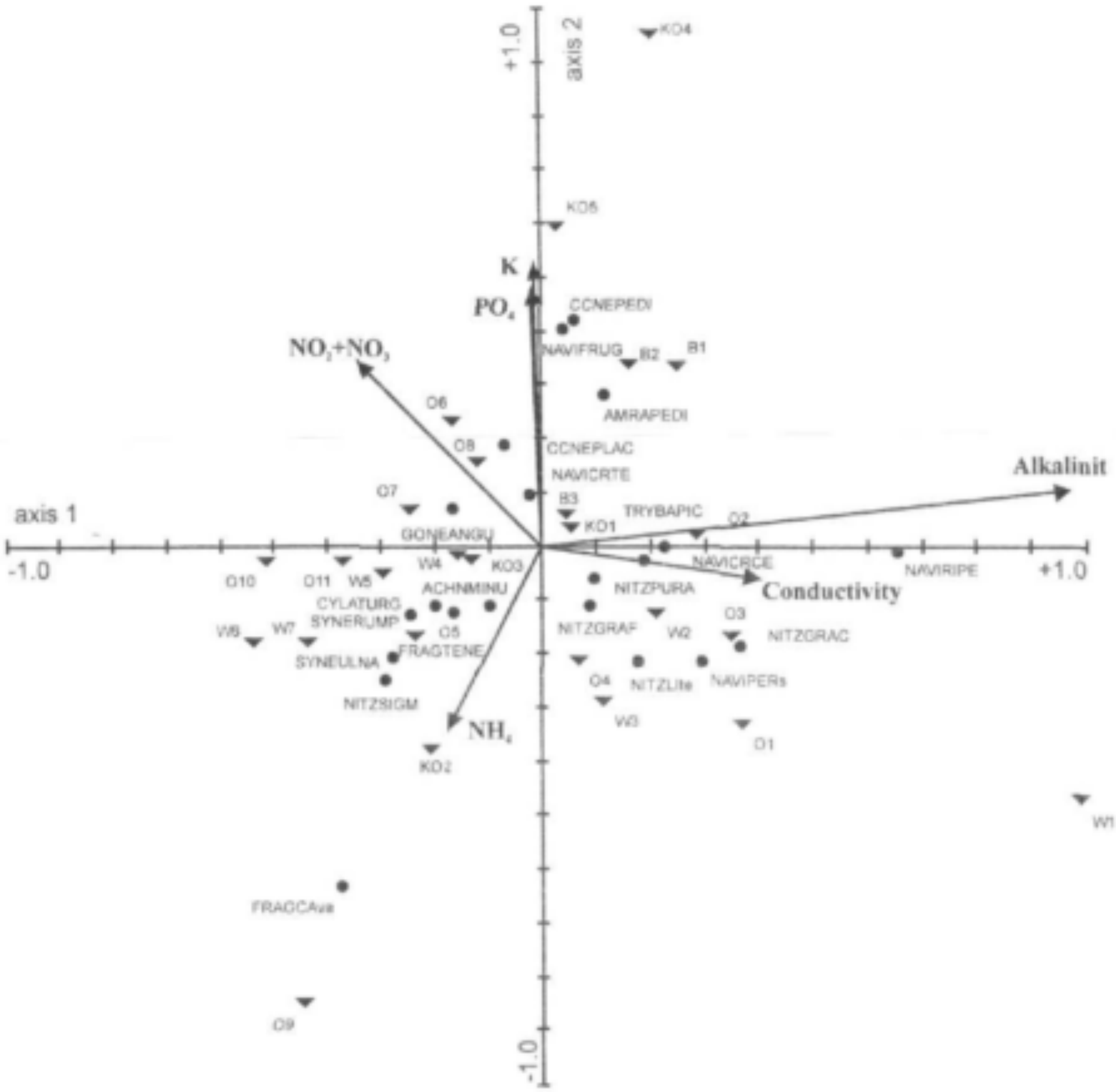

Figure 17. Ordination diagram showing epipelic diatom species (circles), sites (triangles) and water quality variables (arrows) in the catchment of the Olifants River. See Table 31. Species acronyms are given in the Appendix.

There are two groups of water quality variables influencing the species distribution. Axis 1 is highly correlated with alkalinity and conductivity. Axis 2 correlates with various nutrients. A similar trend as in the epilithon is visible along the first axis where upstream sites are at the naturally high alkalinity side of the gradient. The second axis separates the species and sites that are impacted by point sources of nutrients (sewage works outlets).

Weighted-averaging regression and calibration

Weighted-averaging calibration models were developed for the water quality variables that were selected with forward selection (Table 29). For epilithic assemblages the models for pH, ammonium and alkalinity yielded the strongest correlation between observed and predicted values (Table 32).

Table 32. Performance indication of calibration models based on epilithic diatoms in the catchment of the Olifants River. RMSE = root mean square error. r^2 = coefficient of determination of regression between observed and diatom-inferred values. RMSE and r^2 in parentheses derived from jackknifing.

	Epilithon (n=24 sites)			
	inverse		classical	
	RMSE	r^2	RMSE	r^2
pH	0.33	0.66	0.41	0.66
	(0.42)	(0.45)	(0.47)	(0.48)
NH_4	0.02	0.81	0.03	0.81
	(0.05)	(0.22)	(0.04)	(0.44)
alkalinity	0.33	0.69	0.39	0.69
	(0.49)	(0.32)	(0.51)	(0.34)

The inverse regression technique resulted in most instances in slightly lower RMSE and was therefore the preferred model. The decrease in r^2 under cross validation (jackknifing) is a result of the small sample size. There were for instance only 5 sites at which the ammonium concentration was above the detection limit. The assemblage composition at those sites was distinctly different, which illustrates the effect of this variable on the species distribution. If these circumstances were to be observed more frequently, the performance of the model would increase. To illustrate the performance of the present models, the observed values of each water quality variable can be plotted against the predicted (Jackknifed) value at each site. In the theoretical event that both observed and predicted values are the same, the points would be plotted on a 1:1 line. Figure 18 illustrates the correlation between predicted and observed values of the water quality variables for which indicator values were inferred, based on epilithic taxa.

For epipelic diatoms, the models for alkalinity, nitrite/nitrate, ammonium and phosphate yielded the strongest correlation between observed and predicted values (Table 33).

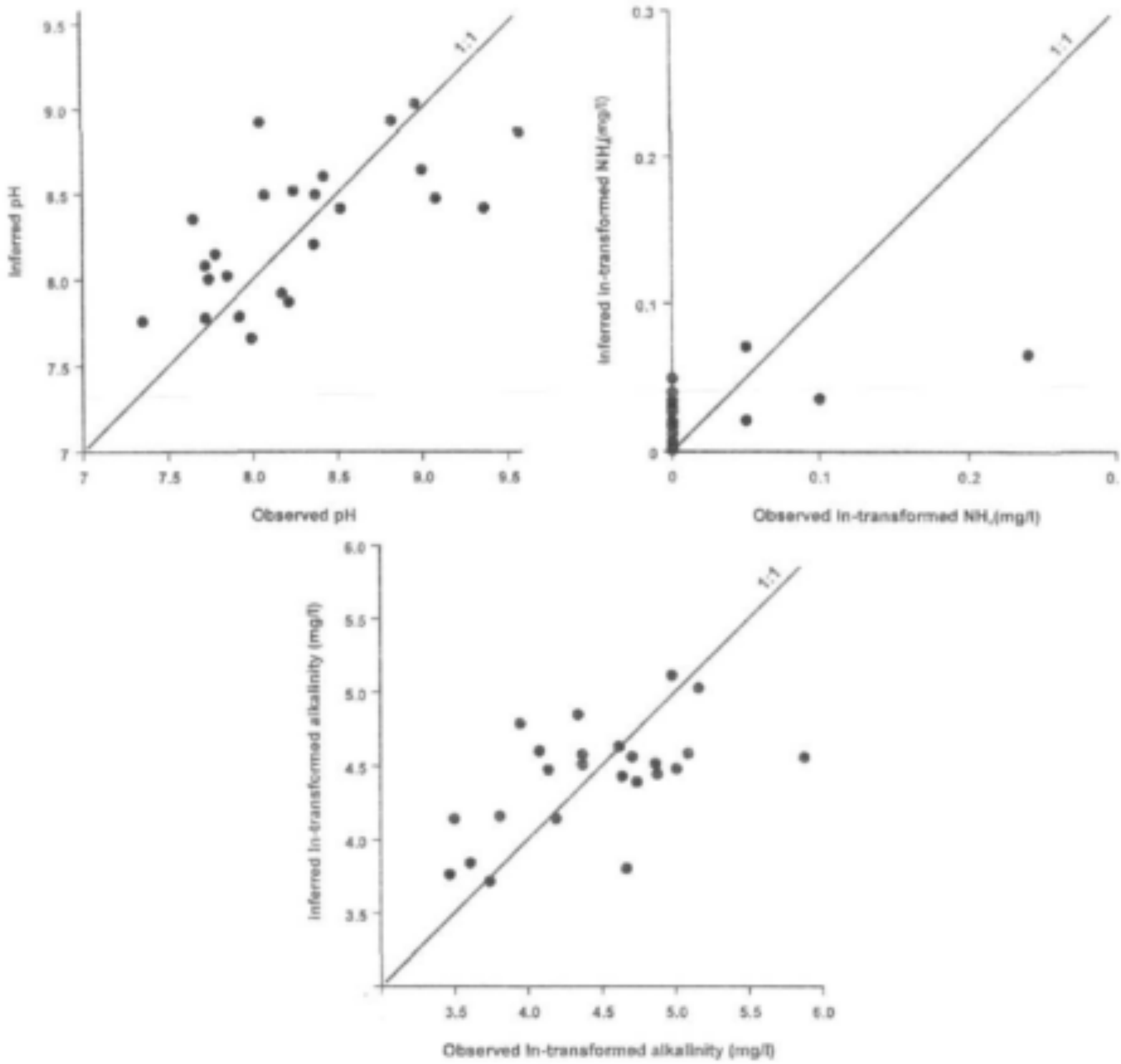

Figure 18. Correlation between observed and diatom inferred (predicted) values for pH, NH_4 and alkalinity based on epilithic diatoms.

Table 33. Performance indication of calibration models based on epipelic diatoms in the catchment of the Olifants River. RMSE = root mean square error. r^2 = coefficient of determination of regression between observed and diatom-inferred values. RMSE and r^2 in parentheses derived from jackknifing.

	Epipelon (n=26 sites)			
	inverse		classical	
	RMSE	r^2	RMSE	r^2
alkalinity	0.22	0.87	0.23	0.87
	(0.36)	(0.64)	(0.35)	(0.65)
NO_2+NO_3	0.39	0.78	0.45	0.78
	(0.72)	(0.26)	(0.74)	(0.28)
NH_4	0.03	0.86	0.03	0.86
	(0.08)	(0.05)	(0.08)	(0.05)
PO_4	0.23	0.77	0.26	0.77
	(0.48)	(0.09)	(0.50)	(0.10)

As with the models based on epilithic diatoms, the inverse regression technique resulted in slightly lower RMSE and was therefore the preferred model. The decrease in r^2 under cross validation (jackknifing) is a result of the small sample size. The performance of the models is illustrated in Figure 19.

Weighted-average optima and tolerances for diatom species in the epilithon and epipelon are listed in Tables 34 and 35. For each species the maximum relative abundance (Max) and the number of effective occurrences (N_2) in the epilithon and epipelon are also listed. Optima of species with a low Max and N_2 are to be interpreted with caution. These species were included in the model since the RMSE increased when rare species (maximum relative abundance between 1% and 5%) were omitted.

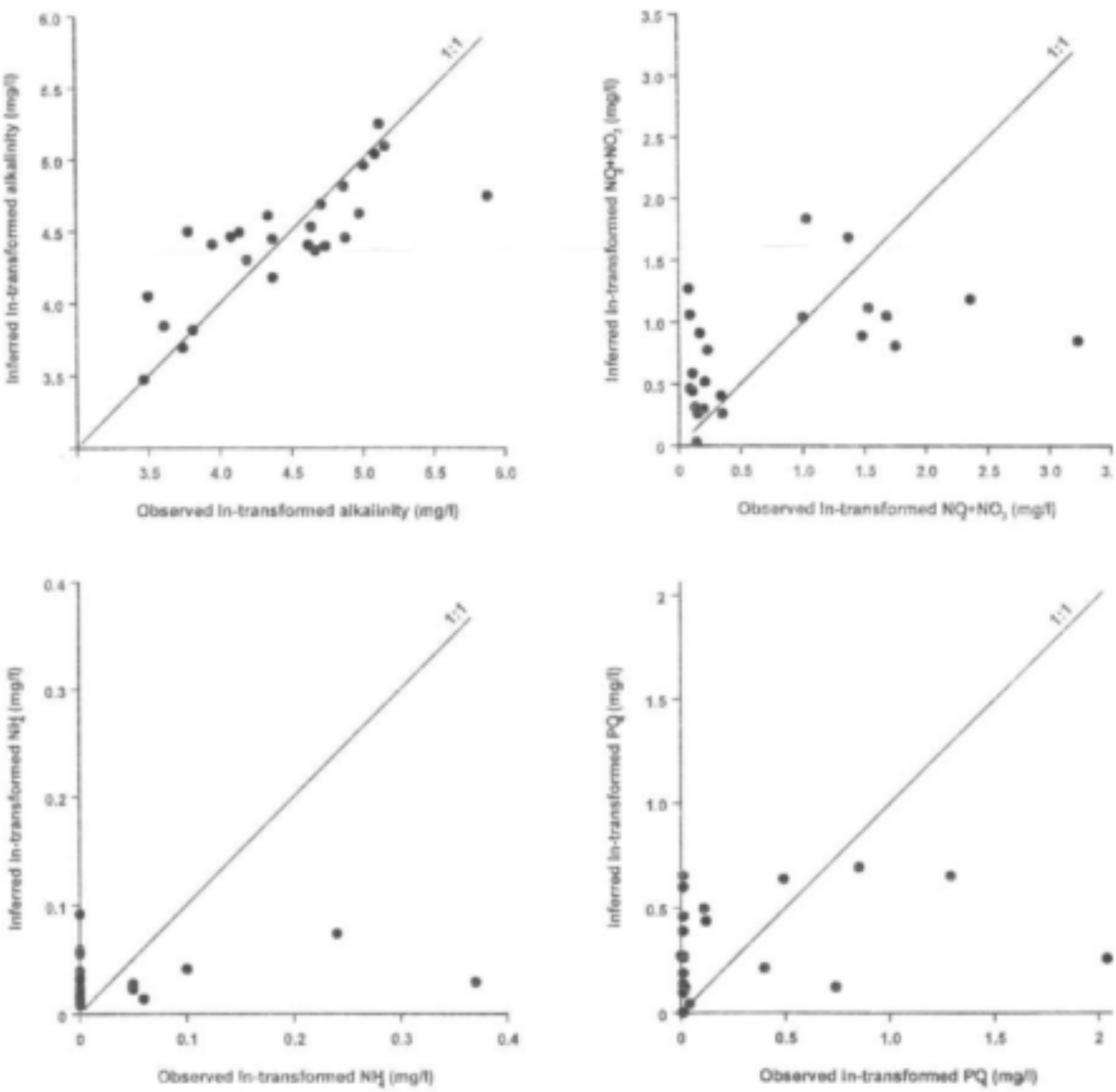

Figure 19. Correlation between observed and diatom inferred (predicted) values for alkalinity, NO_2+NO_3, NH_4 and PO_4 based on epipelic diatoms.

Table 34. The maximum percent abundance (max), effective number of occurrences (Hill's N_2) and optima and tolerances for WA transfer functions for pH, NH_4 (mg l^{-1}) and alkalinity (mg l^{-1}) for diatom species in epilithon. See the Appendix for explanation of acronyms.

	Max	N2	pH		NH4		alkalinty	
			Opt	Tol	Opt	Tol	Opt	Tol
ACHNENGE	11.3	4.0	9.2	0.7	0.01	-0.02	81.1	0.2
ACHNMINU	93.1	22.9	8.2	0.6	0.02	0.07	81.8	0.9
AMRAPEDI	35.9	7.0	8.4	0.4	0.01	0.03	139.0	0.7
CCNEPEDI	9.2	5.8	8.9	0.5	0.00	-0.23	100.8	0.4
CCNEPLAC	9.8	7.2	8.8	0.6	0.01	0.02	90.7	1.0
CYCLMENI	36.1	6.3	8.6	0.6	0.01	-0.01	114.9	0.6
CYLAKAPI	2.7	3.5	7.9	0.3	0.02	0.04	113.0	0.3
CYLAMIC1	7.6	4.2	7.9	0.3	0.02	0.04	93.1	0.6
CYLAMIC2	18.0	4.7	7.9	0.3	0.02	0.04	107.1	0.3
CYLATURG	5.4	7.2	8.1	0.5	0.02	0.03	72.3	0.7
CYSTDUBI	4.0	11.2	8.5	0.7	0.00	-0.04	88.8	0.6
DIATVULG	65.9	4.8	8.7	0.6	0.00	-0.03	93.6	0.6
ENCYMINU	1.0	3.6	8.3	0.4	0.02	0.01	119.9	0.6
FRAGCAru	1.6	3.3	7.7	0.6	0.13	0.23	39.5	0.4
FRAGCAva	4.6	3.1	7.7	0.5	0.16	0.21	52.1	1.4
FRAGELLI	7.2	6.0	8.7	0.5	0.01	-0.01	88.7	0.4
FRAGTENE	8.4	9.5	8.0	0.4	0.03	0.07	67.1	0.8
GONEANGU	7.9	9.6	8.2	0.5	0.02	0.03	75.0	0.7
GONECLja	6.4	4.0	7.9	0.2	0.01	0.00	44.8	0.3
GONEPAmi	1.5	2.8	7.8	1.2	0.19	0.18	39.6	0.8
GONEPARV	2.4	13.3	8.3	0.5	0.02	0.06	99.0	0.8
NAVICAPI	3.3	10.9	8.5	0.6	0.00	0.02	91.8	0.6
NAVICLOA	7.3	4.1	8.1	0.6	0.00	-0.28	50.0	0.8
NAVICRCE	2.1	4.9	8.7	0.6	0.00	-0.25	112.0	0.9
NAVICRex	3.6	10.8	8.6	0.6	0.00	-0.18	100.2	1.3
NAVICRTE	3.1	12.2	8.5	0.7	0.00	0.02	82.0	0.7
NAVIFRUG	3.5	7.0	8.5	0.6	0.01	-0.02	103.1	0.6
NAVIGREG	1.2	4.9	9.1	0.3	0.00	-0.25	82.4	0.3
NAVITELO	2.7	7.5	8.5	0.6	0.00	-0.20	83.7	0.9
NITZACIC	1.9	3.3	8.5	1.1	0.03	0.00	127.5	0.7
NITZCOMU	1.0	2.0	8.1	0.1	0.03	0.04	249.6	0.7
NITZDISS	14.8	14.6	8.5	0.6	0.01	0.03	95.3	0.7
NITZFRUS	17.5	8.7	8.8	0.5	0.00	0.02	97.0	1.1
NITZGRAF	8.5	6.5	8.6	0.6	0.00	0.02	128.2	0.8
NITZPACE	34.8	9.7	8.7	0.6	0.01	0.03	100.8	0.6
NITZPALE	23.5	12.0	8.7	0.6	0.01	0.03	91.1	0.6
NITZPURA	1.0	4.8	8.2	0.3	0.01	0.00	158.3	1.6
SYNERUMP	9.0	7.2	8.0	0.3	0.04	0.06	64.4	0.6
SYNEULNA	5.1	5.0	7.8	0.6	0.14	0.17	46.4	0.8

Table 35. The maximum percent abundance (max), effective number of occurrences (Hill's N_2) and optima and tolerances for WA transfer functions for alkalinity (mg l^{-1}), NO_2+NO_3 (mg l^{-1}), NH_4 (mg l^{-1}) and PO_4 (mg l^{-1}) for diatom species in epipelon. See the Appendix for explanation of acronyms.

	Max	N_2	alkalinity		NO_2+NO_3		NH_4		PO_4	
			Opt	Tol	Opt	Tol	Opt	Tol	Opt	Tol
ACHNENGE	23.3	6.1	74.0	0.49	2.12	0.59	0.00	0.01	0.392	0.58
ACHNEXIG	6.9	7.8	66.0	0.71	3.21	2.05	0.07	0.23	0.774	1.47
ACHNMINU	64.7	20.7	72.9	0.88	0.95	1.12	0.03	0.09	0.122	0.41
AMRAFONT	1.2	3.3	151.2	5.06	1.10	2.49	0.00	-0.45	0.123	0.31
AMRALIBY	1.1	6.9	145.2	0.20	0.26	0.49	0.02	0.03	0.304	0.43
AMRAPEDI	4.5	8.4	110.3	0.87	2.20	2.23	0.04	0.17	1.065	0.97
CALOSCHU	20.8	2.5	163.1	0.04	0.13	0.03	0.04	-0.06	0.043	0.01
CCNEPEDI	14.2	6.8	102.6	0.53	2.88	1.49	0.00	-0.28	0.891	0.79
CCNEPLAC	16.3	14.5	79.2	0.73	2.38	1.86	0.04	0.15	0.697	1.01
CYCLMENI	5.0	9.4	95.9	0.76	1.30	1.14	0.02	0.06	0.293	0.43
CYLAKAPI	9.4	8.1	91.3	0.48	0.74	1.38	0.04	0.09	0.151	0.69
CYLAMIC1	5.9	3.9	97.5	0.43	0.33	0.73	0.02	0.04	0.036	0.16
CYLAMIC2	1.1	6.3	92.0	0.53	0.65	1.10	0.02	0.04	0.125	0.41
CYLASPEC	1.9	2.3	52.0	0.45	3.50	0.38	0.00	-0.59	0.166	0.65
CYLATUMI	2.3	10.0	84.7	0.66	0.46	0.79	0.01	-0.05	0.187	0.43
CYLATURG	27.8	13.7	62.6	0.75	0.77	0.93	0.02	0.07	0.072	0.35
CYSTDUBI	5.7	10.4	92.0	0.73	1.15	1.17	0.02	0.07	0.196	0.39
DIATVULG	31.2	11.5	82.1	0.58	1.49	2.42	0.05	0.18	0.619	1.21
DIPLELLI	1.3	9.1	116.7	0.60	0.64	1.28	0.02	0.09	0.159	0.63
ENCYMINU	1.9	8.8	98.9	0.51	0.23	0.23	0.01	0.02	0.081	0.26
FALATENE	1.5	4.1	167.7	0.94	0.23	0.45	0.01	0.03	0.142	0.37
FRAGELLI	3.3	6.4	77.1	0.81	2.09	1.49	0.02	-0.03	0.526	0.84
FRAGTENE	6.3	10.1	66.6	0.81	0.72	1.27	0.04	0.09	0.125	0.66
GONEANGU	6.7	12.3	67.0	0.61	1.31	1.30	0.00	0.03	0.189	0.52
GONECLja	14.3	4.3	48.3	0.68	0.38	0.41	0.00	-0.37	0.021	0.01
GONEPARs	1.7	4.3	92.4	0.91	0.76	4.62	0.11	0.16	0.336	2.17
GONEPARV	5.7	11.0	73.8	0.63	1.45	2.59	0.08	0.17	0.473	1.36
GONESUCL	1.1	2.6	38.5	0.12	0.44	0.52	0.00	-0.55	0.025	0.01
GYROACUM	1.6	13.4	95.7	1.12	1.06	1.20	0.01	0.04	0.187	0.38
NAVICAPI	31.1	17.6	88.5	0.63	0.71	1.09	0.01	0.05	0.274	0.55
NAVICRCE	3.8	12.3	121.8	0.88	0.65	1.05	0.01	0.03	0.216	0.49
NAVICRex	18.1	16.3	97.4	1.03	1.54	1.73	0.03	0.12	0.416	0.86
NAVICRTE	7.0	18.6	88.1	0.68	1.13	1.25	0.02	0.06	0.322	0.59
NAVIFRUG	2.5	6.5	100.0	0.66	3.86	2.24	0.05	0.19	1.510	1.00
NAVIGREG	9.9	8.7	64.4	0.50	2.66	2.22	0.06	0.21	0.601	1.44
NAVIHUca	7.3	7.0	123.9	0.62	0.68	1.82	0.05	0.13	0.398	0.97
NAVIMENI	25.2	11.3	102.2	0.57	0.83	1.25	0.03	0.08	0.381	0.58
NAVIPERs	5.7	6.0	148.3	0.96	0.19	0.15	0.02	0.03	0.021	0.02
NAVIPUPU	3.1	3.7	105.4	0.82	1.07	4.33	0.07	0.25	0.644	1.96
NAVISCHR	3.7	10.8	73.3	0.88	2.83	1.64	0.05	0.11	0.578	0.98
NAVITELO	8.0	13.5	84.1	0.88	1.44	1.97	0.04	0.15	0.323	1.09
NAVITRIP	1.1	3.2	150.2	0.24	0.13	0.07	0.03	0.04	0.371	0.74
NAVITRIV	14.8	4.7	89.6	0.94	1.21	4.10	0.06	0.25	0.566	1.87
NAVIVIro	2.7	13.4	93.5	0.85	0.99	1.14	0.01	0.04	0.184	0.38
NAVIVIvi	1.4	3.2	116.4	0.17	0.21	0.13	0.01	-0.07	0.112	0.44

	Max	N_2	alkalinity		NO_2+NO_3		NH_4		PO_4	
			Opt	Tol	Opt	Tol	Opt	Tol	Opt	Tol
NITZACIC	3.9	8.4	123.6	0.87	0.46	0.60	0.01	0.03	0.100	0.20
NITZCOMU	1.9	2.1	334.4	0.91	0.10	0.06	0.01	-0.11	0.080	1.24
NITZDIme	4.1	2.7	154.4	0.31	0.11	0.03	0.01	-0.07	0.054	0.10
NITZDISS	19.8	15.9	91.3	0.64	0.71	0.94	0.01	0.03	0.181	0.31
NITZFRUS	3.0	13.2	94.9	0.83	1.33	1.24	0.02	0.09	0.312	0.64
NITZGRAC	18.0	4.2	158.2	0.67	0.12	0.08	0.01	0.03	0.045	0.21
NITZGRAF	30.6	15.2	105.6	0.79	0.32	0.55	0.02	0.04	0.065	0.18
NITZLIsu	2.3	5.1	87.7	0.67	0.99	2.29	0.00	-0.07	0.321	1.29
NITZPACE	17.8	14.0	104.3	0.70	0.84	1.16	0.03	0.08	0.268	0.56
NITZPALE	24.2	20.7	85.2	0.79	1.53	1.85	0.05	0.14	0.433	1.00
NITZPURA	5.0	16.3	104.7	0.79	0.70	1.25	0.03	0.08	0.233	0.62
NITZRAUT	7.2	1.7	167.0	0.02	0.16	0.04	0.07	0.04	0.039	0.01
NITZRECT	15.9	13.8	99.9	0.70	0.48	1.12	0.03	0.08	0.317	0.61
NITZSIGM	8.0	3.9	43.4	0.33	8.75	4.20	0.28	0.24	2.026	5.97
NITZLIte	5.7	5.3	112.3	0.93	1.22	5.85	0.11	0.22	0.520	2.79
PLACELGI	5.0	3.0	161.6	0.34	0.14	0.04	0.04	0.04	0.189	0.65
PLANLANC	3.8	4.4	132.4	0.74	0.12	0.03	0.02	0.04	0.273	0.74
RHOPGIBA	1.0	2.7	144.7	0.78	0.38	1.47	0.03	-0.05	0.092	0.22
SURIBREB	2.7	3.4	139.4	0.18	0.16	0.15	0.01	0.03	0.019	0.01
SYNERUMP	8.0	8.4	54.2	0.77	1.48	2.66	0.07	0.19	0.365	1.90
SYNEULNA	10.4	8.6	55.1	0.50	0.82	1.14	0.06	0.10	0.088	0.41
TRYBANGU	2.4	3.9	122.7	0.30	0.43	2.19	0.04	0.03	0.274	0.73
TRYBAPIC	3.6	8.2	126.4	0.98	1.28	2.66	0.06	0.18	0.613	1.29

DISCUSSION

There is a notable difference in the site separations in the ordination diagrams based on the epilithic and the epipelic species distribution. The epilithic diatom communities at the downstream sites in the Olifants River resemble the composition of the upstream sites. The water quality conditions do indeed recover over the last three sites, but the water remains of inferior quality compared to the upstream sites. This is reflected in the epipelic species composition. A possible explanation for this discrepancy could be that the diatoms that live among the sediment grains (the epipelon) are usually found in places in the river bed where deposition prevails (Cattaneo *et al.*, 1997). This could mean that the microenvironment in which these diatoms live is a more time-integrated reflection of the water quality in the river. The epilithic species on the other hand, are usually directly exposed to the water that is flowing past. They can therefore react more quickly to any change in the quality of the water.

During the process of data screening, two samples had to be omitted because the values of the key water quality variables were identified as outliers. The species composition at these sites was also considerably different. The dominant diatom species at these sites can be good indicators of the observed conditions, but this can only be confirmed if these species are repeatedly found in comparable conditions.

The water quality variables that influenced the distribution of the diatoms significantly (alkalinity, ammonium, conductivity, pH, phosphate and nitrite/nitrate) are important factors in affecting the river health. A decrease in alkalinity (as was seen on the most impacted sites) could be an effect of low-pH- source effluents from industries, mine drainage or acid precipitation resulting from atmospheric pollution (DWAF, 1996). Many of these sources are likely in the Olifants River catchment. Phosphorus is considered to be the principle nutrient controlling the degree of eutrophication in aquatic ecosystems and elevated levels may result from domestic and industrial effluents and diffuse sources generated by surface and subsurface drainage (DWAF, 1996). High levels of inorganic nitrogen are primarily of concern due to its stimulatory effect on aquatic plant growth and algae (DWAF, 1996). The sources of nitrogen are similar to those of phosphorus and therefore a strong indication of pollution.

The indicator values calculated in this study are preliminary, since they are based on a once off sampling trip. The performance of the weighted-averaging regression and calibration models could be enhanced by collecting more diatom and water quality data in this region.

Diatoms can give additional information to that of the biomonitors that are currently used within the NAEBP. The biomonitoring systems SASS4, based on macro-invertebrates (Chutter, 1998), and IBI, based on fish communities (Uys *et al.*, 1996), rate the water quality in qualitative terms (e.g. excellent-poor). The indicator values of diatoms have the potential to quantitatively specify the water quality variables that affect the state of the river at the site of study. Results of IBI and SASS4 assessments were not available at time of going to press.

EPILITHIC AND EPIPELIC DIATOMS IN RELATION TO WATER QUALITY IN RIVERS IN THE WESTERN CAPE.

Introduction

The aim of this study was to investigate the relationship between diatom assemblages in the epilithic and epipelic habitats and the water quality in which they were found in selected rivers in the Western Cape. The selection criteria were:

- The presence of a water quality gradient from the source to the head of the estuary, relying on an existing database of water quality for each river;
- A minimum of 5 sampling sites in the river that are part of regular monitoring by the Department of Water Affairs and Forestry (DWAF).

When the study sites in a river are spaced along a water quality gradient, the abundance of benthic diatom species can be studied in pristine and impacted situations. If it is also possible to find a habitat that is present throughout the river catchment, then water quality can be correlated with changes in the dominance of diatom species (Cattaneo, 1997). Comparisons between sites within one catchment are more meaningful than among different catchments, due to possible differences in geology, climate and land use. However, to study general patterns in species distribution it becomes necessary to compare similar river systems (Allanson *et al.*, 1990). Various attempts have been made to classify South African rivers. A modified version of the classification by Harrison is given in Allanson *et al.* (1990). The Cape System sub-region stretches from the Olifants River on the West Coast of South Africa to the Swartkops River in the Eastern Cape. This region contains four main types of rivers: (1) unbuffered and acid waters, low in TDS, (2) neutral to alkaline waters, (3) a combination of 1 and 2 within one catchment (e.g. Gamtoos) and (4) saline, alkaline and largely temporary waters (Allanson *et al.*, 1990). The rivers discussed in this section are all of the first type.

The rivers that were selected were the Eerste, Palmiet, Bot, Klein and Groot Brak and Keurbooms rivers. These rivers were visited in May and June of 1998 together with employees from the DWAF Belville and George offices.

STUDY AREAS

Eerste River

The area of the Eerste River catchment has been estimated to be 400 km² and is situated between latitudes South 34°03' and 34°0' and longitudes East 18°43' and 19°0'. The river is approximately 40 km in length and has eight tributaries. The Kuils River is the major tributary to the Eerste River (Figure 20). The geology of the Eerste River catchment is dominated by Cape Granite and Malmesbury Shale. The catchment lies within a climatic region that receives most of its rainfall in winter. About 80 percent of the rain falls in a series of winter storms that bring the river down in spate. The Eerste River is linked via the Riviersonderend-Berg River tunnel system to the Theewaterskloof scheme, so that the flow of the Eerste River can be supplemented by water from other sources (Grindley, 1982).

The Eerste River was sampled on 4 May 1998. Table 36 explains which sites were visited and what habitats were sampled. For the purpose of this study, the sites are named R1-R7 (R stands for a site in the main river). Site R1 is situated in the Jonkershoek nature reserve and has very few anthropogenic impacts. Site R2 is situated just outside the reserve, but no potential sources of impacts are present between these two sites. Site R3 is situated just below the Plankenburg River confluence. The natural situation has been altered to such an extent, however, that water from the Plankenburg is redirected into an irrigation system and only reaches the Eerste River in cases of high flow (Rossouw, pers.comm.). This was not the case at the time of sampling. Site R4 is situated just upstream from the Veldwachters River confluence. The sewerage works from Stellenbosch discharges into the Veldwachters. Site R5 is situated downstream from this confluence. The Eerste River continues to flow through agricultural land (mainly wine farms). Site R6 is situated upstream from the Kuils River confluence. This river carries sewerage water from the Zandvliet sewerage works on the Cape Flats. Site R7 is situated downstream from this confluence (Figure 20).

Table 36. Sampling sites in the Eerste River. * indicates which community was sampled. See also Figure 20.

Site	DWAF-code	Date	epilithon	epipelon	latitude (S)	longitude (E)
R1	ER720A1	04-May-98	*		33°58'22"	18°56'12"
R2	ER720B	04-May-98	*		33°56'29"	18°53'29"
R3	ER720B1	04-May-98	*		33°55'49"	18°51'08"
R4	ER720C	04-May-98	*		33°56'55"	18°50'19"
R5	ER720D	04-May-98	*		33°57'39"	18°48'59"
R6	ER720E	04-May-98	*	*	34°00'31"	18°45'41"
R7	ER720F	04-May-98		*	34°03'45"	18°44'52"

Figure 20. Eerste River catchment. Sampling sites R1-R7.

Palmiet River

The area of the Palmiet River catchment has been estimated to be 500 km² and is situated between latitudes South 34° 02' and 34° 21' and longitudes East 18°53' and 19°10'. The river is approximately 74 km in length and has 11 tributaries. The geology of the Palmiet River catchment is dominated by Table Mountain Group sandstones (TMS), quartzites and shales and Bokkeveld shales and sandstones. As a result of the dominance of TMS in the catchment, the river water is often deeply stained with humic acids to the colour of strong tea (Koop, 1982). The catchment lies within a climatic region that receives most of its rainfall in winter from about May to September and is characterised by a warm to hot and dry summer. The Palmiet River and its tributaries are extensively impounded, mainly for irrigation purposes. Major impoundments are the Nuweberg dam, Eikenhof dam, Applethwaite and Kogelberg dams and the Arieskraal dam (Figure 21) (Clarke, 1989).

Table 37. Sampling sites in the Palmiet River. * indicates which community was sampled. See also Figure 21.

Site	DWAF-code	Date	epilithon	epipelon	latitude (S)	longitude (E)
R1	PR400A	11-May-98	*	*	34°05'	19°02'
R2	PR400B	11-May-98	*	*	34°07'	19°01'
R3	PR400C	11-May-98		*	34°09'	19°01'
R4	PR400D	11-May-98	*		34°13'	18°52'
R5	PR400E	11-May-98		*	34°20'	18°59'
T1	KR400A	11-May-98		*	34°07'	18°59'
T2	KR400B	11-May-98		*	34°08'	19°01'

Figure 21. Catchment of the Palmiet River. Sampling sites R1-R5.

On 11 May 1998 a total of 7 sites were visited in the Palmiet catchment. On that day, the Palmiet was flowing at a very high rate due to recent rainfall events. The implications of this will be discussed in subsequent paragraphs. Table 37 shows the sites that were visited and the habitats that were sampled. For the purpose of this study, sites are named R1-R5 (R stands for the main river) and T1-T2 (where T stands for tributary, in this case the Klipdrif). Site R1 is situated in the Hottentots Holland Nature reserve and usually has very few anthropogenic impacts. Site R2 is situated just above the Eikenhof dam, where the river flows through the 'Molteno brothers' orchard. Uncontrolled dumping of waste from orchards is often associated with high levels of COD (Chemical Oxygen Demand) (van Koller, pers. comm.). Just above the town of Grabouw, two sites in the Klipdrif River (a tributary to the Palmiet) were sampled. The Klipdrif was also in spate at the time. At site R3 the Palmiet River flows through 'Elgin' orchards and from there, into the Applethwaite dam. Downstream of the Kogelberg dam (which is directly downstream from the Applethwaite dam) a sample was taken at site R4, just below a DWAF weir. The last site was situated at the head of the Palmiet estuary, below the DWAF gauging weir just above the coastal road bridge near Kleinmond (Figure 21).

Bot River

Estimations for the area of the Bot River catchment vary between 813 and 1000 km^2. It borders the Palmiet River catchment on the east. The river is approximately 42 km in length and has a number of small tributaries. The Jakkals and Swart rivers are the major tributaries (Figure 22). The geology of the Bot River catchment is dominated by Bokkeveld shales and sandstones although some Table Mountain Group sandstone is present on both its western and eastern borders. As a result, the river usually carries turbid, alkaline waters. The catchment lies within the same climatic region as the Palmiet River catchment. In the Bot River catchment, no State-constructed dams are present, although many farmers have their own earth dams that collect rainwater for irrigation purposes and which are occasionally fed with pumped river water (Koop, 1982).

The Bot River was sampled on 11 May 1998. Table 38 shows the sites that were visited and which habitats were sampled. For the purpose of this study, the sites are named R1-R2 (R stands for the main river) and T1 (where T stands for tributary, in this case the Jakkals River). On the day of sampling the river was coming down in spate. The implications of this will be discussed in subsequent paragraphs. The original plan was to sample more stations in the river. Due to the high water level, however, two sites could not be reached.

Table 38 Sampling sites in the Bot River. * indicates which community was sampled. See also Figure 22.

Site	DWAF-code	Date	epilithon	epipelon	latitude (S)	longitude (E)
R1	BR400A	11-May-98	*		34°12'	19°12'
R2	BR400B	11-May-98		*	34°14'	19°12'
T1	JR400A	11-May-98		*	34°12'	19°08'

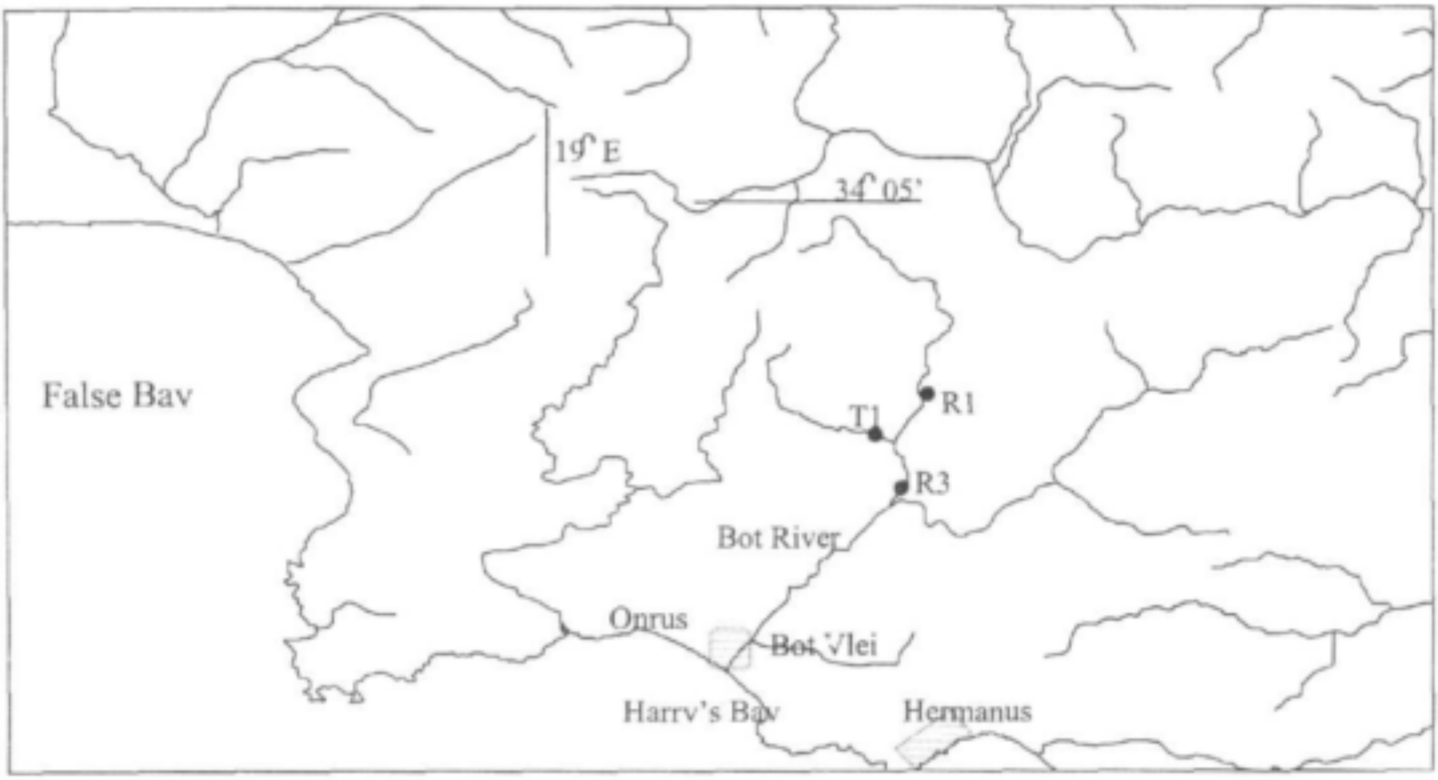

Figure 22. Catchment of the Bot River. Sampling sites R1, R2 and T1.

Brak Rivers

During this study, sites in both the Klein and Groot Brak River catchments were sampled. Both catchments are small (Klein Brak 550km² and Groot Brak 190 km²) and are situated between latitudes South 33°59' and 33°03' and longitudes East 22°51' and 22°14'. Both rivers are ca. 30 km long. The catchment geology is a mixture of Table Mountain sandstone, Sandkraal Formation and Tertiary/Quaternary valley alluvial deposits. The catchments lie within a region that receives more or less equal amounts of rain in all seasons, with slight peaks in spring and autumn. The region has a generally mild climate

(Morant, 1983). Two major dams (the Ernest Robertson dam and the Wolwedans dam) are situated in the Groot Brak River (Figure 23).

The Brak Rivers were sampled on 7 May 1998. Table 39 shows the sites that were visited and the habitats sampled. For the purpose of this study, the sites are named KB1-3 (KB stands for Klein Brak) and GB1-3 (GB stands for Groot Brak, Figure 23). Site KB1 is situated in the Pine Grove Forest, a commercial forest. The river itself, however, is situated in a small gorge with indigenous forest. The other two sites in the Klein Brak River (KB2 and KB3) are both situated in parts of the river that flow through plantation and agricultural land. The Groot Brak River at GB1 is reduced to a channel connecting the Robertson dam with the Wolwedans dam (Figure 23). Sites GB2 and GB3 are both situated below the Wolwedans dam in forest areas. Water quality problems are only recorded in the estuaries of both rivers as a combined effect of mouth closure and sewerage water outlet (Morant, 1983).

Keurbooms River

The catchment area of the Keurbooms River has been estimated to be 860 km² and is situated between latitudes South 33°45' and 34°0' and longitudes East 22°56' and 23°24'. The total length of the river is 70 km. The river has 10 tributaries. The geology of the Keurbooms River catchment is dominated by Table Mountain Group orthoquartzites and silicified conglomerates of the Robberg Formation. The catchment lies within a climatic region that receives more or less equal amounts of rain in all seasons, with slight peaks in spring and autumn. An important feature of the Keurbooms River is that it is one of few southern Cape rivers that traverses the Outeniqua Mountains and links the Klein Karoo with the southern coastal plain (Duvenage and Morant, 1984). There are no major impoundments on the river. Water from the Keurbooms is the main source of drinking water for Plettenbergbaai.

Table 39 Sampling sites in the Brak Rivers. * indicates which community was sampled. See also Figure 23.

Site	DWAF-code	Date	epilithon	epipelon	latitude (S)	longitude (E)
KB1	K1H002	07-May-98	*	*	33°56'06"	22°07'17"
KB2	K1H004	07-May-98	*	*	34°01'55"	22°03'12"
KB3	K1H005	07-May-98	*	*	34°02'23"	22°08'00"
GB1	K2H003	07-May-98		*	34°01'25"	22°12'15"
GB2	K2H006	07-May-98	*		34°00'54"	22°13'15"
GB3	K2H002	07-May-98	*		34°01'40"	22°13'21"

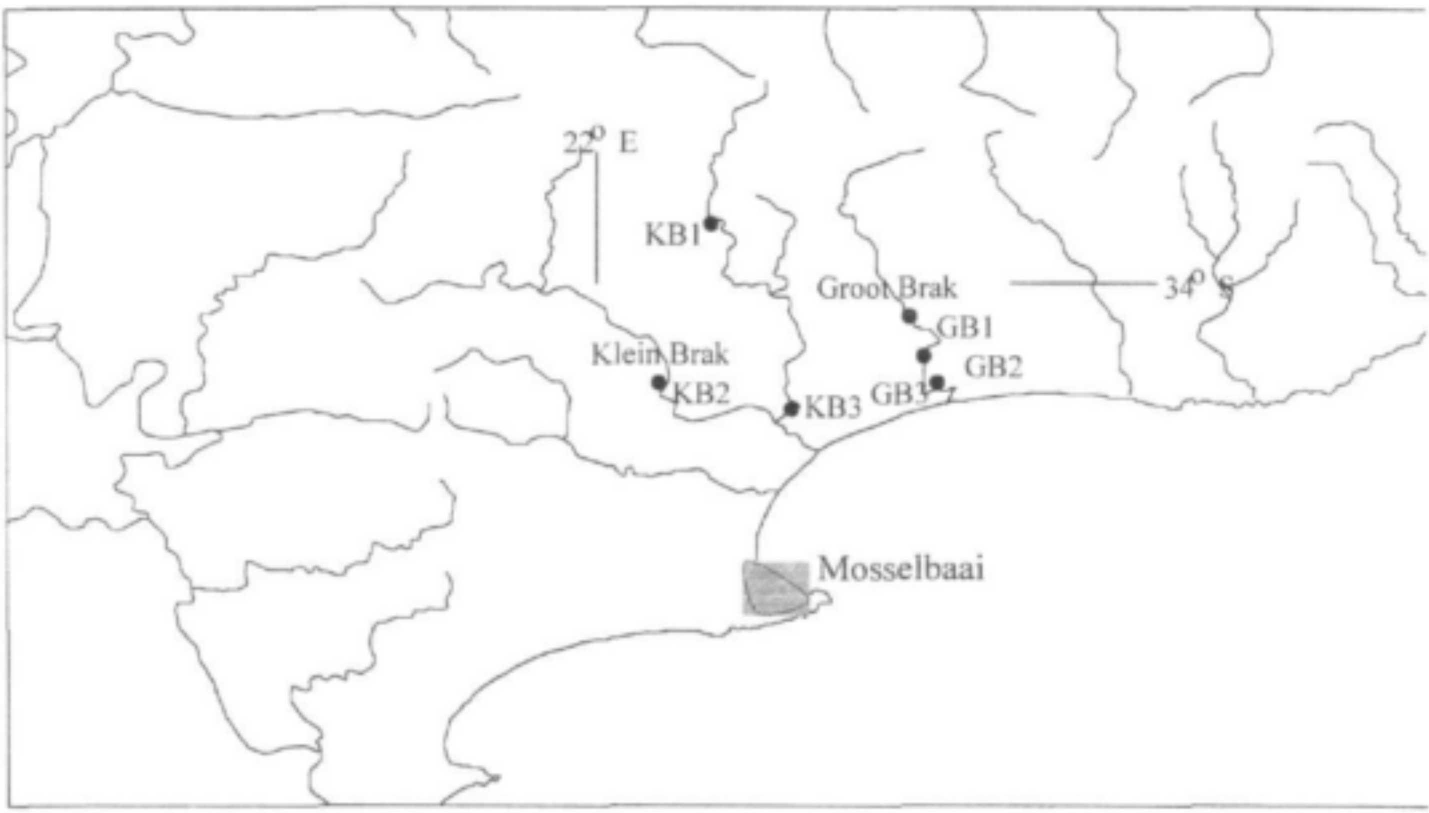

Figure 23. The Klein Brak (KB1-KB3) and Groot Brak (GB1-GB3) Rivers.

The Keurbooms River was sampled on 2 and 3 May 1998. Table 40 shows the sites that were visited and what habitats were sampled. For the purpose of this study the sites are named R1-R3 (R stands for a site in the main river) and T1-2 (where T stands for tributary, in this case the Kwaai River). The Keurbooms River drains an area that is dominated by forestry. At the confluence with the Kwaai River a trout farm is situated. Sites T1 and T2 are situated upstream and downstream respectively, from this trout farm. Site R3 is situated at the pump station for the drinking water treatment plant in Plettenbergbaai (Figure 24).

Water quality analyses

In situ pH, conductivity (EC) and temperature (Temp) were measured (see earlier in methods for details). The water samples for the Klein and Groot Brak and Keurbooms rivers were analysed at the Institute for Water quality studies (IWQS) in Pretoria. The water quality variables that were analysed were: pH, NH_4-N, NO_3+NO_2-N, F, total alkalinity as $CaCO_3$ (TAL), Na, Mg, Si, PO_4-P, SO_4, Cl, K, Ca, conductivity and total dissolved salts (TDS). The water quality samples taken in the Eerste, Plamiet and Bot rivers were analysed by the South African Bureau for Standards, Environment Laboratory Services Division in Cape Town. The water quality variables that were analysed were: pH, NH_4-N, NO_3+NO_2-N, PO_4-P and conductivity. Diatoms were sampled, identified and enumerated according to the methods described in earlier in methods for details.

Table 40. Sampling sites in the Keurbooms River. * indicates which community was sampled. See also Figure 24.

Site	DWAF-code	Date	epilithon	epipelon	latitude (S)	longitude (E)
R1	K6H002	02-Jun-98	*	*	33°56'18"	23°22'04"
R2	K6H007	02-Jun-98	*		33°49'18"	23°11'12"
R3	K6H011	03-Jun-98	*	*	33°48'41"	23°10'31"
T1	K6H010	02-Jun-98	*		33°48'55"	23°11'15"
T2	K6H008	02-Jun-98	*		33°49'17"	23°10'55"

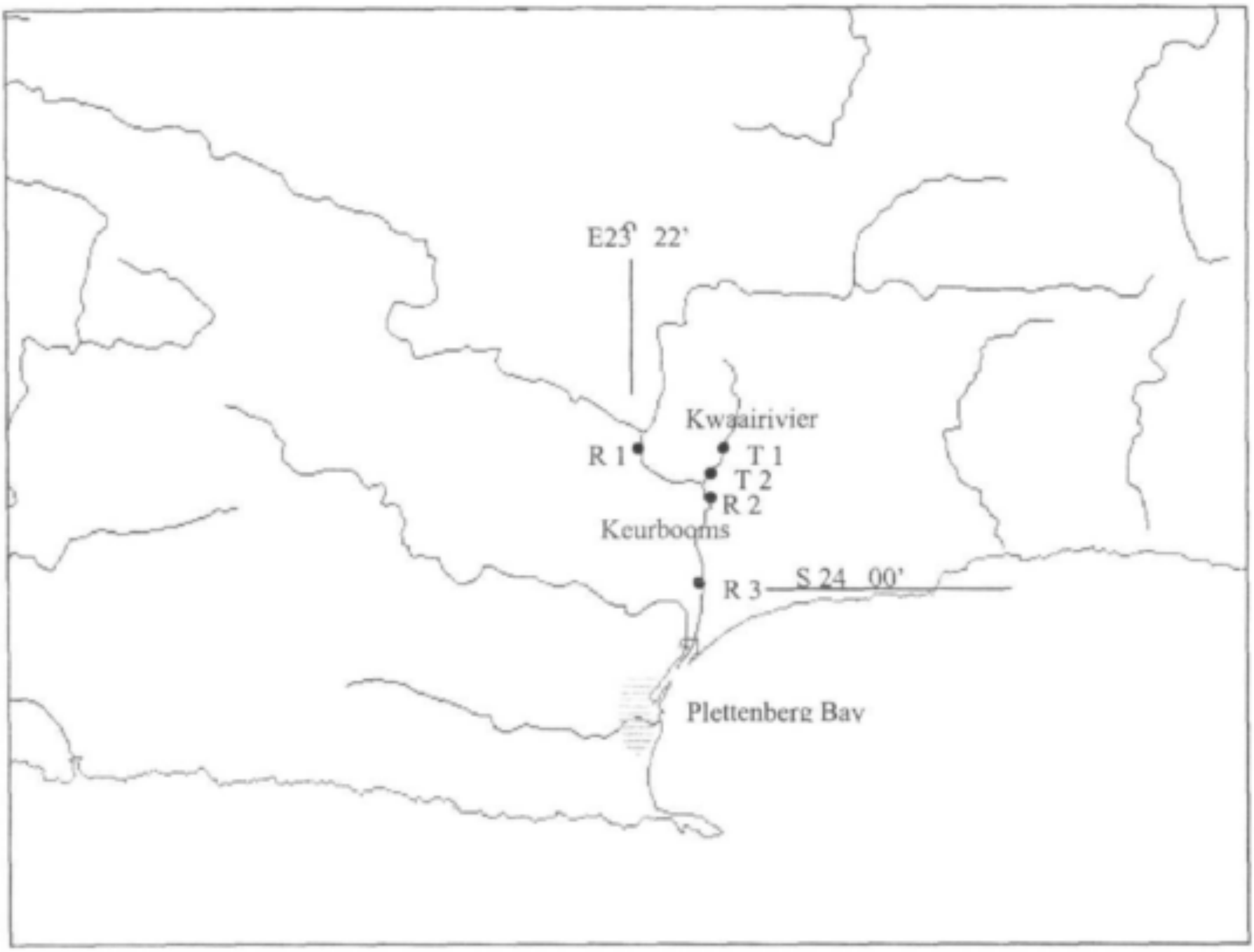

Figure 24. The Keurbooms River. Sampling sites R1-R3. The Kwaai River is a small tributary of the Keurbooms (T1-T2).

RESULTS

Bot, Eerste and Palmiet rivers

Epilithic diatom distribution

Although the objective was to sample both the epilithic and epipelic habitats at all sites, the nature of several sites was such that epipelic samples could not be taken. The riverbed in the Eerste River consisted of boulders and stones along most of its length. Figure 25 illustrates the relative abundance of epilithic diatom taxa (>5% abundance) at sites in the Bot, Eerste and Palmiet rivers (see the Appendix for explanation of acronyms).

In the upstream sites in the Eerste River *Achnanthes subatomoides* (ACHNSUAT) was dominant at most sites. *Eunotia incisa* (EUTIINCI) was only abundant at site ER1. *Cocconeis placentula* (CCNEPLAC) was found abundant at sites ER2 and ER3. Sites ER5 and ER6 showed a rather different composition with *Navicula cryptocephala* (NAVICRCE) and *Achnanthes engelbrechtii* (ACHNENGE) as respective dominants. The upstream sites in the Palmiet were dominated by *Eunotia* (EUTI-) taxa, changing into a dominance of *Achnanthes minutissima* (ACHNMINU) at site PR4. At the only site in the Bot River at which the epilithon could be sampled, *Achnanthes oblongella* (ACHNOBLO) was dominant.

Epipelic diatom distribution

The composition of epipelic diatom assemblages is illustrated in Figure 26. *Achnanthes engelbrechtii* (ACHNENGE) and *Navicula pupula* (NAVIPUPU) were dominant in the assemblages in the lower reaches of the Eerste River (sites ER6 and ER7 respectively). The most abundant species in the Palmiet epipelon were *Frustulia rostrata* (FRUSROST), *Eunotia tenella* (EUTITENE), *Navicula tenelloides* (NAVITELO) and *Pinnularia braunii* (PINNBRAU). *Navicula tenelloides* (NAVITELO) and *Achnanthes oblongella* (ACHNOBLO) were dominant in the assemblages that could be sampled at two sites in the Bot River (BR2 and BT1) (Figure 26 6.7).

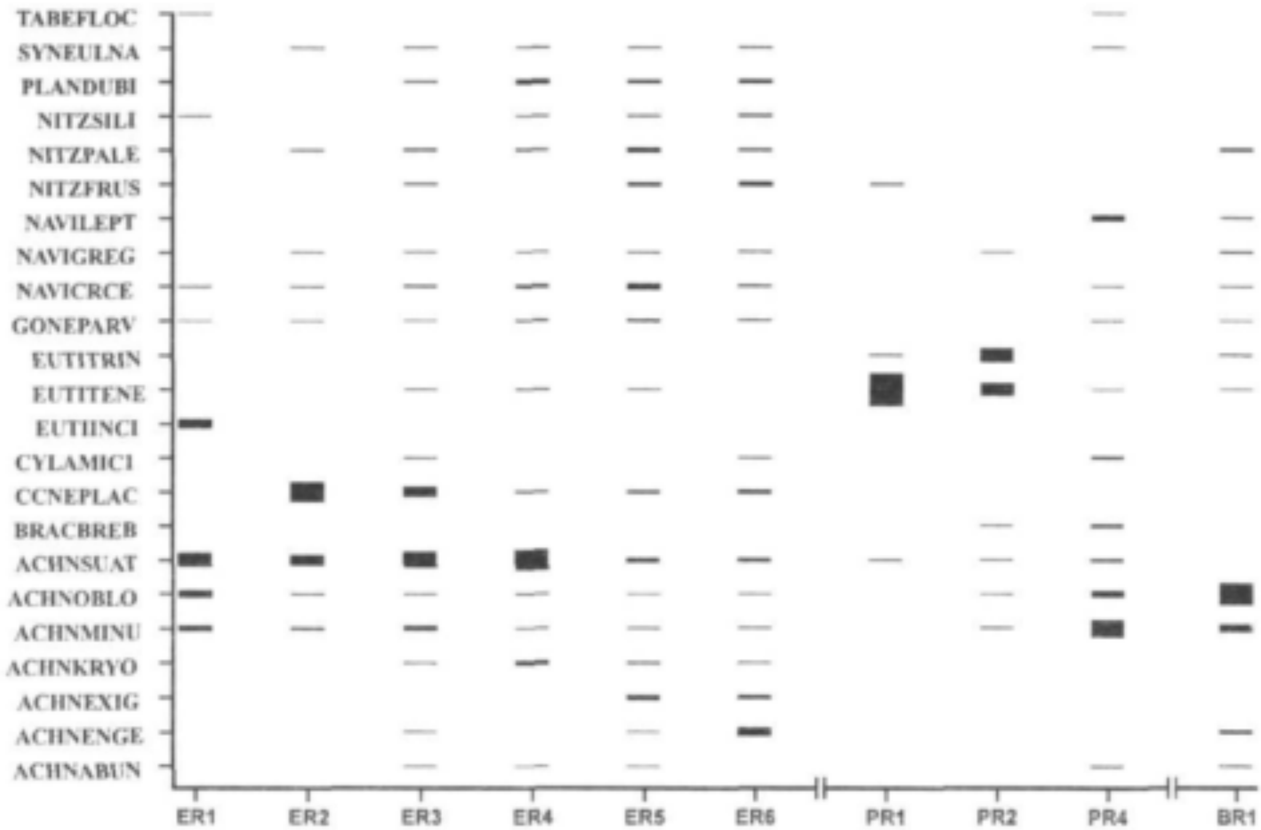

Figure 25. Illustration of the epilithic diatom species distribution (> 5% relative abundance) along the Eerste (ER1-ER6), Palmiet (PR1-PR4) and Bot (BR1) Rivers.

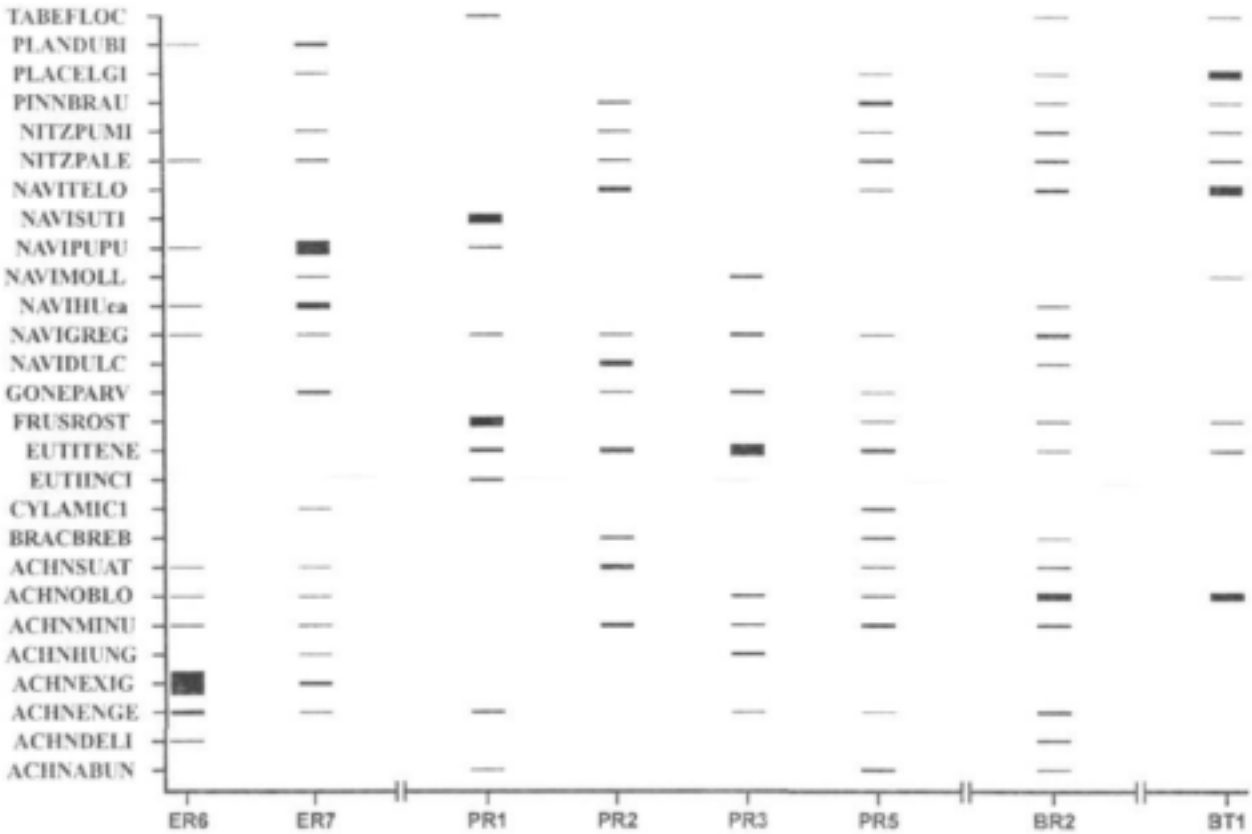

Figure 26. Illustration of the epipelic diatom species distribution (> 5% relative abundance) along the Eerste (ER6 and ER7), Palmiet (PR1-PR5) and Bot (BR2 and BT1) Rivers.

Water quality

The results of the water quality analyses are given in Table 41. In the upper reaches of all three rivers the pH was low (4.7-6.8). In the Palmiet River the pH remained below 6.5 in the lower reaches. In the Eerste River, several point sources of pollution could be identified. The impact of the treated sewerage outlet into the Veldwachters River, which has its confluence between ER4 and ER5 is visible as the amounts of nitrite/nitrate, phosphate and COD are high at ER5. At ER7, just below the Kuils River confluence, the amount of ammonium is high (3 mg/l). This is an indication that the Zandvliet sewerage treatment works, which enters the Kuils River a few kilometres upstream from the confluence, is not functioning optimally. At the time of sampling, the Palmiet and Bot Rivers were coming down in spate as a result of recent events of rainfall. At site PR4, the Kogelberg Dam (Figure 21) had reduced the amplitude of the flow in the Palmiet.

Table 41 illustrates the water quality variables measured at each site. It is clear that the unusual large amount of water dilutes any possible source of pollution. Only at R3, just below the town of Grabouw, the nitrite/nitrate levels were slightly raised. In the Bot River nitrite/nitrate levels were generally high at the three stations that could be sampled (Table 6.6). Characteristically for the geological region in which the Bot River catchment is situated, the water was very turbid, which is reflected in high TSS values (Table 41).

Table 41. Water quality variables measured in the Bot (BR1-BT1) Eerste (ER1-ER7) and Palmiet (PR1-PR5) Rivers on 4 May 1998 (Eerste) and 11 May 1998 (Bot and Palmiet).

Sites	pH	Conductivity (mS/m)	NH_4^+ ($mg.l^{-1}$)	$NO_2^-+NO_3^-$ ($mg.l^{-1}$)	PO_4^{3-} ($mg.l^{-1}$)	TSS ($mg.l^{-1}$)
BR1	7	51.8	<0.3	5.2	<0.05	42
BR2	6.7	49.1	<0.3	4.5	<0.05	142
BT1	5.7	33.8	<0.3	3.5	<0.05	108
ER1	6.8	7.4	<0.3	<0.3	<0.05	<10
ER2	6.8	8.4	<0.3	<0.3	<0.05	<10
ER3	7.1	10.3	<0.3	<0.3	<0.05	<10
ER4	7.1	11.6	<0.3	<0.3	<0.05	<10
ER5	7.2	55.7	<0.3	12.2	4.94	11
ER6	7.4	47.2	<0.3	2.4	1.39	<10
ER7	7.4	70.8	3	1.4	1.19	20
PR1	4.2	4.1	<0.3	0	<0.05	<10
PR2	4.7	6.3	<0.3	0.4	<0.05	<10
PR3	6.2	14.8	<0.3	1.9	<0.05	<10
PR4	6.4	8.3	<0.3	0	<0.05	<10
PR5	6.4	17.0	<0.3	0.8	<0.05	11

Correlation between diatom distribution and water quality

The relationship between diatom assemblages and water quality variables was investigated with CCA. Table 42 gives a summary of the CCA analysis of the epilithic dataset. Figure 6.8 gives a graphic representation. A large proportion (51.3%) of the species distribution is explained by the measured environmental variables.

Table 42 Summary of CCA of epilithic diatom species in Eerste, Palmiet and Bot Rivers.

	Axis 1	Axis 2	Axis 3	Axis 4	Total inertia
Eigenvalues	0.646	0.324	0.164	0.087	2.381
Species-environment correlations	0.990	0.900	0.959	0.987	
Cumulative percentage variance					
of species data	27.1	40.7	47.6	51.3	
of species-environment relation	52.9	79.4	92.8	100	
Sum of all unconstrained eigenvalues					2.381
Sum of all canonical eigenvalues					1.222

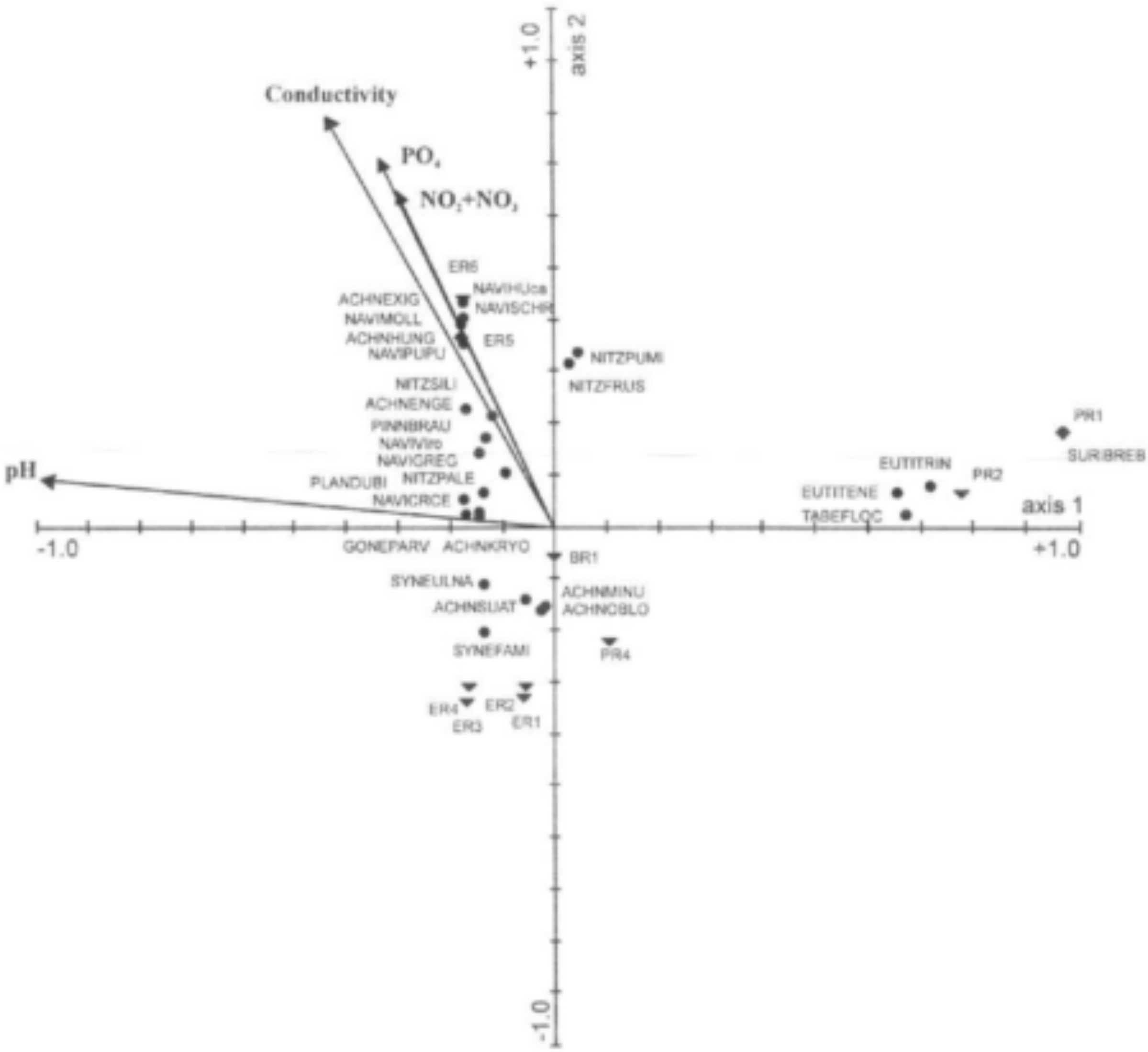

Figure 27. CCA ordination showing epilithic diatom species (circles), sites (triangles) and water quality variables (arrows) in the Eerste, Palmiet and Bot Rivers. See Table 42. Species acronyms given in the Appendix.

Axis 1 is highly correlated with pH. Along this gradient, sites (PR1 and PR2) and species (e.g. *Eunotia tenella* (EUTITENE) from the upper reaches of the Palmiet are placed on the acid end (right-hand side). The second axis is an enrichment gradient (conductivity and nutrients) along which the separation is most noticeable between the upstream sites (ER1-ER4) and more impacted sites (ER5-ER6) in the Eerste River.

Table 43 gives a summary of the CCA analysis of the epipelic dataset. Figure 28 shows a graphic representation. A large proportion (59.2 %) of the species distribution is explained by the measured environmental variables.

Table 43. Summary of CCA of epipelic diatom species in Eerste, Palmiet and Bot Rivers.

	Axis 1	Axis 2	Axis 3	Axis 4	Total inertia
Eigenvalues	0.547	0.339	0.290	0.181	2.289
Species-environment correlations	0.994	0.936	0.998	0.942	
Cumulative percentage variance					
of species data	23.9	38.7	51.3	59.2	
of species-environment relation	40.3	65.3	86.6	100	
Sum of all unconstrained eigenvalues					2.289
Sum of all canonical eigenvalues					1.356

The gradient in phosphate is highly correlated with axis 1. The last site in the Eerste River (ER7) is situated at the positive end of the gradient. *Navicula hungarica* var. *capitata* (NAVIHUca) is characteristic for these conditions. *Navicula pupula* (NAVIPUPU), the dominant diatom at this site, also occurred in the upstream parts of the Palmiet River (Figure 26) and is therefore not specifically indicative of the impacted conditions found at ER7. Axis 2 corresponds with a gradient in the Palmiet River of slightly increasing nitrogen levels.

Klein Brak, Groot Brak and Keurbooms Rivers

Epilithic diatom distribution

Figure 6.10 illustrates the relative abundance (>5%) of the epilithic diatoms in the Brak and Keurbooms Rivers. Various *Achnanthes* species (ACHN-) were dominant in the assemblages sampled in the Brak and Keurbooms Rivers. KB1 was situated in a small remaining patch of indigenous forest. Large parts of the catchment area are used as a pine plantation. The diatom assemblage at this site was dominated by *Eunotia incisa* (EUTIINCI). In a tributary to the Keurbooms (the Kwaai River) *Gomphonema clevei* var *javanica* (GONECLja) was found to be dominant upstream of a trout farm in this river (KT1). Just downstream of the trout farm (KT2), the species composition had changed considerably

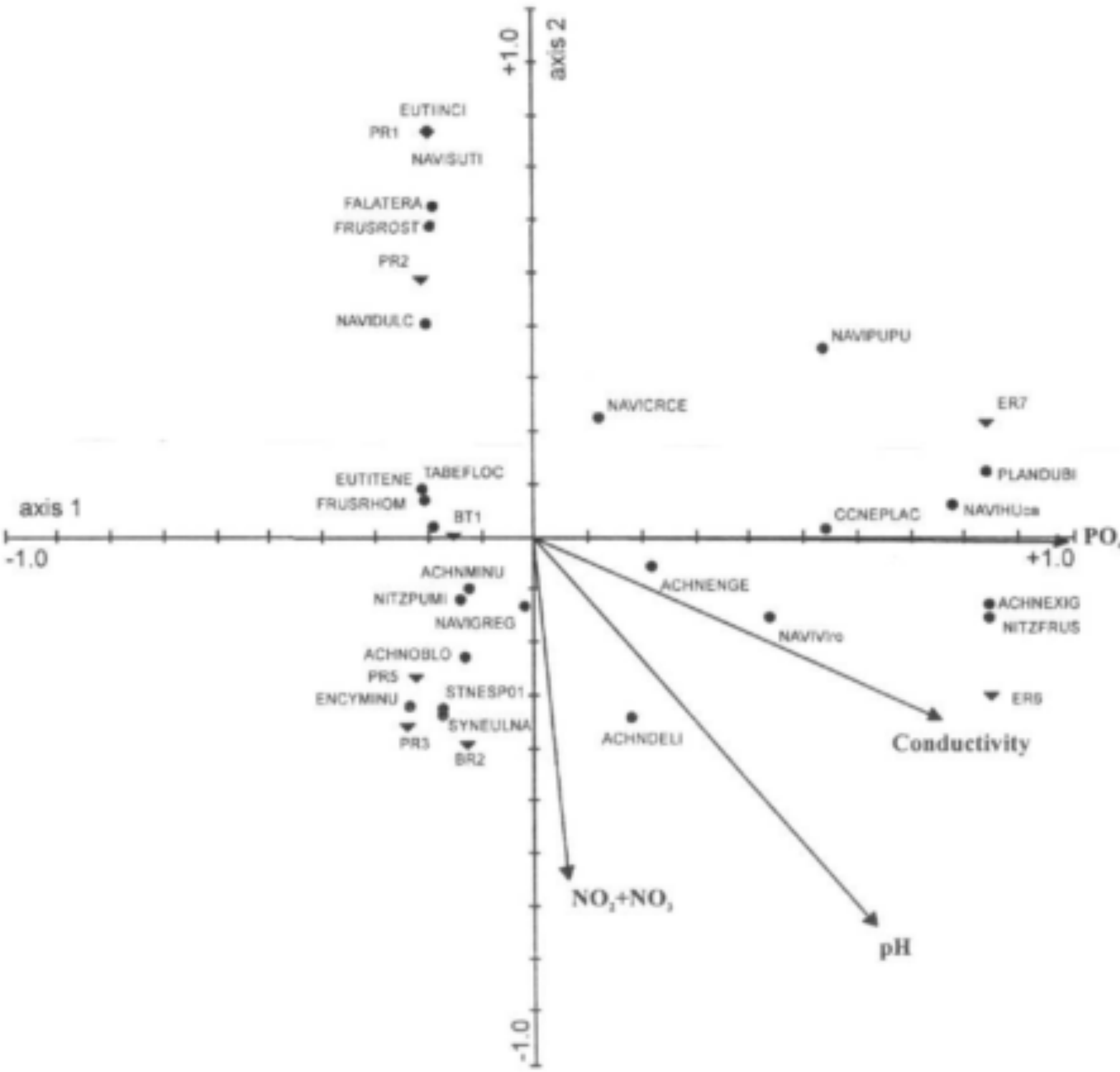

Figure 28. CCA ordination showing epipelic diatom species (circles), sites (triangles) and water quality variables (arrows) in the Eerste, Palmiet and Bot Rivers. See Table 43. Species acronyms are given in Appendix B.

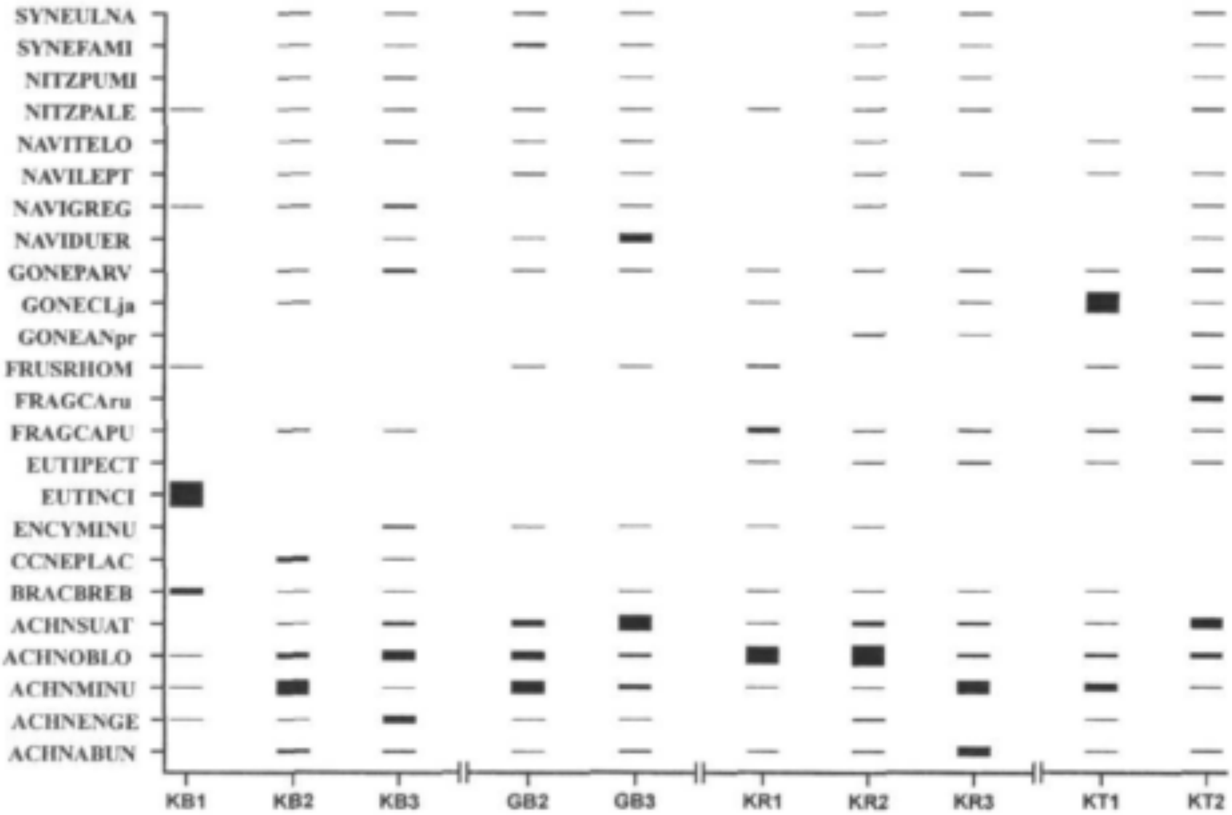

Figure 29. Illustration of the epilithic diatom species distribution (> 5% relative abundance) along the Klein Brak (KB1-KB3), Groot Brak (GB2, GB3) and Keurbooms (KR1-KT2) Rivers.

Epipelic diatom distribution

The riverbed of the Keurbooms consists of boulders and stones along most of the river's length. For this reason epipelic samples could only be taken at sites R1 and R3. In the Brak Rivers four epipelic samples were taken. Figure 30 illustrates the distribution of the epipelic diatoms. Just as in the epilithon, *Eunotia incisa* (EUTIINCI) was dominant at KB1. *Navicula gregaria* (NAVIGREG) (KB3), *Nitzschia palea* (NITZPALE) (GB1) and *N. pumila* (NITZPUMI) (KB2) were dominant in the assemblages at other sites. In the Keurbooms the epipelic diatom composition was similar to that in the epilithon (Figure 30, see also Figure 29).

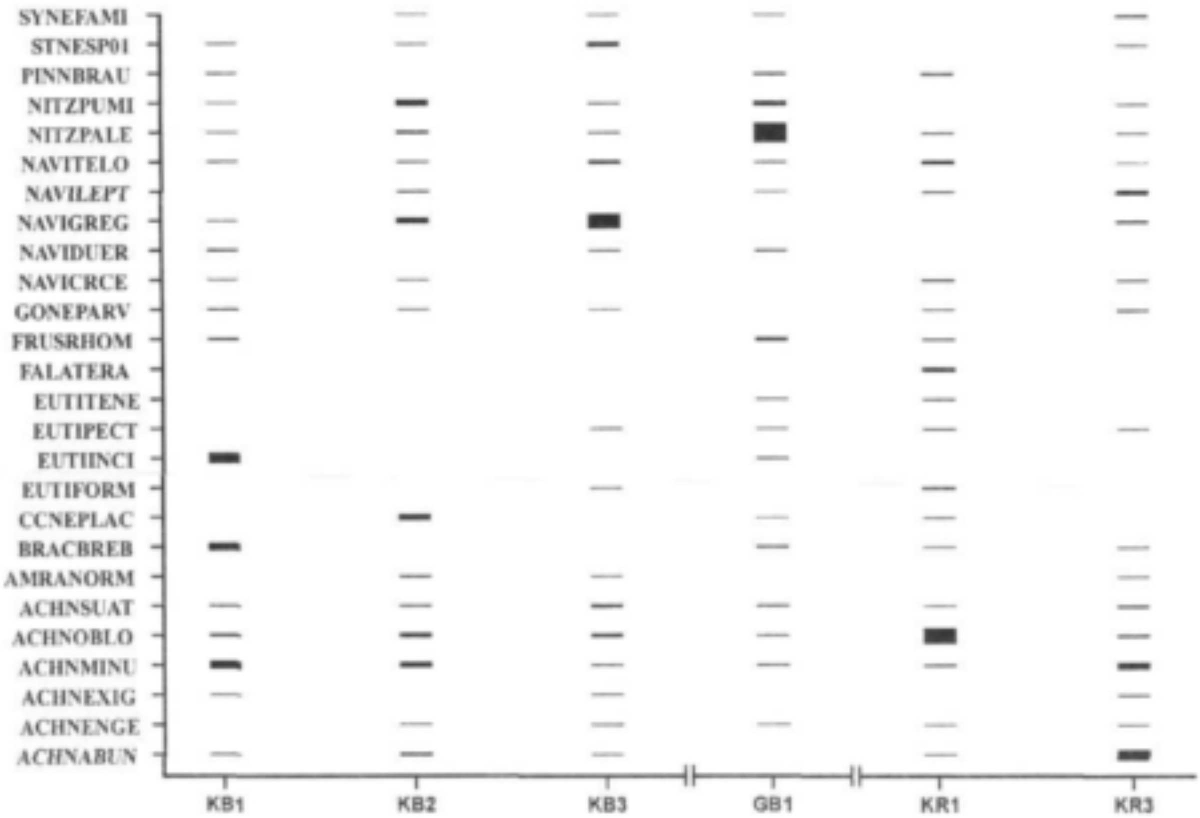

Figure 30. Illustration of the epipelic diatom species distribution (> 5% relative abundance) along the Klein Brak (KB1-KB3), Groot Brak (GB1) and Keurbooms (KR1, KR3) Rivers.

Water quality

The Klein Brak and Groot Brak showed characteristically low levels of nutrients, except at site KB1, where nitrite/nitrate levels were elevated (Table 44). The levels of pH were low in the upper reaches of both rivers. The impact of the trout farm in the Kwaai River (Keurbooms catchment, between T1 and T2) was visible, as the concentrations of ammonium and phosphate were high at T2. The impact of the tributary on the Keurbooms River could not be seen however, as the levels of these particular variables were back to normal at R2 (just downstream of the Kwaai-Keurbooms confluence). The pH levels were between 6.4 and 7.3 (Table 44).

Table 44. Water quality variables measured in the Klein Brak (KB1-KB3), Groot Brak (GB1-GB3) and Keurbooms (KR1- KR3, KT1 and KT2) Rivers on 7 May 1998 (Brak) and 2 June 1998 (Keurbooms).

	PH	Conductivity (MS/m)	NH_4^+ ($mg.l^{-1}$)	$NO_2^-+NO_3^-$ ($mg.l^{-1}$)	PO_4^{3-} ($mg.l^{-1}$)
GB1	4.9	12.9	0.06	0.17	0.078
GB2	7.4	27.1	0.08	0.18	0.038
GB3	7.4	50.9	0.04	0.14	0.030
KB1	4.7	13.5	0.02	0.65	0.016
KB2	7.3	23.3	0.02	0.10	0.027
KB3	6.9	19.3	0.05	0.06	0.076
KR1	6.7	14.4	0.03	0.05	0.014
KR2	6.9	15.3	0.04	0.05	0.012
KR3	7.3	29.6	0.02	0.04	0.002
KT1	6.4	8.4	0.02	0.03	0.005
KT2	6.7	8.9	0.38	0.05	0.106

Correlation between diatom distribution and water quality

The relationship between diatom assemblages and water quality variables was investigated with CCA. Table 45 gives a summary of the CCA analysis of the epilithic dataset. Figure 31 gives a graphic representation. A large proportion (65.5%) of the species distribution is explained by the measured environmental variables.

Axis 1 is highly correlated with the gradient in pH and nitrite/nitrate. KB1, where *Eunotia incisa* (EUTIINCI) was dominant, is placed at the acid end of the gradient with relatively high nitrogen concentrations. Along the second axis the gradient in conductivity and ammonium describes the differences between the Keurbooms and Brak Rivers sites.

Table 45. Summary of CCA of epilithic diatom species in Brak and Keurbooms Rivers.

	Axis 1	Axis 2	Axis 3	Axis 4	Total inertia
Eigenvalues	0.618	0.246	0.210	0.161	1.887
Species-environment correlations	0.991	0.984	0.963	0.969	
Cumulative percentage variance					
of species data	32.7	45.8	57.0	65.5	
of species-environment relation	46.5	65.1	81.0	93.1	
Sum of all unconstrained eigenvalues					1.887
Sum of all canonical eigenvalues					1.328

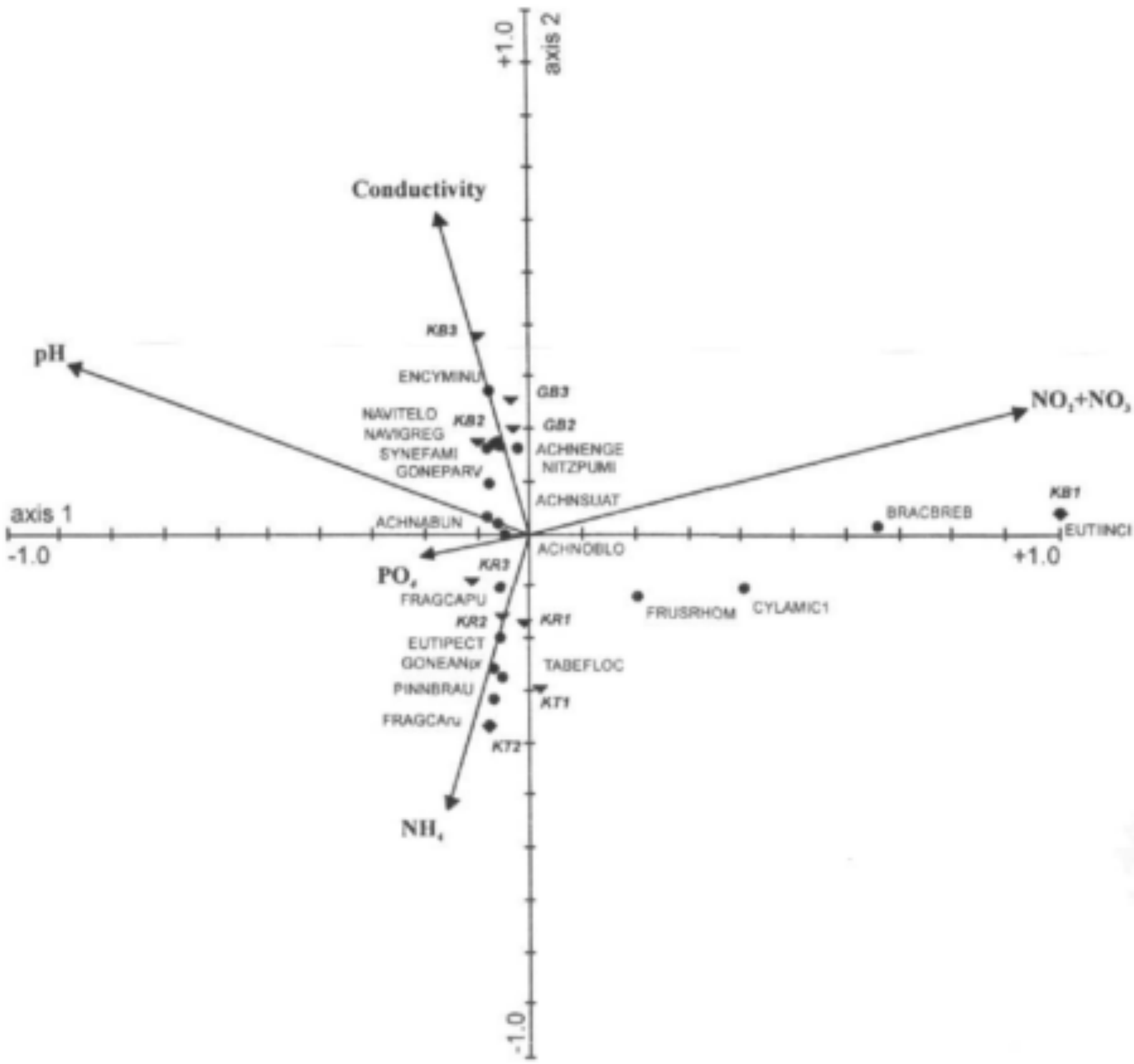

Figure 31. CCA ordination showing epilithic diatom species (circles), sites (triangles) and water quality variables (arrows) in the Brak and Keurbooms Rivers. See Table 45. Species acronyms are given in Appendix B

Table 46 is a summary of the CCA analysis of the epipelic dataset. Figure 32 gives a graphic representation. A large proportion (87.1%) of the species distribution is explained by the measured environmental variables.

Table 46. Summary of CCA of epipelic diatom species in Brak and Keurbooms Rivers.

	Axis 1	Axis 2	Axis 3	Axis 4	Total inertia
Eigenvalues	0.387	0.325	0.245	0.193	1.319
Species-environment correlations	1.000	0.998	0.994	0.970	
Cumulative percentage variance					
of species data	29.3	54.0	72.5	87.1	
of species-environment relation	33.7	62.0	83.2	100.0	
Sum of all unconstrained eigenvalues					1.319
Sum of all canonical eigenvalues					1.149

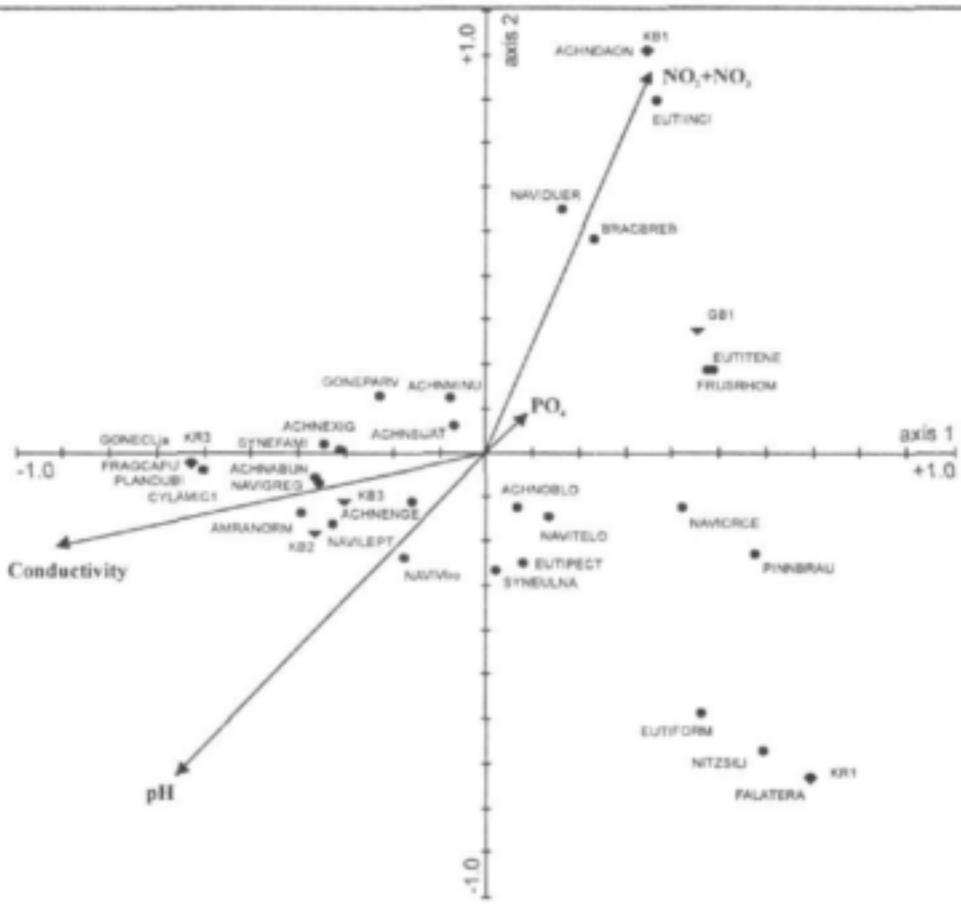

Figure 32. CCA ordination showing epipelic diatom species (circles), sites (triangles) and water quality variables (arrows) in the Brak and Keurbooms Rivers. See Table 46. Species acronyms aregiven in the Appendix.

As in the epilithon, site KB1 and its dominant species *Eunotia incisa* (EUTIINCI), are at the acid end of the pH gradient, at relatively high nitrogen concentrations. The separation between the Keurbooms upstream site (KR1) and the site in the lower reaches (KR3) along the first axis is mainly a result of the gradient in conductivity.

Species diversity

Table 47 illustrates the average species diversity (as Shannon diversity) and richness of the epilithic and epipelic samples. From this table it becomes clear that the species diversity is generally higher in the epipelon. In the epilithon 22 species and in the epipelon 24 species had a relative abundance of at least 10% (Table 47).

Table 47. Mean Shannon diversity, species richness and total amount of taxa that occurred in 10% abundance or more in the studied Western Cape rivers.

	Shannon Diversity		Species Richness		Species over 10%
	Mean	SE Mean	Mean	SE Mean	
epilithon	0.70	0.05	15.95	1.10	22
epipelon	0.85	0.05	18.43	1.24	24

DISCUSSION

The aim of this study was to investigate the changes of dominant benthic diatoms along an environmental gradient in each river. Due to high rainfall in the Palmiet and Bot catchment, the water quality gradient, which was apparent from historic data, was not present at the time of sampling. The high flow also had an influence on the diatom samples that were collected from, in particular, the epipelic samples. The sediment that was collected in the Palmiet and Bot rivers contained only a few diatoms. In two cases, epipelic samples from the Klipdrif in the Palmiet catchment contained so few cells, that these samples had to be disregarded from further analyses. It is possible that the high flow washed away most of the sediment in which the epipelic diatoms were present and only bare sediment was left. Another reason might be that due to the high water level, places where an established epipelic diatom community was present could not be reached. This argument would also apply to diatoms collected from stones (epilithon). Epilithic diatom communities are also likely to be affected by high flow, however, due to the greater stability of the habitat substrate, to a lesser extent than the epipelon (Cattaneo, 1997).

The diversity in the epilithic samples was on average lower than in the epipelon. As described by Round (1993) the epilithic communities consist of several layers each with distinct growth forms of diatoms. It is possible to collect these layers separately by careful sampling. It seems, from the low average diversity, that the sampling of one of the microhabitats within the epilithon was successful. A great advantage of sampling a specific microhabitat is the collection of fewer growth forms (hence species) so that the species that dominate the microhabitat come out more clearly. Being attached to larger substrata, epilithic diatoms are generally associated with fast currents. These attached communities are therefore provided with better nutrient exchange but are also exposed to increased scouring. The epipelic diatoms, living among sediment grains, are found in slower currents and are therefore less exposed to scouring. The sediments can, however, be enriched by seston deposition (Cattaneo, 1997), therefore altering the effective water quality in which these diatoms grow. Since both habitats have their advantages and disadvantages, it remains advisable to sample both habitats at each site.

The method used to find a correlation between species distribution and water quality variables, requires the number of sampling sites to be one more than the number of variables that can be tested. For this reason, five sampling sites has been shown to be a bare minimum, since samples could not always be taken from the same habitat, bringing down the number of effective sites for each analysis. This aspect should be taken into consideration by the design of future research projects on diatoms as indicators of water.

EPILITHIC AND EPIPELIC DIATOMS IN RELATION TO WATER QUALITY IN RIVERS IN THE EASTERN CAPE.

Introduction

The Eastern Cape is largely a transition zone of climate types and seasonality of rainfall is much less pronounced than in other parts of the country (Stone, 1988). Figure 33 illustrates the distribution of rainfall areas. The Gamtoos River catchment is situated in a spring maximum area. The other river systems (Sundays, Buffalo and Nahoon Rivers) experience an autumn maximum in the upper reaches and a spring maximum in the lower reaches. In all river systems in this study, various dams regulate the runoff. During the sampling trips that are reported in this section, river water was flowing at all sites. The sampling sites were chosen from a set that are sampled regularly (ranging from weekly to every two months) by the Department of Water Affairs and Forestry (DWAF). At most of these sites, weirs are present with continuous data loggers to record the water levels. The water quality analyses were done by the DWAF. The Gamtoos and Sundays catchments were sampled in co-operation with technicians from the DWAF hydrology office in Cradock. The Buffalo and Nahoon were sampled with a technician from the DWAF water quality office in East-London.

Study Area

Gamtoos River

The Gamtoos River catchment area has been estimated at 34 400 km^2 with and MAR of 485×10^6 m^3 and is the fourth largest catchment in the Cape. The two major tributaries to the Gamtoos are the Groot and Kouga Rivers. The Groot River catchment lies largely in the Karoo Region and is the main contributor to the silt load in the Gamtoos River. This is illustrated by the fact that the capacity of the Beervlei Dam (in the Groot Catchment) was reduced by 2×10^6 m^3 between 1960 and 1967 as a result of the entrapment of silt. It was therefore necessary to raise the dam wall to increase the storage capacity (Heinecken, 1981). The second major tributary, the Kouga River, drains a catchment area dominated by Valley Bushveld (Lubke and Van Wijk, 1988). As a result, the river is relatively silt-free (Heinecken, 1981). The Kouga Dam is one of the major suppliers of drinking water for the Port Elizabeth municipality. A third tributary, the Loerie River, enters the

Gamtoos Estuary, 8.5 km from its mouth. The Loerie Dam receives water from the Kouga Dam as part of an intra catchment transfer scheme (Heinecken, 1981).

Figure 33. Seasonal distribution of rainfall in the Eastern Cape, South Africa (from Köpke, 1988).

Figure 34 illustrates the 10 sampling sites in the Gamtoos River catchment area. All sites and codes are listed in Table 48. Site R1 (R stands for the main river as opposed to T, which stands for tributary) was situated directly downstream from the Beervlei Dam. Site R2, not part of the regular sampling programme of the DWAF and therefore sampled ad hoc, was situated just upstream from the confluence with the Heuningklip River, one of the tributaries to the Groot River. Site T1 was situated in the Heuningklip River. Site T2 was situated in the Wabooms River, a tributary to the Kouga. Site T3 is situated in the Kouga. Site R5 was situated in the Gamtoos, just after the confluence of the Kouga and Groot Rivers. Normally no water is released from the Kouga Dam (approximately 1 km upstream from site R5). T4 was situated just downstream from the Loerie Dam, which was overflowing at the time of sampling.

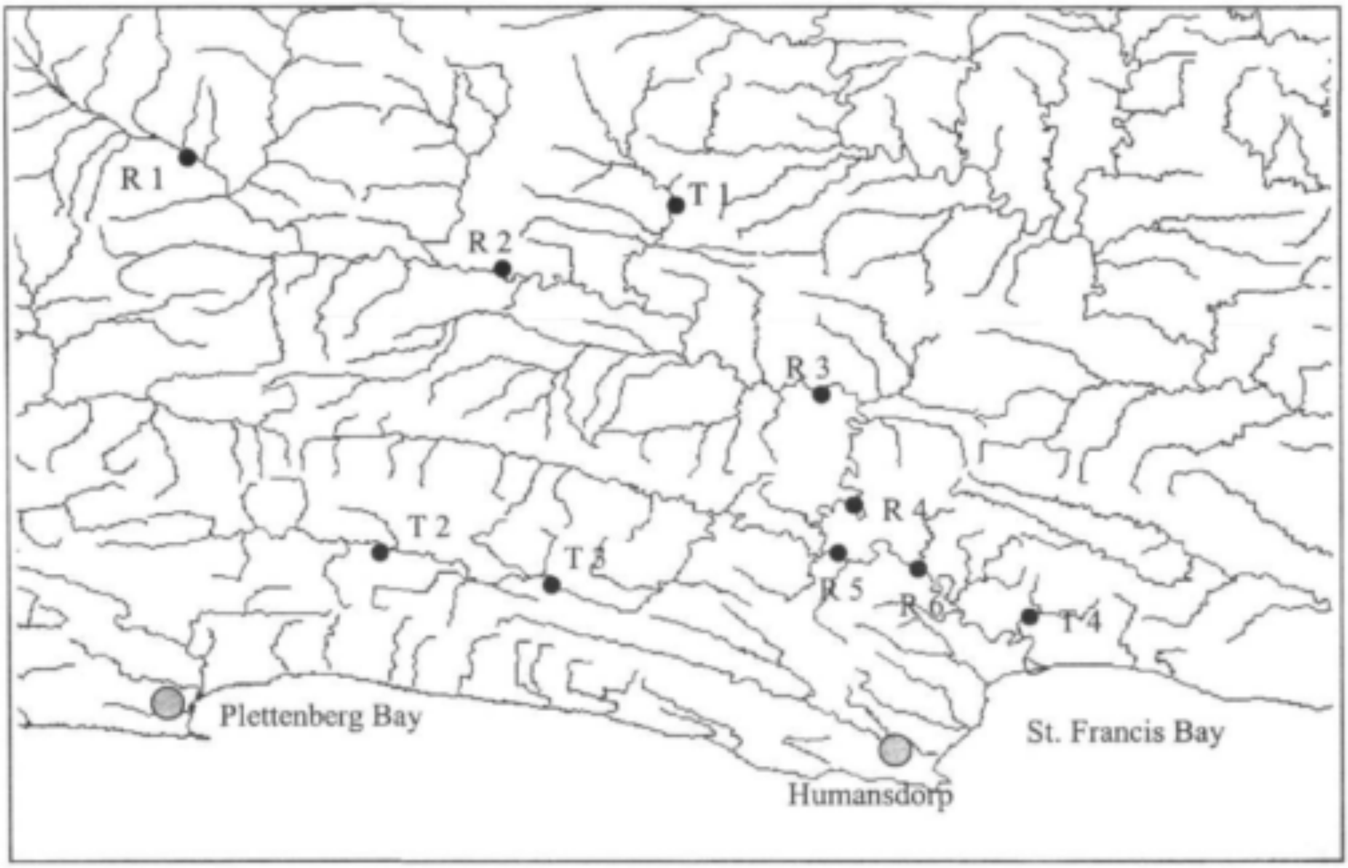

Figure 34. The Catchment of the Groot, Kouga and Gamtoos Rivers, showing sampling sites. R= site on the main river; T= site on a tributary to the main river.

Table 48. Sampling sites in the Groot, Kouga and Gamtoos Rivers. * Indicates which community was sampled. See also Figure 34.

Site	DWAF code	date	epipelon	epilithon
R1	L3R001	12/8/1997	*	
R2	ad hoc	12/8/1997	*	*
R3	L7H007	12/8/1997	*	*
R4	L7H006	29/7/1997	*	*
R5	ad hoc	29/7/1997		*
R6	ad hoc	29/7/1997	*	*
T1	L6H001	12/8/1997		*
T2	L8H001	30/7/1997	*	
T3	L8H005	30/7/1997	*	*
T4	L9H005	29/7/1997	*	*

Sundays River

The largest part of the Sundays River Catchment (total of 20 729 km^2, MAR = 186 x 10^6 m^3) lies in the Karoo Region (geology dominated by various shale groups). This results in river water with high TDS and silt loads. The Darlington Dam (capacity 206 x 10^6 m^3) acts as a giant sediment trap. The other major dam in the catchment (Van Ryneveld Pass) has a capacity of 53 x 10^6 m^3. With an overall mean annual precipitation of 323 mm, the Sundays River catchment is a relatively dry area (Reddering and Esterhuysen, 1981). Water from the Orange-River transfer scheme (implemented in 1978) enters the catchment, via the Great Fish River, in the Skoenmakers River, which flows into the Darlington Dam (Archibald, 1983).

Figure 35 illustrates the 7 sampling sites in the Sundays River that are listed in Table 49. Site R1 was situated directly downstream from the Van Ryneveld Pas Dam in the river at Graaff Reinet. T1 was situated in the Voël River, a tributary to the Darlington Dam. R4 was situated directly downstream from this dam.

Table 49. Sampling sites in the Sundays River. * Indicates which community was sampled. See also Figure 35.

Site	DWAF code	date	epipelon	epilithon
R1	N1H013	11/8/1997		*
R2	N2H002	13/8/1997	*	
R3	N2H007	12/8/1997		*
R4	N2H010	13/8/1997		*
R5	N4H001	13/8/1997	*	
R6	N4H003	13/8/1997	*	
T1	N3H002	13/8/1997		*

Buffalo River

The Buffalo River is a short (125 km) system, typical of the eastern seaboard of South Africa. The catchment covers an area of 1276 km^2 and has a MAR of approximately 114 x 10^6 m^3. The river consists of a mountain reach zone, characterised by steep, turbulent, clear water, in shallow, narrow channels; followed by a foothill zone. The turbidity increases downstream, as a result of the entrainment of sediment and the development of phytoplankton. There are four major impoundments in the catchment that have a profound effect on the physico-chemical conditions in the river (Palmer and O'Keeffe, 1990; O'Keeffe *et al.*, 1996). Various point and diffuse sources (e.g. sewerage works effluents, run-off from informal settlements and small industries) seriously impact the water quality of the river. The major variables of concern are faecal bacteria, TDS and nutrient enrichment (O'Keeffe *et al.*, 1996).

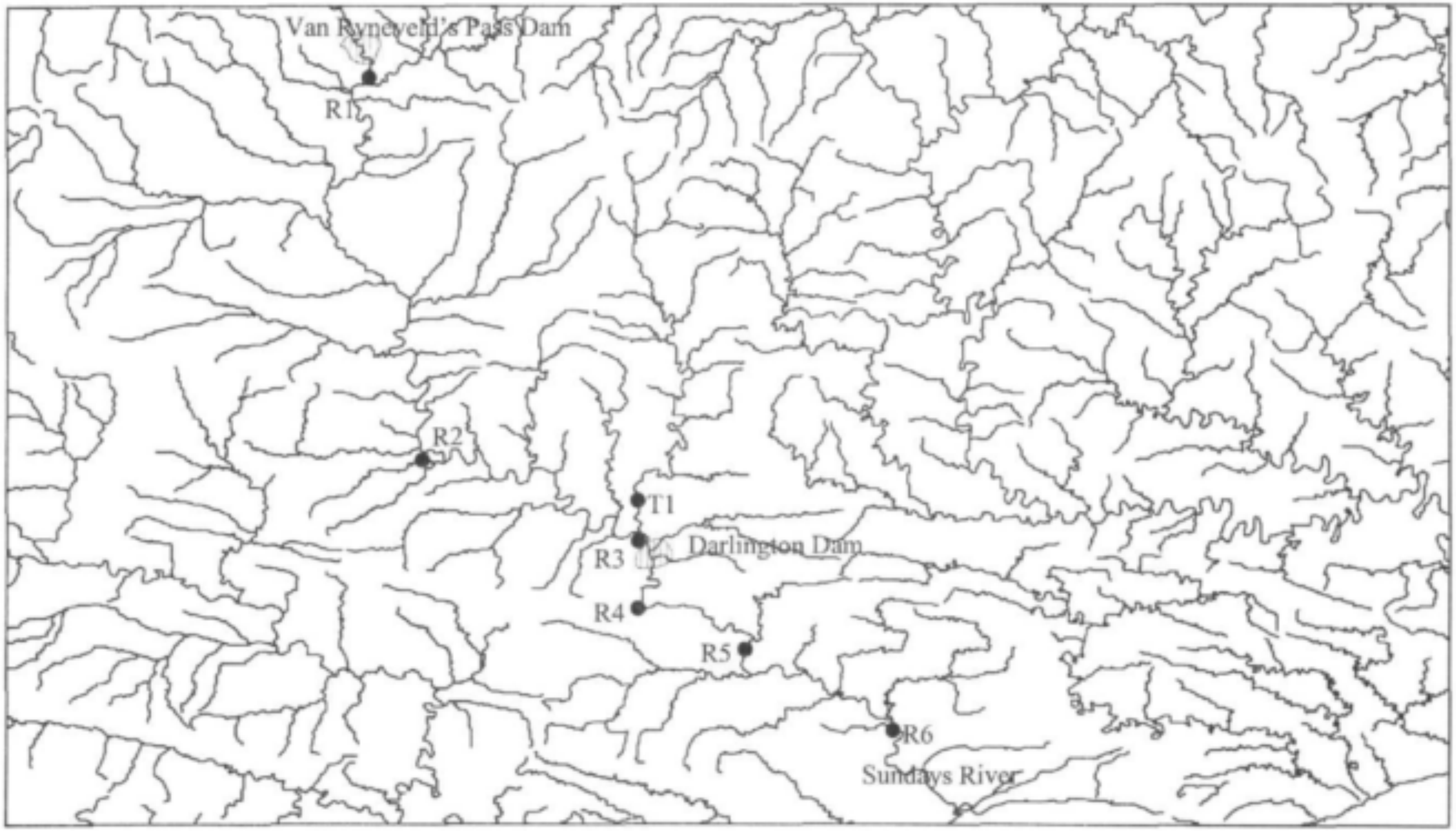

Figure 35. The Catchment of the Sundays River, showing sampling sites. R= site on the main river; T= site on a tributary to the main river.

The sampling sites in the Buffalo River (Figure 36) are part of a local monitoring scheme run by the DWAF office East London, but do not have a national DWAF code (Table 50). Site R1 is situated directly below the Maden Dam. Site R3 was situated just downstream from the King Williams town (KWT) sewerage treatment outlet. Site R4 was situated just downstream from Laing Dam. Site R5 was situated just before the Buffalo River entered the Bridle Drift Dam. Site R6 was situated approximately 8 km downstream from the Bridle Drift Dam outlet.

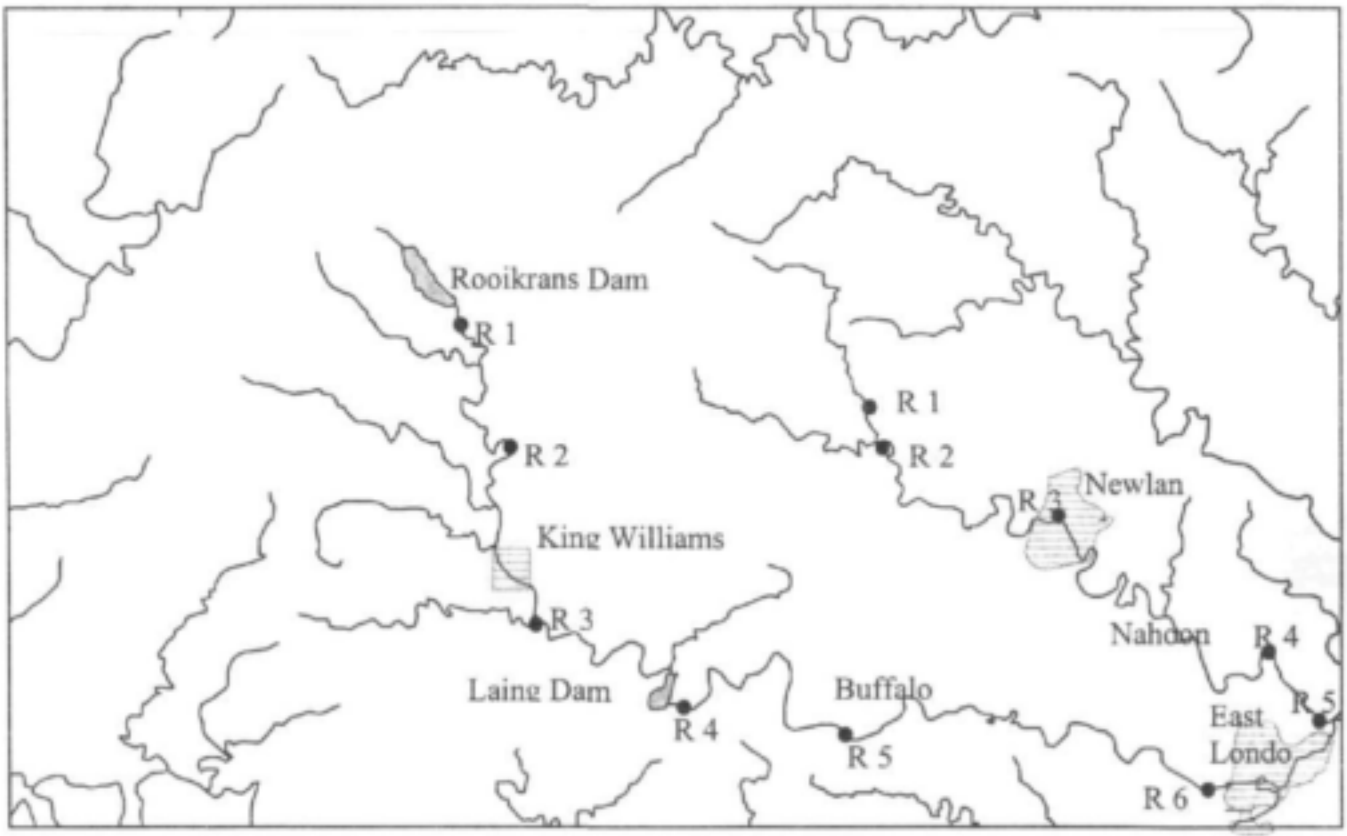

Figure 36. The Catchment of the Buffalo and Nahoon Rivers showing sampling sites. R= site on the main river.

Table 50. Sampling sites in the Buffalo River. * indicates which community was sampled. See also Figure 36.

Site	DWAF name	date	epipelon	epilithon
R1	Maden dam	4/8/1997		*
R2	Horse Shoe bend	4/8/1997	*	
R3	KWT sewerage	4/8/1997		*
R4	Laing dam	4/8/1997		*
R5	Needs camp	4/8/1997		*
R6	Buffalo pass	4/8/1997		*

Nahoon River

The Nahoon River catchment (approximately 600 km^2) borders the Buffalo River catchment. The Nahoon River is short (90 km) with a MAR of 34×10^6 m^3. There is one major impoundment in the main channel of the river, the Nahoon Dam, which has a capacity of 22×10^6 m^3. The catchment is dominated by grasslands and has a high sediment yield of 201 000 tonnes p.a. (Reddering and Esterhuysen, 1985; Wiseman *et al.*, 1993).

In the Nahoon River 4 epilithic samples and 1 epipelic sample were collected (Figure 36 and Table 51). The latter was collected at site R5, which is just upstream from the head of the Nahoon estuary. The Nahoon Dam is situated between R3 and R4.

Table 51. Sampling sites in the Nahoon River. * indicates which community was sampled. See also Figure 7.4.

Site	DWAF name	date	epipelon	epilithon
R1	Berlin	4/8/1997		*
R2	Witchkrans	4/8/1997		*
R3	Newlands	4/8/1997		*
R4	Dorchester	4/8/1997		*
R5	Abbotsford	4/8/1997	*	

The methods for water quality analyses; diatom collection, identification and enumeration and data analyses are described earlier in the section on methods.

RESULTS

Gamtoos and Sundays

In the Gamtoos River catchment, 10 sites were sampled (Figure 34). At sites R2-R6 and T3 and T4 the epilithic habitats were sampled. The epipelic habitats were sampled at sites R1-R3, R6 and T2-T4 (Table 48). Note that sites T2-T4 were situated in tributaries to the Groot and Gamtoos Rivers (Figure 34). T2 and T3 were situated in the Kouga River. T4 was the site in the Loerie River just below the Loerie Dam, which was overflowing at the time.

In the Sundays River, 6 sites were sampled (Figure 35). At sites R2, R5 and R6 the epipelic habitats were sampled, at the other 3 sites (R1, R3 and R4) epilithic habitats were sampled. Site T1 was situated in the Voël River, a tributary to the Darlington dam, which is part of the Sundays River system.

Gamtoos and Sundays epilithon

Figure 37 illustrates the relative abundance of epilithic diatom taxa (>5% abundance) at sites in the Gamtoos and Sundays Rivers (see the Appendix for an explanation of acronyms). In the Gamtoos River, sites GR2 and GR3 were dominated by *Nitzschia fonticola* (NITZFONT). Site GR4 showed a dominance of *Cocconeis placentula* (CCNEPLAC). At site GR5 *Achnanthes engelbrechtii* (ACHNENGE) was dominant changing to a dominance of *Navicula gregaria* (NAVIGREG) at site GR6. Site GT3 (situated in the Kouga River) was dominated by *Achnanthes oblongella* (ACHNOBLO). In the Loerie River (site GT4, situated just downstream of the Loerie dam) *Gomphonema parvulum* (GONEPARV) was dominant with *Navicula gregaria* (NAVIGREG) a co-dominant having an almost equal abundance (Figure 37).

In the Sundays River at site SR1, *Nitzschia fonticola* (NITZFONT) was dominant (Figure 37). This species appeared in relative high abundance at all sites but was only dominant at SR1. This was also the case for *Nitzschia frustulum* (NITZFRUS), which was dominant at site ST1. *Synedra tabulata* (SYNETABU) dominated the epilithic diatom community at site SR3. At site SR4, there was a dominance of *Diatoma vulgare* (DIATVULG) (Figure 37).

Gamtoos and Sundays Rivers epipelon

Figure 38 illustrates the relative abundance of epipelic diatom species (>5% abundance) at sites in the Gamtoos and Sundays Rivers. In the Gamtoos at site GR1 *Nitzschia fonticola* (NITZFONT) was dominant. *Nitzschia frustulum* (NITZFRUS) was dominant at sites GR2 and GR3. At site GR4 *Diploneis puella* (DINEPUEL) and at site GR5 *Navicula gregaria* (NAVIGREG) were dominant. At site R6, *Hantzschia distepunctata* (HANTDIST) and *Amphora cognata* (AMRACOGN) were most abundant. *Hantzschia distepunctata* (HANTDIST) did not occur on any of the other sites. The species composition at GT2 was considerably different, with *Eunotia fallax* var. *groenlandica* (EUTIFALA, plate 2) as the dominant. At both sites GT3 and GT4, *Navicula gregaria* (NAVIGREG) was dominant. In the epipelon of the Sundays River, *Nitzschia linearis* var. *tenuis* (NITZLIte) was found at all three sites and was dominant at SR2. *Navicula mollis* (NAVIMOLL) was found at sites SR5 and SR6 and was dominant at SR5. *Navicula phyllepta* (NAVIPHYL) was found and was dominant only at site SR6 (Figure 38).

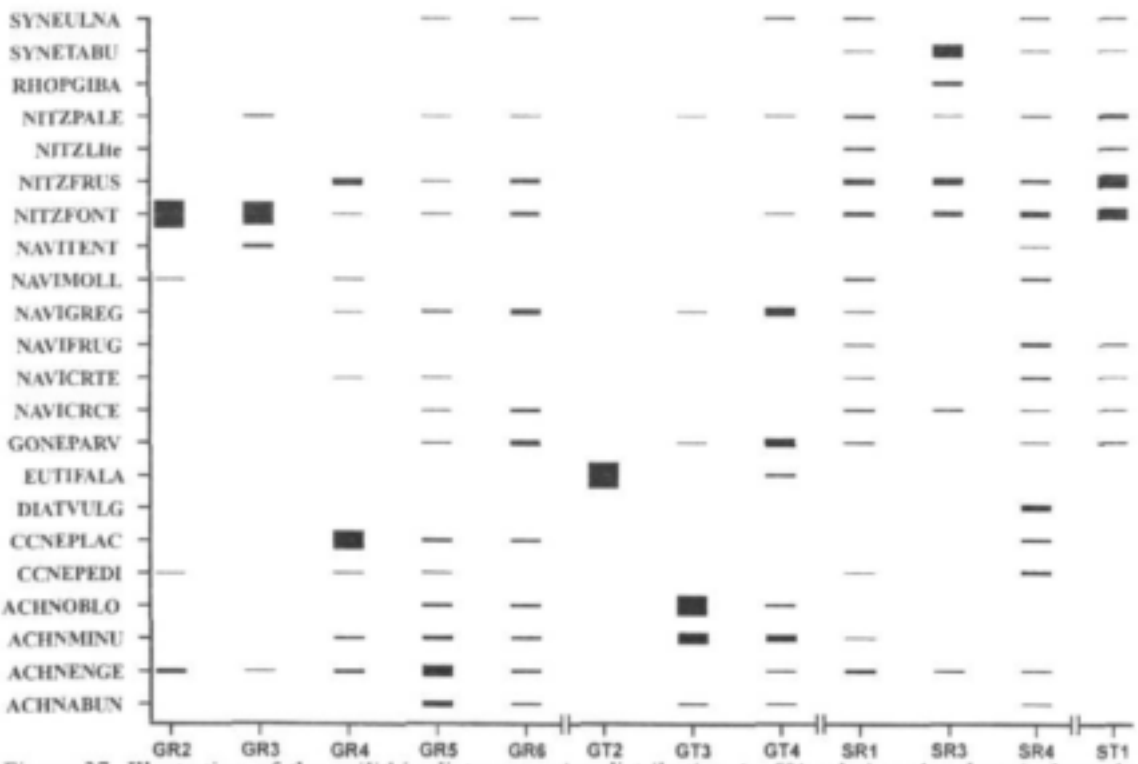

Figure 37. Illustration of the epilithic diatom species distribution (> 5% relative abundance) along the Gamtoos and Sundays Rivers. Sampling sites in Gamtoos (GR2-GR6), tributaries to the Gamtoos (GT2-GT4), Sundays (SR1-SR4) and tributary to Sundays (ST1).

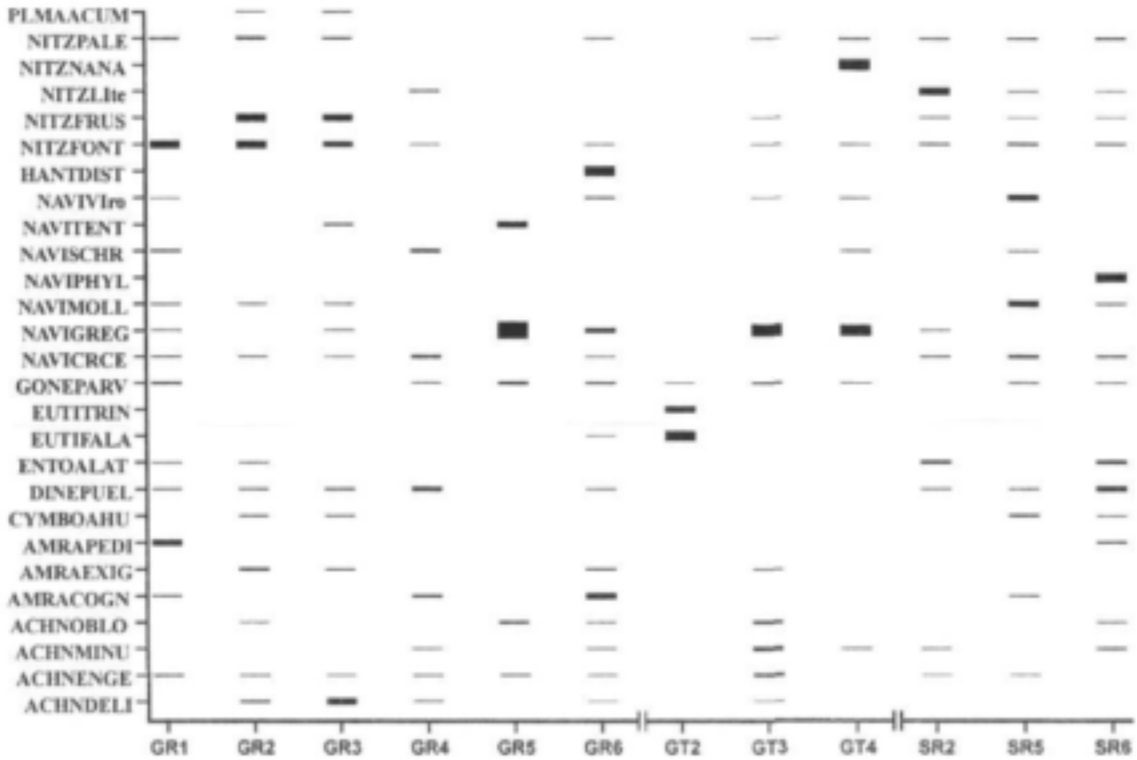

Figure 38. Graphic illustration of the epipelic diatom species distribution (> 5% relative abundance) along the Gamtoos and Sundays Rivers. Sampling sites in Gamtoos (GR1-GR6), tributaries to the Gamtoos (GT2-GT4) and sites in the Sundays River (SR2-SR6).

DCA

A Detrended Correspondence Analysis (DCA) was conducted to investigate patterns of distribution of epilithic and epipelic diatom taxa in the Gamtoos and Sundays Rivers. An initial DCA revealed that the epilithic and epipelic assemblages at site T2 in the Gamtoos River were outliers. These samples are probably outliers because of the low pH levels at this site (pH=4.9 at GT2, see Table 52). A subsequent DCA was done on the data set without these outliers (Figure 39). A separation is visible between samples from the lower reaches of the Gamtoos (GR4-GR6 and GT3-GT4), sites in the upper reaches (GR1-GR3) and samples from the Sundays River (SR1-SR6, ST1). Sundays River sample SR3 is similar to Gamtoos samples GR2-GR3 and the epipelon from GR4. All these sites are within the Karoo region. The epilithic and epipelic samples at most other sites were plotted at similar distances as neighbouring sites (e.g. GT3, pGT3 and GT4, pGT4). This indicates that the difference between sites was similar to the difference between habitats. For one site (GR4) however, this was not the case. The epipelic assemblage at GR4 is more similar to the assemblages directly upstream (GR3 and GR2). The epilithic assemblage at GR4 is more similar to the downstream sites GR5 and GR6. As will be discussed in later sections, most water quality variables at GR4 were similar to GR5 and GR6, suggesting that the epilithon reacts differently to changing water quality than does

Water Quality

The water quality measured in the Gamtoos and the Sundays are summarised in Table 52. Where the data was available from the DWAF database, an average of the water quality at the sites at time of sampling, one and two weeks prior to sampling was taken. In the upper reaches (Karoo region) of the Gamtoos (GR1-GR3), the electrical conductivity was generally high. At sites GR4 - GR6 these concentrations decreased considerably. This corresponds to a change of vegetation from Karoo karroid vegetation (upper reaches) to False Sclerophyllous Bush (lower reaches) (Midgley *et al.*, 1994a). A decrease in conductivity was visible between SR3 and SR4 in the Sundays River. This could be the effect of the Darlington Dam, which gets its main input from the Orange River transfer scheme. Sediment is normally retained within the dam. Silicate concentrations were increased downstream of the dam. In the upper reaches of the catchment, soils are described as sandy loam. The lower reaches are dominated by clayey loam soils, which corresponds with a decreased erodibility (Midgley *et al.*, 1994b).

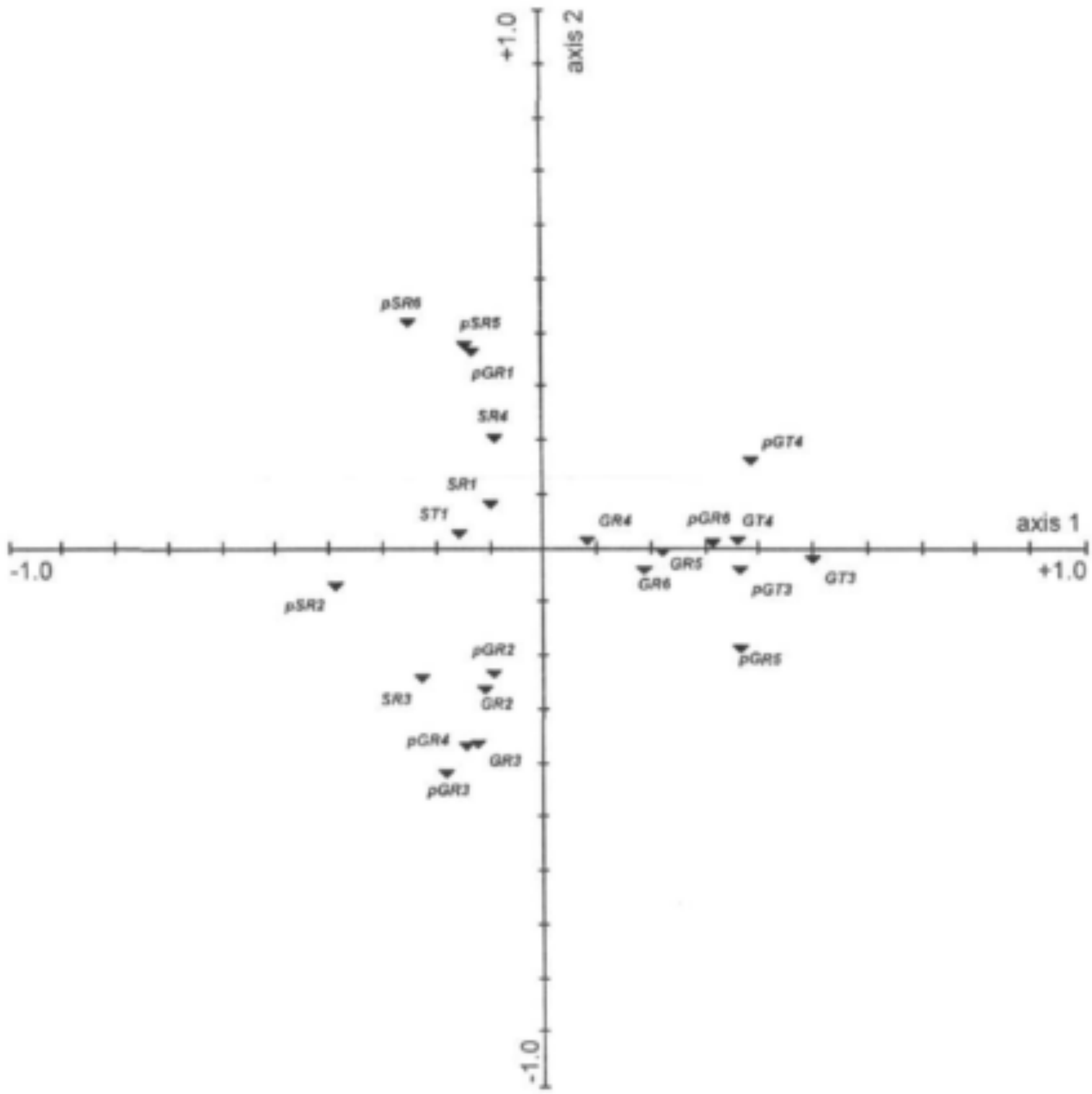

Figure 39. DCA ordination of sites in the Gamtoos and Sundays River catchments. A 'p' indicates a sample from the epipelon, all other samples from epilithon. Eigenvalues: axis 1 = 0.49; axis 2 = 0.34.

Table 52. Water quality variables measured in the Gamtoos and Sundays Rivers between 15 July 1997 and 12 August. Values are geometric means (metric mean for pH) of measurements at time of diatom sampling and two weekly measurements prior to sampling (if available). Missing data at ad hoc sites GR2, SR1 and SR2 due to loss of samples.

	Alkalinity (as $CaCO_3$ in $mg.l^{-1}$)	Ca^{2+} ($mg.l^{-1}$)	Cl^- ($mg.l^{-1}$)	Conductivity ($mS.m^{-1}$)	K^+ ($mg.l^{-1}$)	Mg^{2+} ($mg.l^{-1}$)	Na^+ ($mg.l^{-1}$)	NH_4^+ ($mg.l^{-1}$)	$NO_2^-+NO_3^-$ ($mg.l^{-1}$)	pH	PO_4^{3-} ($mg.l^{-1}$)	SiO_2 ($mg.l^{-1}$)	SO_4^{2-} ($mg.l^{-1}$)	TDS ($mg.l^{-1}$)
GR1	170.9	56.9	292.7	153.1	8.8	30.3	206.0	0.0	0.0	8.4	0.068	1.10	164.9	977.6
	(33.2)	(15.6)	(196.6)	(87.5)	(0.1)	(18.4)	(131.5)	(0.01)	(0.04)	(0.1)	(0.05)	(1.34)	(94.8)	(497.8)
GR2	*	*	*	1103.0	*	*	*	*	*	8.1	*	*	*	*
GR3	276.1	516.5	6896.9	2005.7	24.3	698.9	3708.0	0.1	0.0	8.2	0.022	0.43	2100.5	14284.0
	(32.6)	(35.9)	(148.6)	(75.1)	(2.3)	(16.5)	(163.1)	(0.01)	(0.02)	(0.1)	(0.01)	(0.30)	(85.2)	(480.5)
GR4	66.0	19.0	171.0	74.7	1.7	19.0	100.0	0.0	0.1	8.3	0.009	1.80	53.0	444.0
GR5	29.0	8.0	69.0	23.4	1.7	8.0	41.0	0.1	0.3	7.6	0.026	3.60	28.0	192.0
GR6	51.0	14.0	112.0	49.7	1.9	13.0	65.0	0.0	0.9	7.1	0.023	6.80	36.0	309.0
GT1	281.6	216.1	1807.4	697.4	17.5	220.2	1132.0	0.0	0.0	8.5	0.034	1.55	1058.5	4796.8
	(17.4)	(13.6)	(58.7)	(34.4)	(0.3)	(8.5)	(32.0)	(0.01)	(0.01)	(0.1)	(0.00)	(0.29)	(21.5)	(112.0)
GT2	6.0	1.0	10.0	5.5	0.2	1.0	6.0	0.0	0.2	4.9	0.005	2.00	7.0	34.0
GT3	16.0	5.0	39.0	18.5	1.0	4.0	22.0	0.1	0.3	6.6	0.020	2.40	11.0	104.0
GT4	23.0	5.0	57.0	25.2	1.7	5.0	34.0	0.1	0.3	6.7	0.026	3.30	29.0	162.0
SR1	*	*	*	601.0	*	*	*	*	*	8.6	*	*	*	*
SR2	*	*	*	590.0	*	*	*	*	*	8.1	*	*	*	*
SR3	211.6	233.9	1352.9	480.2	10.2	152.0	645.0	0.0	0.0	8.3	0.031	0.59	524.2	3178.1
	(15.1)	(6.5)	(22.5)	(4.5)	(0.6)	(3.4)	(22.7)	(0.02)	(0.03)	(0.1)	(0.01)	(0.14)	(21.0)	(38.4)
SR4	209.7	46.8	142.2	97.5	4.9	24.8	123.6	0.1	0.1	8.4	0.046	3.57	82.9	682.1
	(6.9)	(2.6)	(6.1)	(2.0)	(0.3)	(1.3)	(5.4)	(0.03)	(0.03)	(0.1)	(0.03)	(0.35)	(6.7)	(24.7)
SR5	219.1	48.2	165.2	98.2	4.8	27.4	131.6	0.1	0.0	8.5	0.050	3.72	70.6	719.4
	(35.9)	(4.9)	(14.3)	(11.7)	(0.2)	(4.7)	(5.5)	(0.33)	(0.01)	(0.0)	(0.01)	(1.70)	(14.7)	(59.3)
SR6	388.7	66.0	611.3	294.7	5.1	69.0	502.0	0.0	1.5	8.6	0.024	4.14	261.7	1997.5
	(23.7)	(5.9)	(56.0)	(34.4)	(0.2)	(2.3)	(59.3)	(0.01)	(0.06)	(0.0)	(0.01)	(0.35)	(24.3)	(172.9)
ST1	231.2	77.2	339.1	170.9	5.3	47.3	195.0	0.0	0.2	8.4	0.021	4.74	104.9	1054.2
	(34.4)	(13.0)	(15.3)	(7.5)	(0.1)	(2.1)	(4.4)	(0.01)	(0.02)	(0.1)	(0.01)	(1.44)	(11.6)	(81.9)

Effect of water quality on diatom distribution

The relationship between diatom assemblages and water quality variables was investigated with CCA. An initial CCA revealed that the variables Ca, Cl, conductivity, K, Na, SO_4, alkalinity and TDS were strongly correlated with each other ($r>0.85$). Therefore, this group of ions was represented by conductivity.

Table 53 gives a summary of the CCA analysis of the epilithic data set. Figure 40 gives a graphic representation. A large proportion (57.2%) of the species distribution is explained by the measured environmental variables.

Table 53. Summary of CCA of epilithic diatom species in Gamtoos and Sundays Rivers.

	Axis 1	Axis 2	Axis 3	Axis 4	Total inertia
Eigenvalues	0.495	0.309	0.224	0.150	2.057
Species-environment correlation	0.996	0.956	0.973	0.931	
Cumulative percentage variance					
of species data	24.1	39.1	50.0	57.2	
of species-environment relation	35.8	58.2	74.4	85.2	
Sum of all unconstrained eigenvalues					2.057
Sum of all canonical eigenvalues					1.382

Axis 1 is mainly correlated with conductivity and pH. Along this axis, sites and species in the lower reaches of the Gamtoos (on the right-handed side of the diagram) are separated from the other sites. Sites and species in the Sundays and the higher reaches of the Gamtoos are mainly correlated with relatively high conductivity and pH (left side of diagram). This gradient has a strong influence on the distribution of *Nitzschia fonticola* (NITZFONT) and *N. frustulum* (NITZFRUS) at the alkaline end of the gradient. Taxa like *Achnanthes oblongella* (ACHNOBLO) and *Eunotia fallax* var *groenlandica* (EUTIFALA) are at the more acid end (pH = 6.5 - 7).

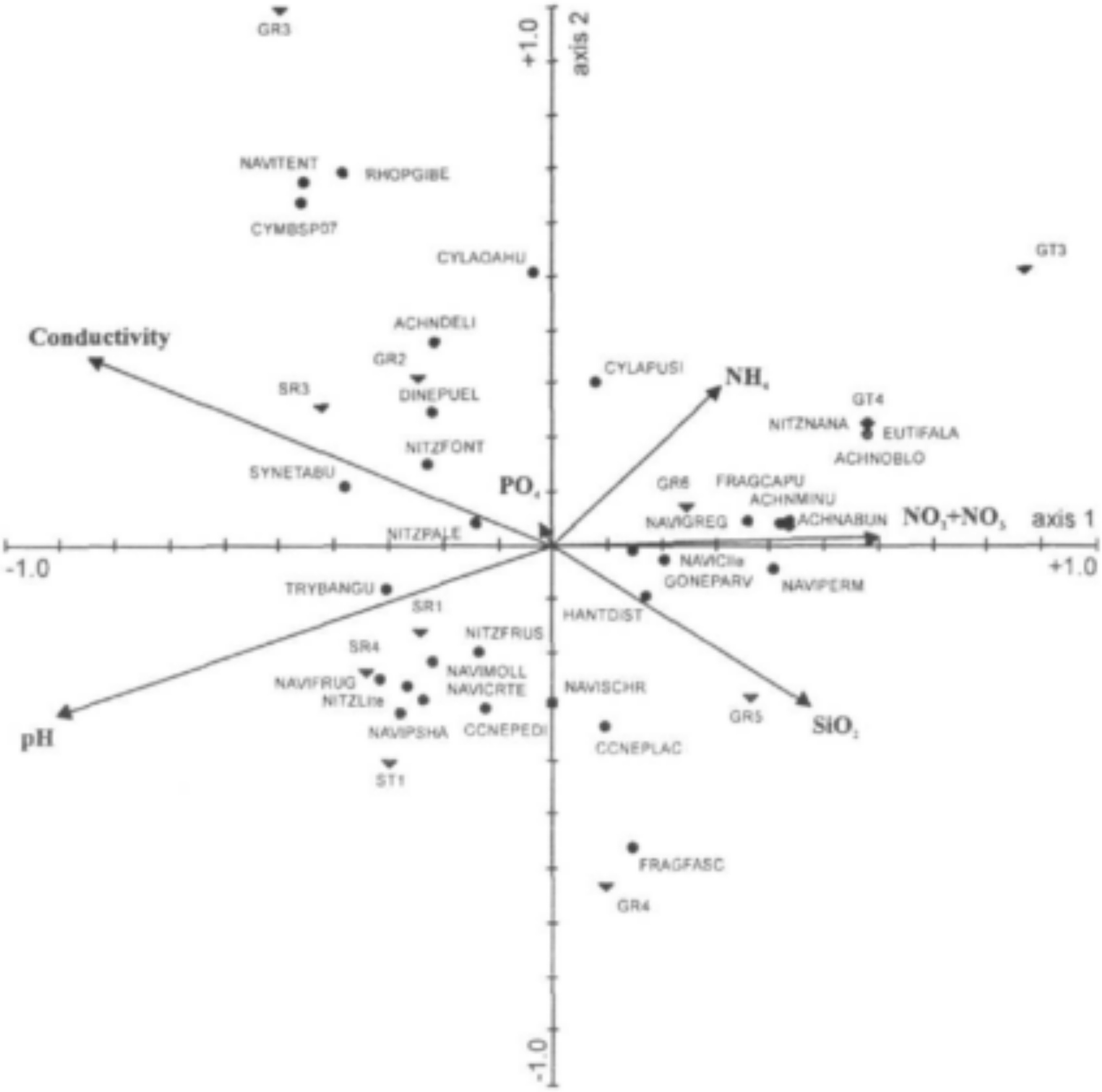

Figure 40. CCA ordination showing epilithic diatom species (circles), sites (triangles) and water quality variables (arrows) in the Gamtoos and Sundays Rivers. See Table 53. Species acronyms given in the Appendix.

Table 54 gives a summary of the CCA analysis of the epipelic data set. Figure 41 gives a graphic representation. A smaller proportion (49.8%) than for the epilithic species distribution, is explained by the measured environmental variables.

Axis 1 is highly correlated with conductivity and pH. As in the epilithon, *Nitzschia fonticola* (NITZFONT) and *N. frustulum* (NITZFRUS) (dominant at site GR2 and GR3) correlate with high conductivity. Taxa such as *Navicula gregaria* (NAVIGREG) and *Nitzschia nana* (NITZNANA) occur at the more acid end of the pH gradient.

Table 54. Summary of CCA of epipelic diatom species in Gamtoos and Sundays Rivers.

	Axis 1	Axis 2	Axis 3	Axis 4	Total inertia
Eigenvalues	0.518	0.385	0.316	0.287	3.025
Species-environment correlation	0.989	0.988	0.971	0.980	
Cumulative percentage variance					
of species data	17.1	29.9	40.3	49.8	
of species-environment relation	27.2	47.4	63.9	79.0	
Sum of all unconstrained eigenvalues					3.025
Sum of all canonical eigenvalues					1.908

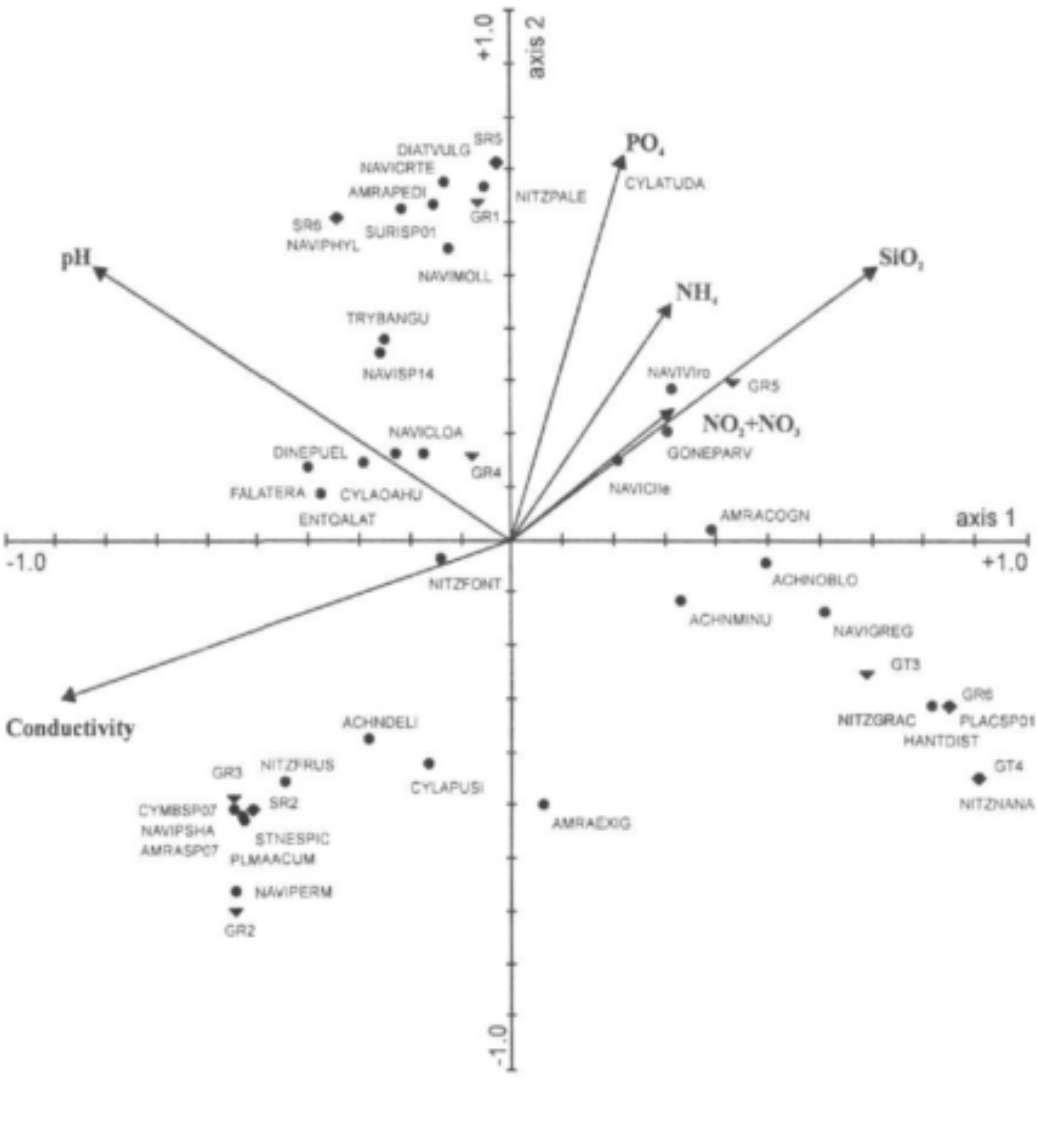

Figure 41. CCA ordination showing epipelic diatom species (circles), sites (triangles) and water quality variables (arrows) in the Gamtoos and Sundays Rivers. See Table 54. Species acronyms given in the Appendix.

Buffalo and Nahoon Rivers

In the Buffalo River, 6 sites were sampled (Figure 36). At site BR2 the epipelic habitat was sampled whereas at the other 5 sites (BR1-BR6), epilithic habitats were sampled. In the Nahoon River, 5 sites were sampled (Figure 36). At site NR5 the epipelic habitat could be sampled, while at the other 4 sites (NR1-NR4), only the epilithic habitats could be sampled. The species composition at sites BR2 and NR5 was very different to the epilithic assemblages in the other parts of the river. At site BR2 *Navicula gregaria* (NAVIGREG) was clearly dominant and at site NR5 *Navicula vandamii* (NAVIVAND) was dominant. Sites BR2 and NR5 were discarded from further analyses, since these were the only two sites at which the epipelon could be sampled and comparisons with the communities in the epilithic habitats would not be useful.

Buffalo and Nahoon epilithon

Figure 42 illustrates the relative abundance (>5%) of the diatom species at each site (see also the Appendix). At sites BR1, BR3 and NR1, *Achnanthes minutissima* (ACHNMINU) was clearly dominant whereas *Achnanthes subatomoides* (ACHNSUAT) was dominant at sites NR2 and NR3. At site NR4 *Gomphonema parvulum* (GONEPARV) was dominant. *Navicula gregaria* (NAVIGREG) dominated the epilithic assemblage at site BR4 changing to a dominance of *N. frugalis* (NAVIFRUG) at sites BR5 and BR6.

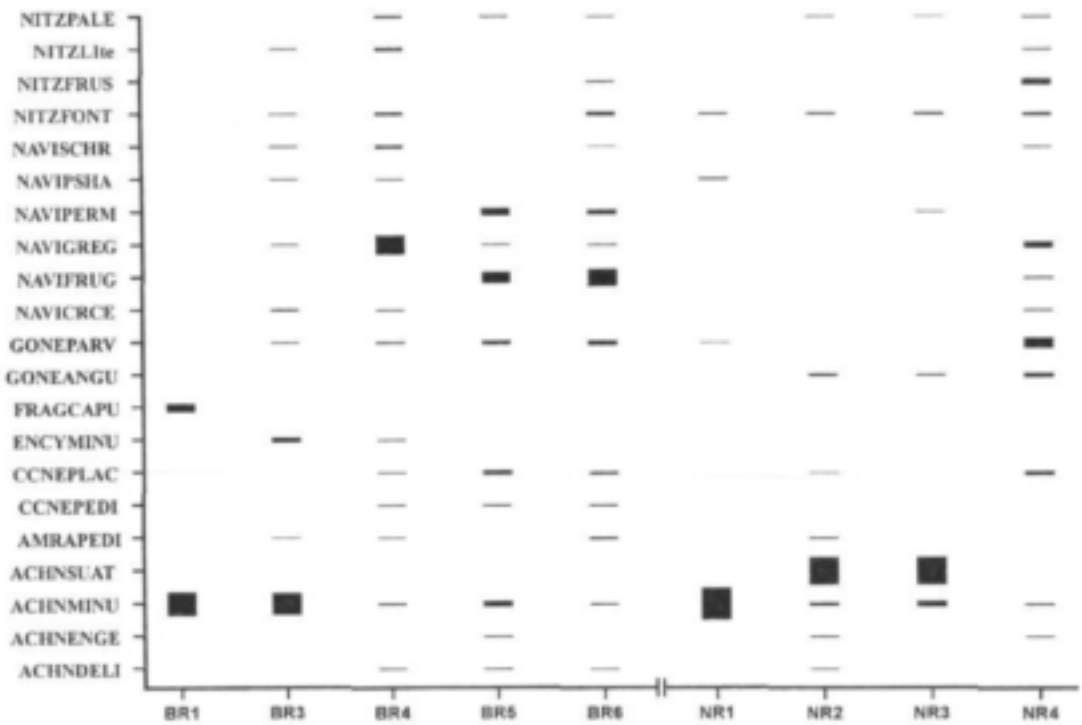

Figure 42. Illustration of the epilithic diatom species distribution (> 5% relative abundance) along the Buffalo and Nahoon Rivers. Sampling sites in Buffalo (BR1-BR6) and Nahoon (NR1-NR4). Sites BR2 and NR5 are not incorporated since only epipelic diatoms could be sampled at these sites

Table 55. Water quality variables measured in the Buffalo and Nahoon Rivers on 4 August 1997

	Alkalinity (as $CaCO_3$ in mg.l^{-1})	Ca^{2+} (mg.l^{-1})	Cl^- (mg.l^{-1})	Conductivity (mS.m^{-1})	K^+ (mg.l^{-1})	Mg^{2+} (mg.l^{-1})	Na^+ (mg.l^{-1})	NH_4^+ (mg.l^{-1})	$NO_2^-+NO_3^-$ (mg.l^{-1})	pH	PO_4^{3-} (mg.l^{-1})	SiO_2 (mg.l^{-1})	SO_4^{2-} (mg.l^{-1})	TDS (mg.l^{-1})
BR1	21.0	4.0	10.0	8.1	0.5	3.0	7.0	0.02	0.10	8.3	0.023	5.90	2.0	54.0
BR2	125.0	24.0	84.0	53.6	1.5	17.0	67.0	0.07	0.89	8.5	0.036	7.30	17.0	368.0
BR3	159.0	34.0	145.0	82.0	3.8	24.0	111.0	0.74	2.81	7.8	0.486	7.00	40.0	566.0
BR4	181.0	39.0	208.0	105.1	5.5	29.0	152.0	0.54	3.13	8.3	0.150	3.60	68.0	737.0
BR5	84.0	19.0	92.0	51.1	3.3	14.0	64.0	0.02	1.18	8.2	0.057	6.00	30.0	330.0
BR6	73.0	17.0	80.0	46.3	4.8	11.0	63.0	0.07	4.69	7.9	0.787	4.70	22.0	310.0
NR1	248.0	45.0	176.0	101.2	2.9	30.0	134.0	0.09	0.17	8.4	0.010	7.50	25.0	716.0
NR2	158.0	35.0	195.0	92.5	3.3	23.0	129.0	0.07	0.79	8.7	0.014	5.70	36.0	618.0
NR3	158.0	36.0	209.0	95.7	3.2	25.0	131.0	0.02	0.95	8.6	0.017	7.30	38.0	638.0
NR4	178.0	37.0	215.0	103.2	4.8	32.0	136.0	0.07	0.25	8.7	0.012	6.50	44.0	689.0
NR5	126.0	26.0	155.0	76.3	3.9	21.0	104.0	0.08	0.52	8.3	0.018	6.60	34.0	501.0

Water Quality

The water quality measured in the Buffalo and Nahoon Rivers is summarised in Table 55. There was no water quality data available from the DWAF previous to this sampling. Both rivers have a naturally high silicate concentration. The conductivity at BR1 was considerably lower than at any of the other sites in both catchments. Site BR1 was situated just downstream from the uppermost dam in the catchment, which is vegetated with transitional forest and shrub as compared to the Karroid vegetation in the lower parts of the Buffalo and Nahoon Catchments (Midgley *et al.*, 1994b).

Effect of water quality on diatom distribution

The relationship between diatom assemblages and water quality variables was investigated with CCA. An initial CCA revealed that the variables Ca, Cl, conductivity, K, Na, SO_4, alkalinity and TDS were strongly correlated with each other ($r>0.85$). Therefore, this group of ions was represented by conductivity. Site BR1 was found to be an outlier and was omitted from further analyses.

Table 56 gives a summary of the CCA analysis of the epilithic data set. Figure 43 gives a graphic representation. A large proportion (75.5%) of the species distribution is explained by the measured environmental variables.

Table 56.. Summary of CCA of epilithic diatom species in Buffalo and Nahoon Rivers.

	Axis 1	Axis 2	Axis 3	Axis 4	Total inertia
Eigenvalues	0.436	0.388	0.281	0.18	1.701
Species-environment correlation	0.999	0.934	0.920	0.965	
Cumulative percentage variance					
of species data	25.6	48.4	65.0	75.5	
of species-environment relation	29.0	54.8	73.4	85.4	
Sum of all unconstrained eigenvalues					1.701
Sum of all canonical eigenvalues					1.504

Axis 1 is highly correlated with ammonium. Site BR3, just downstream from the King Williams Town sewage treatment works, and species *Encyonema minuta* (ENCYMINU) and *Navicula schroeterii* (NAVISCHR) are positively correlated with ammonium. Along the second axis, a gradient of pH, nitrogen, phosphate and silicate, in the upstream sites in the Nahoon are separated from downstream Buffalo sites. *Achnanthes subatomoides* (ACHNSUAT) was dominant under oligotrophic and alkaline conditions, where *Navicula frugalis* (NAVIFRUG) is prominent at the other end of the scale.

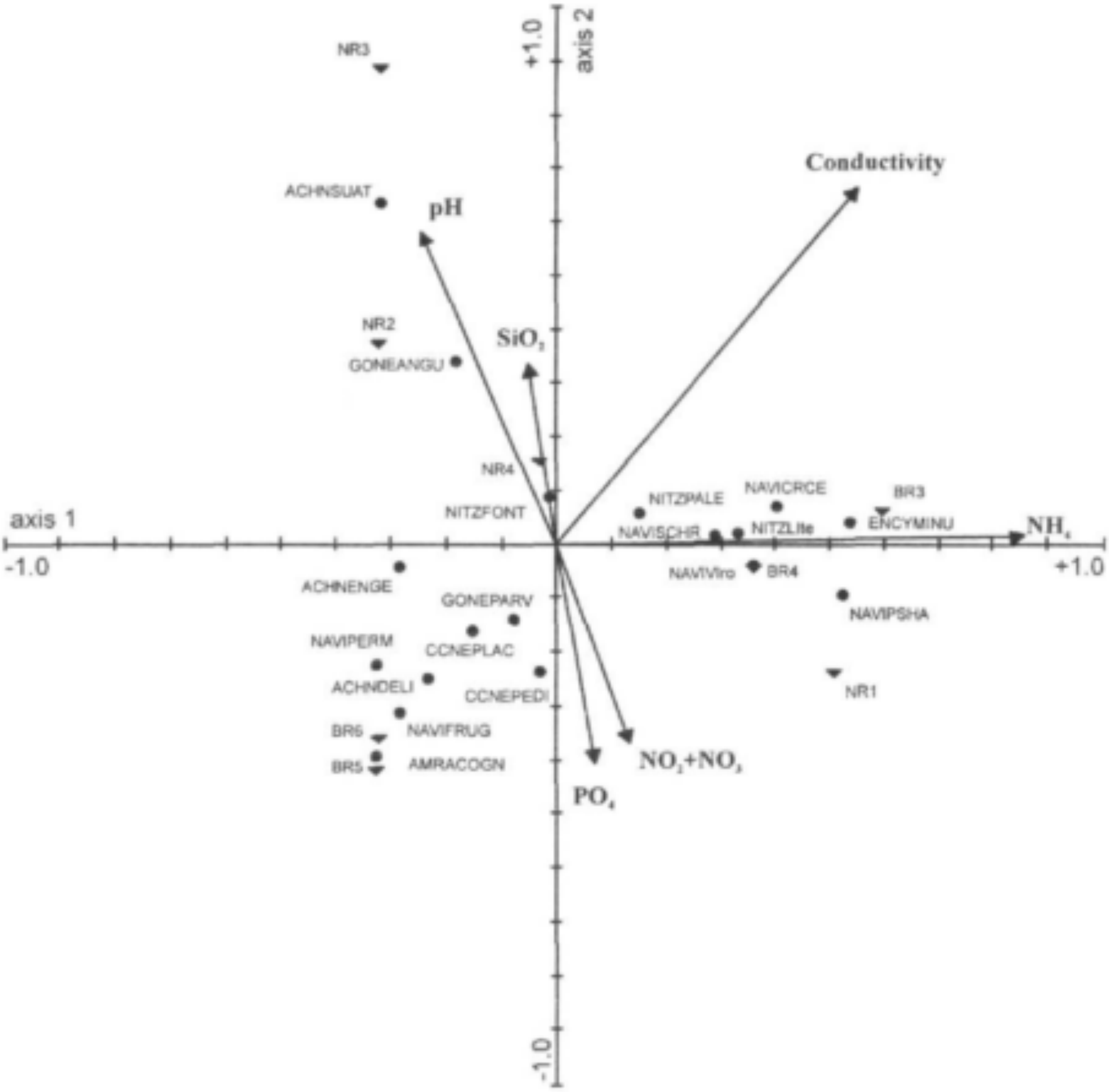

Figure 43. CCA ordination showing epilithic diatom species (circles), sites (triangles) and water quality variables (arrows) in the Buffalo and Nahoon Rivers. See Table 56. Species acronyms given in the Appendix.

Discussion

The concentrations of various water quality variables fluctuated considerably over the length of the rivers sampled. These differences are most apparent when sites just downstream of impoundments are compared with sites at which the water has a lotic history. Palmer and O'Keeffe (1990) and O'Keeffe *et al.* (1996) showed that the impoundments in the Buffalo River had a profound effect on physico-chemical conditions. These effects are not always detrimental as nutrients are taken up by algae and other plants and eventually get stabilised in the sediment. This improves the water quality of the river downstream from dams (O'Keeffe *et al.*, 1996). Other sources of fluctuation are the several diffuse and point sources of pollution such as the King Williams Town sewage water effluent into the Buffalo River.

Following the DCA of the assemblages in the Gamtoos and Sundays Rivers, it was apparent that the variation between sites was larger than the variation between habitats. At one site in the Gamtoos however, the epipelic assemblage was more similar to upstream assemblages while the epilithon was similar to downstream sites. The conductivity at this site had decreased considerably compared to upstream, which might have had an effect on the epilithon. The epipelon however, was most probably under the influence of the water quality conditions at the upstream sites (history of water quality at this site is not known). This trend had also been observed in the Olifants River. In the epipelon a smaller proportion of the species variance was explained by the measured water quality variables. This indicates that the link between water quality variables in the water column and epipelic diatoms is not as strong as with epilithic diatoms.

The most important variables that influence diatom distribution in the Eastern Cape rivers are pH and conductivity. In the Buffalo River, which was the only river in which the water quality was severely impacted by anthropogenic sources, the ammonium gradient had an effect. Other sources of variation could be impoundments, catchment soil type and vegetation.

APPLICATION OF THE VAN DAM INDEX

Introduction

Van Dam *et al.* (1994) presented a checklist of 948 diatom taxa from fresh and weakly brackish water in the Netherlands. Each taxon is given ecological indicator values for pH, salinity, nitrogen-uptake metabolism, oxygen, saprobity and trophic state (Table 57). To calculate an index value (e.g. pH) for a site based on the diatom assemblage present, the weighted average of the indicator values for all species present is taken. The indicator values of dominant species will therefore largely determine the indicator value for the site.

The Van Dam index was applied to the species composition in the Olifants and Swartkops Rivers. For each site, index values were calculated for pH, salinity, nitrogen-uptake, oxygen requirements, saprobity and trophic level based on epilithic and epipelic diatom assemblages.

Results

Comparison of indices based on epilithon and epipelon.

Indicator values based on the Olifants data set showed that except for nitrogen-uptake and trophic level, the Van Dam indicator values were not significantly different based on either the epilithon or the epipelon (paired t-test). Nitrogen-uptake values were significantly higher in the epilithon, indicating that more organically bound nitrogen was required by the taxa. The trophic indices were higher, based on epipelic assemblages. Indicator values based on the Swartkops data set showed significant differences for pH (higher in epipelon), salinity (higher in epilithon), nitrogen-uptake (more organic nitrogen required in epilithon) and oxygen requirements (higher in epilithon). Indices for saprobity and trophic levels were not different.

Table 57. Classification of ecological indicator values in Van Dam index.

(R)	**pH**			
1	acidobiontic	optimal occurrence at pH <5.5		
2	acidophilous	mainly occurring at pH <7		
3	circumneutral	mainly occurring at pH-values about 7		
4	alkaliphilous	mainly occurring at pH >7		
5	alkalibiontic	exclusively occurring at pH >7		
6	indifferent	no apparent optimum		
(H)	**Salinity**			
		Cl^- (mg l^{-1})	Salinity (‰)	
1	fresh	<100	<0.2	
2	fresh brackish	<500	<0.9	
3	brackish fresh	500 – 1000	0.9 - 1.8	
4	brackish	1000 – 5000	1.8 – 9.0	
(N)	**Nitrogen-uptake metabolism**			
1.	Nitrogen-autotrophic taxa, tolerating very small concentrations of organically bound nitrogen			
2.	Nitrogen-autotrophic taxa, tolerating elevated concentrations of organically bound nitrogen			
3.	Facultatively nitrogen-heterotrophic taxa, needing periodically elevated concentrations of organically bound nitrogen			
4.	Obligatory nitrogen-heterotrophic taxa, needing continuously elevated concentrations of organically bound nitrogen			
(O)	**Oxygen requirements**			
1.	Continuously high (about 100% saturation)			
2.	Fairly high (above 75% saturation)			
3.	Moderate (above 50% saturation)			
4.	Low (above 30% saturation)			
5.	Very low (about 10% saturation)			
(S)	**Saprobity**			
		Water quality class	Oxygen saturation (%)	BOD_5^{20} (mg l^{-1})
1.	Oligosaprobus	I, I-II	>85	<2
2.	β-mesosaprobous	II	70 – 85	2 – 4
3.	α-mesosaprobous	III	25 – 70	4 – 13
4.	α-meso-/polysaprobous	III-IV	10 – 25	13 – 22
5.	polysaprobous	IV	<10	>22
(T)	**Trophic state**			
1.	oligotraphentic			
2.	oligo-mesotraphentic			
3.	mesotraphentic			
4.	meso-eutraphentic			
5.	eutraphentic			
6.	hypereutraphentic			
7.	oligo- to eutraphentic (hypereutraphentic)			

Correlation of classes of indicator values

All the index values from pH to trophic level were highly and significantly correlated with each other in the Olifants and Swartkops data sets. This indicates that the trend between sites in each set of indicator values was similar. Both rivers showed a strong gradient of pollution that was reflected in the diatom distribution. Pollution tolerant species dominated at the polluted end of the gradients, which therefore resulted in high index values. The classification of the index has been designed in such a way that an increased value correlates with an increased anthropogenic influence (see Table 57). It is therefore not surprising that all index values were highly correlated.

Correlation between indicator values and observed conditions

Index values based on epilithic diatoms from the Olifants River showed a positive and significant correlation with measured pH. A significant positive correlation was also observed between measured pH and indices for salinity, nitrogen-uptake metabolism, oxygen, saprobity and trophic level. Although these comparisons are without direct theoretical meaning, it does indicate that the pH-pH correlation might be coincidental. As shown before, all indices were highly correlated with each other and it is therefore not surprising that all indices correlated with a measured variable that manifested a similar trend (in this case pH). Based on epipelic assemblages all but nitrogen-uptake and saprobity indicator values correlated significantly and positively with observed pH (Tables 58 and 59).

Index values based on epilithic diatoms from the Olifants River showed a positive and significant correlation between all variables (except for nitrite/nitrate) and the trophic index. This correlation seems to be more meaningful, since the trends in measured pH, ammonium, silicate and phosphate were not correlated with each other in the Swartkops River (see earlier). In this instance, the correlation is not by chance with one of the variables, but consistently with variables that increase under increasing trophic conditions. We suggest therefore that the Van Dam index successfully indicated trophic conditions in the Swartkops River, based on epilithic diatom assemblages. In the epipelon only alkalinity, phosphate and potassium correlated with the trophic index (Tables 60and 61).

Table 58. Correlation coefficients between the calculated Van Dam diatom indices and observed water quality conditions in the Olifants River, based on epilithic assemblages (n = 25). Van Dam index: *R* = pH, *H* = Salinity, N = organic nitrogen-uptake, O = oxygen requirements, S = saprobity, T = trophic state. *Positive* and significant (P< 0.05) correlation is boxed.

	pH	NH_4	NO_2+NO_3	alkalinity	Na	Mg	SiO_2	PO_4	SO_4	Cl	K	Ca	conductivity	TDS	Diss O_2
R	0.66	-0.66	-0.48	0.27	-0.19	0.01	-0.34	-0.42	-0.03	-0.21	0.04	0.02	-0.07	-0.03	0.48
	p=.000	p=.000	p=.015	p=.188	p=.360	p=.975	p=.092	p=.034	p=.897	p=.309	p=.855	p=.930	p=.752	p=.893	p=.014
H	0.63	-0.76	-0.74	0.26	-0.27	0.07	-0.37	-0.71	0.03	-0.28	-0.25	0.04	-0.07	-0.02	0.41
	p=.001	p=.000	p=.000	p=.216	p=.193	p=.754	p=.072	p=.000	p=.885	p=.176	p=.223	p=.832	p=.756	p=.924	p=.043
N	0.65	-0.58	-0.55	0.23	-0.20	0.06	-0.37	-0.46	0.03	-0.19	-0.01	0.05	-0.03	0.00	0.36
	p=.000	p=.003	p=.004	p=.259	p=.333	p=.759	p=.068	p=.019	p=.895	p=.370	p=.967	p=.820	p=.871	p=.993	p=.078
O	0.60	-0.32	-0.20	0.25	-0.12	-0.02	-0.17	-0.05	-0.08	-0.10	0.30	-0.03	-0.06	-0.03	0.25
	p=.001	p=.117	p=.343	p=.228	p=.567	p=.931	p=.417	p=.825	p=.721	p=.633	p=.149	p=.892	p=.793	p=.891	p=.233
S	0.62	-0.57	-0.58	0.26	-0.21	0.03	-0.34	-0.46	-0.01	-0.23	-0.01	0.01	-0.06	-0.03	0.38
	p=.001	p=.003	p=.002	p=.209	p=.319	p=.888	p=.102	p=.019	p=.963	p=.279	p=.974	p=.947	p=.765	p=.901	p=.058
T	0.62	-0.24	0.01	0.26	-0.02	0.00	-0.21	0.16	-0.05	0.01	0.46	0.01	0.00	0.02	0.25
	p=.001	p=.249	p=.962	p=.213	p=.931	p=.987	p=.312	p=.437	p=.813	p=.976	p=.020	p=.955	p=.989	p=.920	p=.224

Table 59. Correlation coefficients between the calculated Van Dam diatom indices and observed water quality conditions in the Olifants River, based on epipelic assemblages (n = 26). Van Dam index: R = pH, H = Salinity, N = organic nitrogen-uptake, O = oxygen requirements, S = saprobity, T = trophic state. Positive and significant (P< 0.05) correlation is boxed.

	pH	NH_4	NO_2+NO_3	alkalinity	Na	Mg	SiO_2	PO_4	SO_4	Cl	K	Ca	conductivity	TDS	Diss O_2
R	0.42	0.02	0.06	0.02	-0.14	-0.15	-0.28	0.13	-0.19	-0.13	0.44	-0.15	-0.14	-0.15	0.17
	p=.031	p=.909	p=.790	p=.923	p=.505	p=.450	p=.165	p=.530	p=.364	p=.513	p=.024	p=.454	p=.492	p=.475	p=.399
H	0.45	0.14	0.23	-0.1	0.05	-0.09	-0.46	0.23	-0.04	0	0.52	-0.04	-0.01	-0.04	0.15
	p=.020	p=.509	p=.269	p=.626	p=.800	p=.676	p=.017	p=.264	p=.829	p=.985	p=.007	p=.851	p=.966	p=.863	p=.475
N	0.26	0.32	0.38	-0.27	-0.07	-0.3	-0.09	0.36	-0.26	-0.12	0.49	-0.24	-0.2	-0.23	0.08
	p=.209	p=.113	p=.057	p=.187	p=.742	p=.140	p=.664	p=.071	p=.198	p=.565	p=.010	p=.242	p=.332	p=.252	p=.691
O	0.43	0.21	0.34	0.03	-0.01	-0.13	0	0.42	-0.16	0.02	0.52	-0.12	-0.08	-0.08	0.22
	p=.029	p=.314	p=.087	p=.890	p=.943	p=.536	p=.995	p=.034	p=.425	p=.936	p=.006	p=.561	p=.715	p=.680	p=.273
S	0.18	0.43	0.38	-0.09	-0.02	-0.17	-0.09	0.43	-0.18	-0.03	0.54	-0.17	-0.1	-0.13	0.1
	p=.374	p=.027	p=.056	p=.652	p=.913	p=.420	p=.665	p=.030	p=.366	p=.884	p=.004	p=.400	p=.616	p=.531	p=.613
T	0.49	0.09	0.23	0.32	0.11	0.1	-0.15	0.36	0.01	0.18	0.5	0.04	0.11	0.12	0.26
	p=.010	p=.677	p=.253	p=.115	p=.577	p=.636	p=.473	p=.074	p=.980	p=.366	p=.010	p=.839	p=.608	p=.574	p=.206

Table 60. Correlation coefficients between the calculated Van Dam diatom indices and observed water quality conditions in the Swartkops River, based on epilithic assemblages (n = 47). Van Dam index: R = pH, H = Salinity, N = organic nitrogen-uptake, O = oxygen requirements, S = saprobity, T = trophic state. Positive and significant (P< 0.05) correlation is boxed.

	pH	NH_4	NO_2+NO_3	alkalinity	Na	Mg	SiO_2	PO_4	SO_4	Cl	K	Ca	conductivity	TDS
R	-0.38	0.18	-0.41	0.12	-0.04	-0.06	0.37	0.38	0.01	-0.05	0.22	-0	-0.11	-0.02
	p=.008	p=.227	p=.004	p=.430	p=.805	p=.683	p=.010	p=.008	p=.951	p=.741	p=.131	p=.978	p=.467	p=.900
H	-0.21	0.23	-0.32	0.28	0.12	0.1	0.33	0.42	0.16	0.11	0.4	0.15	0.04	0.14
	p=.155	p=.118	p=.031	p=.054	p=.419	p=.493	p=.022	p=.003	p=.283	p=.468	p=.005	p=.301	p=.803	p=.343
N	0.27	0.4	0.06	0.27	0.19	0.22	0.28	-0.08	0.27	0.2	0.35	0.22	0.21	0.22
	p=.062	p=.005	p=.674	p=.068	p=.206	p=.135	p=.057	p=.582	p=.065	p=.185	p=.017	p=.135	p=.153	p=.147
O	0.21	0.38	0.05	0.27	0.18	0.21	0.26	-0.06	0.24	0.18	0.34	0.22	0.19	0.2
	p=.157	p=.009	p=.758	p=.071	p=.236	p=.161	p=.080	p=.674	p=.104	p=.217	p=.019	p=.142	p=.204	p=.174
S	-0.39	0.07	-0.35	-0.4	-0.47	-0.46	0.24	-0.31	-0.37	-0.47	-0.31	-0.44	-0.45	-0.46
	p=.007	p=.634	p=.015	p=.005	p=.001	p=.001	p=.109	p=.033	p=.011	p=.001	p=.036	p=.002	p=.002	p=.001
T	0.47	0.47	0.25	0.66	0.56	0.57	0.33	0.29	0.58	0.56	0.71	0.59	0.54	0.58
	p=.001	p=.001	p=.089	p=.000	p=.000	p=.000	p=.024	p=.045	p=.000	p=.000	p=.000	p=.000	p=.000	p=.000

Table 61. Correlation coefficients between the calculated Van Dam diatom indices and observed water quality conditions in the Swartkops River, based on epipelic assemblages (n = 71). Van Dam index: R = pH, H = Salinity, N = organic nitrogen-uptake, O = oxygen requirements, S = saprobity, T = trophic state. Positive and significant (P< 0.05) correlation is boxed.

	pH	NH_4	NO_2+NO_3	alkalinity	Na	Mg	SiO_2	PO_4	SO_4	Cl	K	Ca	conductivity	TDS
R	-0.49	-0.29	-0.01	-0.36	-0.38	-0.44	0.02	0.01	-0.27	-0.39	-0.24	-0.41	-0.39	-0.4
	p=.000	p=.016	p=.927	p=.002	p=.001	p=.000	p=.864	p=.902	p=.022	p=.001	p=.048	p=.000	p=.001	p=.001
H	-0.37	-0.36	-0.02	-0.13	-0.23	-0.28	-0	0.07	-0.18	-0.25	-0.01	-0.25	-0.24	-0.23
	p=.001	p=.002	p=.882	p=.288	p=.050	p=.019	p=.986	p=.580	p=.134	p=.032	p=.933	p=.038	p=.048	p=.055
N	-0.29	-0.24	-0.04	0.07	0.01	-0.03	0.09	0.28	0.01	-0.01	0.11	0.01	-0.01	0.02
	p=.015	p=.042	p=.769	p=.538	p=.928	p=.817	p=.453	p=.017	p=.907	p=.917	p=.352	p=.932	p=.920	p=.877
O	-0.26	-0.24	0.02	0.08	0.05	0.02	0.09	0.25	0.04	0.03	0.09	0.04	0.02	0.05
	p=.028	p=.044	p=.876	p=.509	p=.690	p=.899	p=.468	p=.039	p=.711	p=.815	p=.439	p=.721	p=.852	p=.670
S	-0.34	-0.32	-0.22	-0.04	-0.31	-0.34	0.13	0.02	-0.3	-0.33	0.12	-0.28	-0.3	-0.28
	p=.004	p=.006	p=.061	p=.737	p=.009	p=.004	p=.268	p=.868	p=.010	p=.004	p=.329	p=.016	p=.012	p=.020
T	-0.14	-0.17	0.05	0.25	0.16	0.14	0.09	0.27	0.13	0.13	0.25	0.18	0.14	0.18
	p=.259	p=.152	p=.654	p=.038	p=.192	p=.249	p=.451	p=.023	p=.295	p=.265	p=.033	p=.127	p=.231	p=.132

Discussion

There are several possible explanations for the observed lack of correlation (in most instances) between the Van Dam index and observed conditions. Firstly, the species identifications are mostly based on European floras. Round (1993) pointed out that there might be subtle variations in appearance of diatoms collected in the Southern Hemisphere. Species are then identified to the nearest form in a European flora. This does not have to be a concern when the data are interpreted locally (e.g. calculating indicator values from the local data set). However, when comparisons are made that were developed in entirely different regions, the discrepancies in identification could interfere with the level of relevance.

The basis of the Van Dam index is the authors' own published and unpublished observations together with hundreds of other (international) publications. It is specifically designed to be applied in watercourses and lakes in the Netherlands. Environmental conditions are likely to be considerably different in South African rivers. Water quality is just one of the suite of variables (such as light, temperature or disturbance) affecting the structure of benthic diatom assemblages. It is possible that these factors override the water quality component when comparing the Van Dam index with South African conditions. This makes the calibration of a local diatom index necessary. The senior author of the Van Dam index was not surprised when he was advised that the application of the index in its present form did not result in a highly significant correlation with the South African data (H. van Dam, pers. comm.).

GENERAL DISCUSSION & CONCLUSIONS

Water quality and analysis

The study undertaken in this project has been one in which an attempt has been made to relate the presence of species of benthic diatoms to the water quality in the rivers in which they are found. What the water manager requires is data on the water chemistry or information that allows for the manipulation of water resources. In order to obtain the required chemical information, managers sample the water from rivers and subject that sample to rigorous chemical analysis, using only accredited laboratories who in turn use only approved methods and equipment. The end result is that we believe the data accruing from the chemical laboratory to be as correct as it is possible to obtain. The samples are taken "carefully" by trained personnel, always from the "same" place in the river, placed in containers of approved quality to which mercuric chloride is added to suppress biological activity and hence "hold" the chemical characteristics unaltered. Despite what some analytical chemists may think of the adequacy of these sampling and analytical procedures, the water chemistry data are considered to be the correct data against which all biological information is assessed.

Rivers receive their water from springs, run-off from the ground and directly from rain. As the level of hyperheic groundwater alters, a change in the quality of water in the river might be expected. When water from surface run-off arises from different areas, so the quality of the river water is likely to alter and as the quantity of rainfall changes, so the quality of the river water is likely to alter. Hence, the chemical composition of river water changes depending on the conditions in the catchment. Add to this that the biology of the rivers alters from season to season and place to place depending upon circumstances and we begin to appreciate that the data emanating from a single sample must be subject to a great variance. If a school of fish or herd of cattle happen to be utilising an area of river before the water sample is taken, a considerably different chemical analysis can be expected to another time when the water had been unaffected. Hence, the water chemistry data are likely to be rather inefficient indicators of general water quality. This was identified in multivariate analysis where the statistical analyses indicated that the variability of the water chemistry was greater than that of the benthic diatoms. It is for these reasons that methods are being sought that integrate river water quality and yield useful data. Organisms that integrate the variability of water quality and yield information useful to managers is the aim of biomonitoring research worldwide.

Population ecology

The rationale for using benthic diatoms as indicators of water quality is that the taxon most suited to the water quality surrounding them will be numerically dominant. This is shown in diagrammatically in Figure 44.

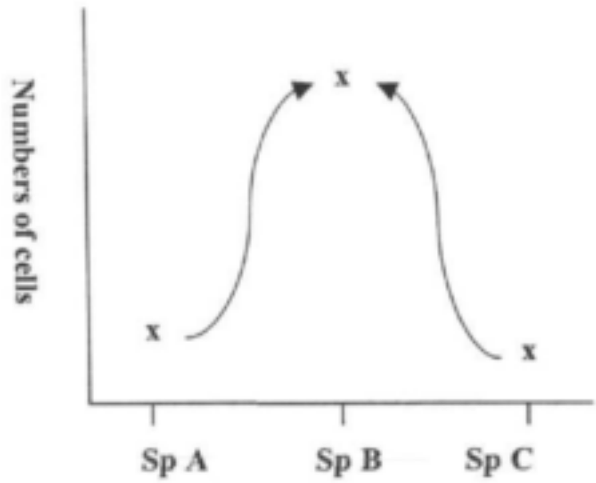

Figure 44. Illustration of the relationship between environmental suitability and cell number in a population. This diagram assumes that the environment is especially suitable for Species B that therefore has the greatest proportion of the population.

In the example in Figure 43, if the water quality changes so that it is either more suitable to Sp A or Sp C, then the response will be for either one of those to become numerically dominant. Because the quality of water is constantly changing, so the relative numbers of Sp A, B, or C may change. The data for all the sites in this study seem to indicate that this is happening, because the water quality for the dominant species and the sub-dominant species appear to be in similar ranges.

Diatom taxonomy

A great deal of work has, and is still being done on the taxonomy of diatoms. Some estimates place the number of species at one million, but this far exceeds the number presently identified. Working with diatoms, one soon realises that giving a specimen a name is difficult because the method of naming involves using the organism's morphology. Much of the diatom nomenclature was done a long time ago at a time when microscopy was not as advanced as it is now. The literature uses descriptions as commonly as it uses diagrams and much of the descriptive work is in German. Scientific German is very precise which makes working in this medium difficult for an English speaking person. Also, the old texts are very expensive and therefore not readily available in most libraries. As light microscopy has been superseded by electron microscopy, many of the old species and genera are being split. Indeed, it is this very necessity for accuracy in species identification that has resulted in diatom ecology being as little used as it presently is.

Van Dam *et al*. (1994) produced a list of species grouped according to the water quality in which they have been found. One of the objectives of this study was to determine whether the data for the Netherlands was suitable for direct transposition to South African conditions. The multivariate analysis showed quite clearly that this will not be possible. Whether this is because the taxa identified in this study are actually different from those identified in the Netherlands study, is unknown. It may be because our South African diatoms are the same species that have been subjected to genetic plasticity and have become adapted to a different environment to what they are adapted to in areas separated by many thousands of kilometres. However, one of the theories behind the importance of annual bird migrations is that taxa would be transported across continents frequently. This would maintain connections and taxa should therefore respond similarly even though separated by long distances. One fact remains, namely that South African diatom taxa respond to different water quality to those in The Netherlands. The result is that we will have to produce our own suite of relationships.

Nomenclature

Diatom nomenclature depends, to a large extent, on the opinion of the author who names the specimen. Hence, names are given that, hopefully, reflect either the morphology or the area from which the specimen was found. Names are also given to honour the author or a colleague. This means that names are a means to an end and are not scientific absolutes. As mentioned earlier, diatom ecology has suffered from the history of diatom taxonomy and the advances in scientific equipment, especially microscopy. The implementation of genetic biochemistry techniques in the nomenclature of the species is likely to result in big changes to the subject. Despite this, diatoms are too useful to be neglected as ecological tools any longer. But the problem of nomenclature remains. It seems that to solve this problem it is necessary to resolve the nomenclature problem. But is this so? The data set presented in the multivariate analysis section indicates that there are only a few hundred taxa involved in South African river systems. We do not have the whole suite from across the world. Many of those identified in this study are seldom, if ever, dominant in our rivers. This study has succeeded in using the abbreviated names proposed by van Dam *et al.* (1994). When we consider the numbers that are relevant to only our rivers, estuaries and wetlands, the numbers are reduced to quite acceptable levels. Consideration should be given to implementing a system of abbreviated names that would simplify remembering and spelling the taxa. It does imply, however, that if diatoms are to be used extensively in the future, some institution in South Africa will have to accept responsibility for their curation. This task was previously undertaken by the CSIR who declare that they no longer have the facilities to retain this responsibility. However, someone has to take responsibility and since these organisms are mainly needed for elucidating water features, there seems to be no better institution than the Environmentek division of CSIR who is government-supported and already has the largest collection of literature and specimens.

Epipelic taxa

The epipelic taxa reside near the surface of river sediments. As has been pointed out in the multivariate analysis, this means that they reside in a medium that is different to the water quality that they are being used to identify. One of the problems is that if the river is taking in small quantities of groundwater that has quite a different quality to that flowing down the river, but not in large quantities, the epipelic diatoms may likely reflect a water quality dissimilar to that in the river. This problem can only be resolved by collecting a large enough data set and identifying the riverbed qualities that produce spurious results. Data collected so far by the team at the University of Port Elizabeth seems to indicate that epipelic diatoms from the sediment surface respond to the quality of the water in the river. This has been the finding in both rivers and estuaries.

Epipelic diatoms are easy to collect and, provided standard techniques are used, should produce data that are dependent on the characteristics of the diatoms being collected rather than the characteristics of the method. The types of data that may be useful require to be determined and strict methods applied to ensure that the data are uniform and meaningful. For example, recent work with benthic diatoms in estuaries has shown that wide variations exist in the numbers of epipelic diatoms collected by what is apparently the same technique. In order for these data to be interpreted with confidence as being characteristic of the diatom flora rather than, say, the physical characteristics of the sediment, we need to be sure that treatments are applied exactly. One such characteristic that may be very useful is the relative number of taxa found per frame observed under the microscope. Another is the relative numbers of the same taxa found per frame. The latter is the way that dominance is determined. To achieve this type of uniformity, the same number of benthic samples should be taken in each case and the samples should be settled in the same type of container for a specified length of time. The same moisture content should be left in each sample at the time cover slips are applied and the same number of cover slips should be placed on the sediment. These should be removed and digested and after cleaning and washing, they must be taken up in exactly the same volume of water. The cover slips used for microscopic enumeration should be spotted in exactly the same way with the same volume and finally, the counting must be done in the same way. These are all simple techniques, but they must be rigorously applied or large between-operator variability will be found.

Epilithic taxa

The data from the statistical analyses shows that the epilithic diatoms respond more quickly to changes in water quality. The suggestion has been made that they will thus reflect a shorter-term integration of water quality than that provided by epipelic diatoms. This may or may not be desirable. If short-term integration is required, this is likely to be used to identify incidents of, or short-term sources, of pollution. As suppliers of this type of information, their value gets close to the information supplied by chemical water analysis. The value of diatoms as indicators of this nature has not been established and there is a necessity to establish clearly the role that benthic diatoms can play.

The technique for obtaining samples of epilithic diatoms, described in the multivariate analysis, seems to indicate that it is possibly quite subjective. The interpretation of "vigorous shaking" to a strong young man will be quite different to that of an elderly lady. This means that the potential exists for the technique to yield different dominant taxa. This type of technique needs to be resolved.

SA diatom information

A large amount of information exists about South African diatoms. The main collectors of this information were Cholnoky, Giffen, Archibald and Schoeman who collected in South Africa professionally. However, many other workers have also collected in this country but much of the work has been published overseas.

Habitat specificity

Diatoms were sampled from two distinct substrata: stones and sediments. The methods for diatom collection defined, to some extent, the boundaries for each habitat. The stones that were selected for the collection of an epilithic sample all had an obvious diatom growth, judged by their appearance and feel and lack of attached filamentous algae. Loosely attached algae were removed before the more tightly attached algae were sampled. This was done by rubbing the stone surface with a finger (see also the methods section). The samples mainly contained prostrate (e.g. *Achnanthes*), stalked (e.g. *Cymbella*) and apically attached (e.g. *Synedra*) life forms. Mobile taxa (e.g. *Navicula* and *Nitzschia*) were also observed but usually in much lower relative abundance than in the epipelon.

Epipelic diatoms were collected with the 'cover slip method' (see the section on methods), which was particularly aimed at the collection of mobile taxa. This was largely successful, although *Achanthes delicatula* and *A. engelbrechtii* (mono-raphid and therefore less mobile than their bi-raphid counterparts) were repeatedly found to be more abundant in the epipelon. Observations of live samples revealed that these species had actively attached to the cover slips and that they were not 'contaminants' originating from the epipsammon. Special care was taken to ensure that no, or very few, sand grains were collected along with the cover slips. These two species seem to be adapted to an epipelic habitat.

Species diversity was generally higher in epipelic than epilithic assemblages. This was mainly due to the larger number of mobile species in the epipelon. Most epilithic species were also found in the epipelon, although with lower relative abundance. It seems, therefore, that the 'cover slip method' is not just picking up mobile life forms but also other taxa that can actively attach to the glass surface within the six to eight hours of 'incubation'.

Use of water quality data at the time of sampling

Physico-chemical data are, strictly speaking, representative of the conditions at the moment of sampling. The composition of a biological sample is an integration of the variation in physico-chemical conditions over a period. The 'snap-shot' data of water quality to which diatom distribution has been correlated in this study is therefore not ideal. It is however, under the circumstances the 'next-best-thing'. Where possible, historic data (2-3 weeks before diatom sampling) was taken into account, but most often, these data were not available. The only solution to this problem seems to be to increase the frequency of sampling sites, especially for nutrients (e.g. Pan *et al.*, 1996). This is because nutrients are taken up rapidly in shallow streams (e.g. Borchard, 1996) and their variability is high (e.g. France and Peters, 1992). The seasonal study of diatoms in the Swartkops River showed that the increased sample size and extensive gradient in water quality resulted in a strong correlation between water quality variables and diatom distribution. The weighted-averaging and calibration models showed a good performance, especially when based on epilithic diatoms. Water column variables explained the variance in epilithic assemblages better than the variance in the epipelon. Epipelic diatoms have resources supplied from the water column in addition to the sediments (McCormick, 1996). Resource supplies from the sediments could explain a considerable part of the variance.

The suitability of diatoms as indicators of water quality

Although diatoms have the potential to be indicative of general river health (e.g. Stevenson and Pan, 1999), efforts in this study were concentrated on water quality variables. No attempts have been made to give a full account of the ecological diversity of benthic diatoms in South African rivers. Other groups of organisms are already employed for the assessment of ecosystem integrity within the National Biomonitoring Programme (Uys *et al.*, 1996). Benthic diatoms could be a useful addition to this programme as they give a time-integrated indication of specific water quality components.

The use of weighted average indices of water quality conditions that are presented in this study, is just one of the ways of employing diatoms in environmental assessments. Lange-Bertalot (1979) classifies species according to their tolerance to certain stressors that improve the characterisation of environmental variability as well as integrated environmental conditions. The data sets on which those classifications are based are a result of many years of research.

No single group of organisms is always best suited for detecting the diversity of environmental perturbations associated with human activities. If the maintenance of ecosystem integrity is the aim of the 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 and Cairns, 1994). Diatoms possess many desirable attributes as indicators of ecosystem integrity and water quality in particular:

- Diatoms are an ecologically important group in riverine ecosystems and occur throughout the river, throughout the year;
- Diatoms are sensitive to a wide range of water quality variables (e.g. pH, conductivity and nutrients);
- Diatoms respond rapidly and predictably to changes in water quality conditions.

The correlation that can be found between diatom distribution and water quality depends on the gradient that exists along the length of a river. In most instances pH, conductivity and nutrients could explain the variance in the distribution. It is possible to investigate the influence of other variables of interest by constraining variables that have a known effect on the axes of ordination. If other variables can still explain a considerable part of the remaining variance, its influence on diatom distribution can be assessed (ter Braak and Šmilauer, 1998).

On a few occasions, river sites were sampled where the water quality conditions were considerably different from up and downstream sites. The diatom assemblages at these sites were also considerably different. These samples had to be classified as outliers as they would obscure the trends detectable with the multivariate analysis of the data sets. However, the information contained in the assemblage composition of these outlier sites, remains valuable. Only when these circumstances can be observed repeatedly, can this information become useful for the development of indicator values.

The technique of weighted-averaging and calibration has provided optimum values and tolerance ranges for individual diatoms species, specified for the habitat of origin. With this knowledge on the autecology of common diatoms, the analysis of (spatial or temporal) shifts in assemblage composition provides insight into the causes of such changes. The data in this study has shown that changes in conductivity, nitrogen (nitrite/nitrate and ammonium), pH and phosphorus can be successfully inferred from the diatoms with a lower degree of variation than monthly monitoring of water chemistry. This is the result of the integration effects that changes in water quality conditions have on diatom assemblage composition.

The data sets used for the development of these models were not large enough to make reasonable comparisons between optimum values for taxa observed across regional boundaries. Indicator values based on the Swartkops dataset showed high r^2_{jack} and low RMSE, where the models based on the Olifants River data set performed less well. Few taxa that occurred in both rivers showed similar indicator values for pH, nitrite/nitrate or phosphate (the only variables for which models could be developed in both rivers). This is most probably a result of the relatively small amount of data on which the Olifants

River model is based. It is probably also due to the fact that the Olifants was visited once whereas the Swartkops was sampled on a monthly basis during a two-year period, along a strong and persistent pollution gradient. Patterns in species distribution were observed repeatedly, increasing the performance of the calibration models.

So far, the lack of commonly accepted, standardised protocols for monitoring with diatom assemblages has limited the use of this group in South African rivers. In addition, the presently obscure state of diatom taxonomy in South Africa made the use of this group unfavourable. With the development of a species identification database at the University of Port Elizabeth, the identification of benthic diatoms that have previously been observed in South African rivers will be facilitated. The methods for field collection of diatom assemblages and processing techniques used during this study are straightforward and uncomplicated. The use of diatoms for water quality monitoring therefore has the potential to become accessible for local and national water authorities.

One of the main factors responsible for the lack of diatom ecology being used today in South Africa is the taxonomy. However, another major problem encountered with this project has been that the literature is spread around thinly and is not easily available. It is difficult to obtain and, with the monetary value of South African currency being what it is today, it is very expensive to acquire the literature. Much of the literature in South Africa is presently housed at the CSIR in Pretoria, who have indicated that they may dispose of it because it is not being used.

The data produced from this study indicates that the production of a diatom reference work detailing all known dominant benthic diatoms is possible. To make this readily accessible to all present workers and to encourage future research in fresh water diatoms, this reference should probably be brought out on a CD. At the present cost of non re-writable CD's this could be sold by WRC at a small profit for about R20.00, excluding production costs.

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APPENDIX A

Raw data

APPENDIX B

Plates of dominant diatoms and the acronyms used in this report.

Plate 1. The diatom ACHNMINU (*Achnanthes minutissima* var *minutissima*) was dominant at 43 sites. It was found in both the epilithon and the epipelon.

Plate 2. The diatom ---------- etc.

APPENDIX C

Spreadsheet of genus database.

APPENDIX D

Compact Disk with the full report.

APPENDIX A

PRIMARY DATA SPREADSHEET

River	Buffalo	Buffalo	Buffalo	Buffalo	Buffalo	Nahoon	Nahoon	Nahoon	Nahoon
habitat	epilithon.	epilithon.	epilithon.	epilithon.	epilithon.	epilithon.	epilithon.	epilithon.	epilithon.
Slide	531	536	533	532	534	540	537	538	539
report station	BR1	BR3	BR4	BR5	BR6	NR1	NR2	NR3	NR4
ACHNMINU	69.51	64.87	3.00	13.49	1.98	95.07	5.96	13.69	1.66
ACHNSUAT					0.00	0.00	80.46	80.57	0.00
CCNEPLAC	0.00	0.00	1.67	11.11	5.56	0.00	0.33	0.00	8.61
ENCYMINU	0.00	12.03	1.33	0.00		0.00	0.00	0.00	0.00
FRAGCAPU	22.30	0.00	0.00	0.00		0.00	0.00	0.00	0.00
GONEANGU	0.00	0.00	0.00	0.00		0.00	5.96	0.96	10.26
GONEPARV	0.00	0.32	2.67	8.73	11.51	0.66	0.00	0.00	30.13
NAVIFRUG	0.00	0.00	0.00	31.75	50.00	0.00	0.00	0.00	1.99
NAVIGREG	0.00	0.95	55.33	1.59	0.40	0.00	0.00	0.00	16.23
NAVIPERM	0.00	0.00	0.00	20.63	10.71	0.00	0.00	1.27	0.00
NITZFRUS	0.00	0.00	0.00	0.00	1.98	0.00	0.00	0.00	15.56
Water Quality									
Ca^{2+} ($mg.l^{-1}$)	4	34	39	19	17	45	35	36	37
Cl^- ($mg.l^{-1}$)	10	145	208	92	80	176	195	209	215
Conductivity ($mS.m^{-1}$)	8.1	82	105.1	51.1	46.3	101.2	92.5	95.7	103.2
F^- ($mg.l^{-1}$)	0.05	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.2
K^+ ($mg.l^{-1}$)	0.5	3.8	5.5	3.3	4.8	2.9	3.3	3.2	4.8
Mg^{2+} ($mg.l^{-1}$)	3	24	29	14	11	30	23	25	32
Na^+ ($mg.l^{-1}$)	7	111	152	64	63	134	129	131	136
NH_4^+ ($mg.l^{-1}$)	0.02	0.74	0.54	0.02	0.07	0.09	0.07	0.02	0.07
NO_2^-+NO_3^- ($mg.l^{-1}$)	0.1	2.81	3.13	1.18	4.69	0.17	0.79	0.95	0.25
pH	8.34	7.8	8.25	8.16	7.9	8.42	8.68	8.56	8.73
PO_4^{3-} ($mg.l^{-1}$)	0.023	0.486	0.15	0.057	0.787	0.01	0.014	0.017	0.012
SiO_2 ($mg.l^{-1}$)	5.9	7	3.6	6	4.7	7.5	5.7	7.3	6.5
SO_4^{2-} ($mg.l^{-1}$)	2	40	68	30	22	25	36	38	44
Alkalinity	21	159	181	84	73	248	158	158	178

River	Buffalo	Buffalo	Buffalo	Buffalo	Buffalo	Nahoon	Nahoon	Nahoon	Nahoon
habitat	epilithon.	epilithon.	epilithon.	epilithon.	epilithon.	epilithon.	epilithon.	epilithon.	epilithon.
Slide	531	536	533	532	534	540	537	538	539
report station	BR1	BR3	BR4	BR5	BR6	NR1	NR2	NR3	NR4
(as $CaCO_3$ in $mg.l^{-1}$)									
TDS ($mg.l^{-1}$)	54	566	737	330	310	716	618	638	689

river	Gamtoos	Gamtoos	Gamtoos	Gamtoos	Gamtoos	Gamtoos	Gamtoos	Gamtoos	Sundays	Sundays	Sundays	Sundays
habitat	epilithon	epilithon	epilithon.	epilithon.	epilithon	epilithon.	epilithon.	epilithon.	epilithon.	epilithon.	epilithon.	epilithon.
Slide	518	519	501	505	503	509	510	508	523	524	527	525
report station	GR2	GR3	GR4	GR5	GR6	GT2	GT3	GT4	SR1	SR3	SR4	ST1
ACHNABUN	0.00	0.00	0.00	14.33	5.45	0.00	3.64	1.97	0.00	0.00	0.63	0.00
ACHNENGE	9.59	2.00	7.28	31.00	6.36	0.00	0.00	0.66	9.71	0.95	1.26	0.00
ACHNOBLO	0.00	0.00	0.00	7.00	8.18	0.00	58.94	3.93	0.00	0.00	0.00	0.00
ACHNMINU	0.00	0.00	4.97	11.67	7.27	0.00	32.45	18.69	1.94	0.00	0.00	0.00
CCNEPLAC	0.00	0.00	54.97	9.00	6.36	0.00	0.00	0.00	0.00	0.00	6.92	0.00
DIATVULG									0.00	0.00	17.61	0.00
EUTIFALA	0.00	0.00	0.00	0.00	0.00	76.92	0.00	5.25	0.00	0.00	0.00	0.00
GONEPARV	0.00	0.00	0.00	3.67	12.73	0.00	0.66	25.57	3.88	0.00	1.26	3.86
NAVIGREG	0.00	0.00	0.66	4.67	14.55	0.00	1.99	24.92	2.91	0.00	0.00	0.00
NAVIFRUG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.97	0.00	10.06	1.10
NITZFRUS	0.00	0.00	16.89	2.00	10.91	0.00	0.00	0.00	14.56	20.25	8.18	36.95
NITZFONT	83.56	69.67	0.33	2.33	10.91	0.00	0.00	0.66	12.62	14.56	16.35	32.54
RHOPGIBA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.71	0.00	0.00
SYNETABU	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.97	36.71	1.26	0.18
Water Quality												
Ca^{2+} ($mg.l^{-1}$)		504	19	8	14	1	5	5		239	46	86
Cl^{-} ($mg.l^{-1}$)		6844	171	69	112	10	39	57		1338	133	356
Conductivity ($mS.m^{-1}$)	1103	1979	74.7	23.4	49.7	5.5	18.5	25.2	601	481	90	166.5

river	Gamtoos	Gamtoos	Gamtoos	Gamtoos	Gamtoos	Gamtoos	Gamtoos	Gamtoos	Sundays	Sundays	Sundays	Sundays
habitat	epilithon	epilithon	epilithon.	epilithon.	epilithon	epilithon.	epilithon.	epilithon.	epilithon.	epilithon.	epilithon.	epilithon.
Slide	518	519	501	505	503	509	510	508	523	524	527	525
report station	GR2	GR3	GR4	GR5	GR6	GT2	GT3	GT4	SR1	SR3	SR4	ST1
F^- (mg.l^{-1})		0.4	0.1	0.05	0.1	0.05	0.05	0.05		0.3	0.5	0.5
K^+ (mg.l^{-1})		26.3	1.7	1.7	1.9	0.15	1	1.7		10.5	4.5	5.3
Mg^{2+} (mg.l^{-1})		690	19	8	13	1	4	5		154	23	48
Na^+ (mg.l^{-1})		3645	100	41	65	6	22	34		648	118	200
NH_4^+ (mg.l^{-1})		0.06	0.02	0.05	0.02	0.02	0.08	0.05		0.06	0.09	0.04
NO_2^-+NO_3^- (mg.l^{-1})		0.04	0.06	0.33	0.92	0.2	0.31	0.27		0.04	0.02	0.19
pH	8.06	8.36	8.25	7.6	7.1	4.9	6.6	6.65	8.55	9.1	8.9	8.5
PO_4^{3-} (mg.l^{-1})		0.033	0.009	0.026	0.023	0.005	0.02	0.026		0.05	0.038	0.026
SiO_2 (mg.l^{-1})		0.5	1.8	3.6	6.8	2	2.4	3.3		0.5	3.6	5.3
SO_4^{2-} (mg.l^{-1})		2114	53	28	36	7	11	29		516	76	107
Alkalinity (as $CaCO_3$ in mg.l^{-1})		258	66	29	51	6	16	23		198	202	259
TDS (mg.l^{-1})		14139	444	192	309	34	104	162		3147	647	1120

river	Gamtoos	Gamtoos	Gamtoos	Gamtoos	Gamtoos	Gamtoos	Gamtoos	Gamtoos	Gamtoos	Sundays	Sundays	Sundays
habitat	epipelon.	epipelon.	epipelon.	epipelon	epipelon.	epipelon.	epipelon	epipelon.	epipelon	epipelon.	epipelon.	epipelon.
Slide	520	521	522	513	514	512	516	515	511	528	529	530
report station	GR1	GR2	GR3	GR4	GR5	GR6	GT2	GT3	GT4	SR2	SR5	SR6
ACHNDELI	0.00	6.35	19.27	3.85	0.00	0.58	0.00	0.64	0.00	0.00	0.00	0.00
ACHNMINU	0.00	0.00	0.00	0.96	0.00	1.75	0.00	13.38	2.33	1.65	0.00	3.83
AMRACOGN	0.98	0.00	0.00	5.77	0.00	21.05	0.00	0.00	0.00	0.00	0.63	0.00
AMROPEDI	21.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.51
DINEPUEL	0.98	0.32	4.65	13.54	0.00	0.58	0.00	0.00	0.00	1.32	1.57	15.65
ENTOALAT	1.96	0.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.24	0.00	10.54
EUTIFALA	0.00	0.00	0.00	0.00	0.00	0.58	36.60	0.00	0.00	0.00	0.00	0.00
EUTITRIN	0.00	0.00	0.00	0.00	0.00	0.00	18.95	0.00	0.00			

river	Gamtoos	Gamtoos	Gamtoos	Gamtoos	Gamtoos	Gamtoos	Gamtoos	Gamtoos	Gamtoos	Sundays	Sundays	Sundays
habitat	epipelon.	epipelon.	epipelon.	epipelon	epipelon.	epipelon.	epipelon	epipelon.	epipelon	epipelon.	epipelon.	epipelon.
Slide	520	521	522	513	514	512	516	515	511	528	529	530
report station	GR1	GR2	GR3	GR4	GR5	GR6	GT2	GT3	GT4	SR2	SR5	SR6
GONEPARV	7.84	0.00	0.00	2.88	10.00	5.26	0.65	5.73	1.00	0.00	3.45	1.60
NAVIVIro	0.98	0.00	0.00	0.00	0.00	2.34	0.00	0.32	1.33	0.00	17.55	0.00
NAVIGREG	0.98	0.00	0.66	0.00	60.00	15.20	0.00	43.63	39.00	0.33	0.00	0.00
NAVIMOLL	1.96	0.32	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	20.69	0.64
NAVISCHR	4.90	0.00	0.00	10.62	0.00	0.00	0.00	0.00	1.00	0.00	0.94	0.00
NAVITENT	0.00	0.00	4.65	0.00	20.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NAVIPHYL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	29.07
NITZFRUS	0.00	28.25	20.27	0.00	0.00	0.00	0.00	0.64	0.00	3.30	0.31	0.64
NITZFONT	29.41	26.98	17.28	1.92	0.00	2.34	0.00	1.91	1.33	4.62	7.52	4.79
NITZNANA	0.00	0.00	0.00			0.00	0.00	0.00	38.00			
NITZDIST	0.00	0.00	0.00	0.00	0.00	36.26	0.00	0.00	0.00	0.00	0.00	0.00
NITZLIte	0.00	0.00	0.00	5.81	0.00	0.00	0.00	0.00	0.00	22.44	1.57	1.28
PLMAACUM	0.00	0.95	2.33	0.00	0.00	0.00	0.00	0.00	0.00	12.21	0.00	0.00
Water Quality												
Ca^{2+} ($mg.l^{-1}$)	69		504	19	8	14	1	5	5		54	70
Cl^- ($mg.l^{-1}$)	463		6844	171	69	112	10	39	57		178	633
Conductivity ($mS.m^{-1}$)	238	1103	1979	74.7	23.4	49.7	5.5	18.5	25.2	590	106.9	295
F^- ($mg.l^{-1}$)	0.5		0.4	0.1	0.05	0.1	0.05	0.05	0.05		0.5	0.7
K^+ ($mg.l^{-1}$)	8.9		26.3	1.7	1.7	1.9	0.15	1	1.7		5	5.1
Mg^{2+} ($mg.l^{-1}$)	46		690	19	8	13	1	4	5		33	71
Na^+ ($mg.l^{-1}$)	319		3645	100	41	65	6	22	34		138	513
NH_4^+ ($mg.l^{-1}$)	0.02		0.06	0.02	0.05	0.02	0.02	0.08	0.05		0.62	0.04
$NO_2^-+NO_3^-$ ($mg.l^{-1}$)	0.02		0.04	0.06	0.33	0.92	0.2	0.31	0.27		0.05	1.53
pH	8.35	8.06	8.36	8.25	7.6	7.1	4.9	6.6	6.65	8.05	8.8	8.92
PO_4^{3-} ($mg.l^{-1}$)	0.043		0.033	0.009	0.026	0.023	0.005	0.02	0.026		0.059	0.034
SiO_2 ($mg.l^{-1}$)	2.4		0.5	1.8	3.6	6.8	2	2.4	3.3		5.9	4.5

river	Gamtoos	Gamtoos	Gamtoos	Gamtoos	Gamtoos	Gamtoos	Gamtoos	Gamtoos	Gamtoos	Sundays	Sundays	Sundays
habitat	epipelon.	epipelon.	epipelon.	epipelon	epipelon.	epipelon.	epipelon	epipelon.	epipelon	epipelon.	epipelon.	epipelon.
Slide	520	521	522	513	514	512	516	515	511	528	529	530
report station	GR1	GR2	GR3	GR4	GR5	GR6	GT2	GT3	GT4	SR2	SR5	SR6
SO_4^{2-} (mg.l^{-1})	245		2114	53	28	36	7	11	29		55	265
Alkalinity (as $CaCO_3$ in mg.l^{-1})	196		258	66	29	51	6	16	23		262	394
TDS (mg.l^{-1})	1391		14139	444	192	309	34	104	162		785	2045

river	Eerste	Eerste	Eerste	Eerste	Eerste	Eerste	Palmiet	Palmiet	Palmiet	Bot
habitat	epilithon	epilithon	epilithon	epilithon	epilithon	epilithon	epilithon	epilithon	epilithon	epilithon
slide	550	553	571	556	559	565	574	580	585	591
report station	ER1	ER2	ER3	ER4	ER5	ER6	PR1	PR2	PR4	BR1
DWAFstation	ER720 A1	ER720 B	ER720 B1	ER720C	ER720D	ER720E	PR400 A	PR400 B	PR400 D	BR400A
ACHNENGE	0.00	0.00	0.72	0.00	0.98	20.61	0.00	0.00	0.00	6.34
ACHNMINU	12.64	4.67	9.24	1.29	1.77	1.78	0.00	0.74	48.31	18.70
ACHNOBLO	19.41	3.04	1.66	3.10	0.32	1.47	0.00	0.25	15.69	58.94
ACHNSUAT	37.16	28.35	44.16	56.03	10.75	7.41	0.99	0.74	5.70	0.00
CCNEPLAC	0.00	56.68	25.99	1.64	6.23	8.30	0.00	0.00	0.00	0.00
EUTIINCI	24.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EUTITENE	0.00	0.00	0.31	1.67	0.32	0.00	93.07	32.95	0.27	0.99
EUTITRIN	0.00	0.00	0.00	0.00	0.00	0.00	1.98	36.69	0.00	0.96
NAVICRCE	0.32	1.44	2.90	5.86	13.01	3.49	0.00	0.00	0.27	0.32
NAVIHEIM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.38	0.33
NITZFRUS	0.00	0.00	0.51	0.00	7.35	10.74	1.98	0.00	0.00	0.00
NITZPALE	0.00	0.40	2.99	2.95	11.70	4.17	0.00	0.00	0.00	4.28
PLANDUBI	0.00	0.00	3.18	11.09	4.96	8.57	0.00	0.00	0.00	0.00
TABEFLOC	0.31	0.00	0.00	0.00	0.00	0.00	0.00	26.42	0.27	0.00
Water Quality										
EC	7.36	8.35	10.3	11.6	55.7	47.2	4.13	6.29	8.33	51.8

river	Eerste	Eerste	Eerste	Eerste	Eerste	Eerste	Palmiet	Palmiet	Palmiet	Bot
habitat	epilithon	epilithon	epilithon	epilithon	epilithon	epilithon	epilithon	epilithon	epilithon	epilithon
slide	550	553	571	556	559	565	574	580	585	591
report station	ER1	ER2	ER3	ER4	ER5	ER6	PR1	PR2	PR4	BR1
DWAFstation	ER720 A1	ER720 B	ER720 B1	ER720C	ER720D	ER720E	PR400 A	PR400 B	PR400 D	BR400A
NH4	0	0	0	0	0	0	0	0	0	0
NO2+NO3	0	0	0	0	12.2	2.4	0	0.4	0	5.2
pH	6.8	6.8	7.1	7.1	7.2	7.4	4.2	4.7	6.4	7
PO4	0	0	0	0	4.94	1.39	0	0	0	0

river	Eerste	Eerste	Palmiet	Palmiet	Palmiet	Palmiet	Bot	Houhoek
habitat	epipelon	epipelon	epipelon	epipelon	epipelon	epipelon	epipelon	epipelon
slide	562	568	577	581	583	588	594	599
Report station	ER6	ER7	PR1	PR2	PR3	PR5	BR2	BT1
DWAF station	ER720E	ER720F	PR400 A	PR400 B	PR400 C	PR400 E	BR400B	JR400A
ACHNEXIG	78.35	7.52	0.00	0.00	0.00	0.00	0.00	0.00
ACHNMINU	0.50	0.33	0.00	9.36	3.70	10.17	7.00	0.00
ACHNOBLO	0.34	0.10	0.00	0.00	4.55	3.24	21.36	24.05
ACHNSUAT	0.68	0.52	0.00	11.33	0.00	1.73	1.14	0.00
EUTITENE	0.00	0.00	11.54	14.29	37.54	9.68	1.77	3.38
FRUSROST	0.00	0.00	31.35	0.00	0.00	0.39	0.16	0.42
NAVIDULC	0.00	0.00	0.00	12.81	0.00	0.00	0.33	0.00
NAVIHUNG	1.67	18.00	0.00	0.00	0.00	0.00	0.32	0.00
NAVIPUPU	0.33	43.73	4.35	0.00	0.00	0.00	0.00	0.00
NAVISUTI	0.00	0.00	27.68	0.00	0.00	0.00	0.00	0.00
NAVITELO	0.00	0.00	0.00	14.78	0.00	2.93	9.57	29.54
PINNBRAU	0.00	0.00	0.00	5.91	0.00	13.07	0.48	0.42
PLACELGI	0.00	0.10	0.00	0.00	0.00	0.37	1.44	25.32
TABEFLOC	0.00	0.00	2.17	13.79	8.25	5.91	0.33	0.84
Water Quality								
EC	47.2	70.8	4.13	6.29	14.8	17	49.1	33.8

river	Eerste	Eerste	Palmiet	Palmiet	Palmiet	Palmiet	Bot	Houhoek
habitat	epipelon	epipelon	epipelon	epipelon	epipelon	epipelon	epipelon	epipelon
slide	562	568	577	581	583	588	594	599
Report station	ER6	ER7	PR1	PR2	PR3	PR5	BR2	BT1
DWAF station	ER720E	ER720F	PR400 A	PR400 B	PR400 C	PR400 E	BR400B	JR400A
NH4	0	3	0	0	0	0	0	0
NO2+NO3	2.4	1.4	0	0.4	1.9	0.8	4.5	3.5
pH	7.4	7.4	4.2	4.7	6.2	6.4	6.7	5.7
PO4	1.39	1.19	0	0	0	0	0	0

river	Bedeke	Brandwag	Moordkuil	Grootbrak	Grootbrak	Keurbooms	Keurbooms	Keurbooms	Keurbooms	Keurbooms
habitat	epilithon	epilithon	epilithon	epilithon	epilithon	epilithon	epilithon	epilithon	epilithon	epilithon
slide	604	610	622	619	616	631	637	640	643	646
Report station	KB1	KB2	KB3	GB3	GB2	KR1	KR2	KT2	KT1	KR3
DWAF station	K1H002	K1H004	K1H005	K2H002	K2H006	K6H002	K6H007	K6H008	K6H010	K6H011
ACHNABUN	0.00	9.16	6.17	1.65	0.78	0.66	1.95	3.21	0.33	26.43
ACHNENGE	0.36	0.65	20.17	0.76	0.64	0.00	5.12	0.00	0.40	0.00
ACHNMINU	2.26	45.01	0.15	12.23	36.13	1.32	1.46	3.32	21.83	38.38
ACHNOBLO	0.28	14.82	29.59	7.75	23.61	51.19	62.20	12.76	8.33	8.45
ACHNSUAT	0.00	2.29	8.50	45.79	17.05	0.81	11.71	30.77	1.81	7.38
BRACSP01	16.05	0.00	0.15	0.00	0.00	0.50	0.00	0.00	0.13	0.00
CCNESP01	0.00	15.03	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EUTIINCI	76.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FRAGCAPU	0.00	3.98	1.23	0.00	0.00	12.45	1.22	3.03	3.49	5.59
FRAGSP01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.64	0.00	0.00
GONECLEV	0.00	0.83	0.00	0.00	0.00	0.16	0.00	0.12	61.57	1.65
NAVIDUER	0.00	0.00	0.49	25.94	1.65	0.00	0.00	0.99	0.00	0.00
SYNEULNA	0.00	1.49	0.16	0.13	3.28	23.07	0.49	1.98	0.00	1.47
EC	13.5	23.3	19.3	50.9	27.1	14.4	15.3	8.9	8.4	29.6
NH4	0.02	0.022	0.05	0.035	0.078	0.03	0.037	0.384	0.015	0.018
NO2+NO3	0.646	0.099	0.059	0.139	0.175	0.047	0.048	0.048	0.025	0.042

river	Bedeke	Brandwag	Moordkuil	Grootbrak	Grootbrak	Keurbooms	Keurbooms	Keurbooms	Keurbooms	Keurbooms
habitat	epilithon	epilithon	epilithon	epilithon	epilithon	epilithon	epilithon	epilithon	epilithon	epilithon
slide	604	610	622	619	616	631	637	640	643	646
Report station	KB1	KB2	KB3	GB3	GB2	KR1	KR2	KT2	KT1	KR3
DWAF station	K1H002	K1H004	K1H005	K2H002	K2H006	K6H002	K6H007	K6H008	K6H010	K6H011
pH	4.72	7.33	6.94	7.39	7.35	6.66	6.87	6.65	6.4	7.26
PO4	0.016	0.027	0.076	0.03	0.038	0.014	0.012	0.106	0.005	0.002

river	Bedeke	Brandwag	Moordkuil	Salskanaal	Keurbooms	Keurbooms
habitat	epipelon	epipelon	epipelon	epipelon	epipelon	epipelon
slide	607	613	625	628	634	649
Report station	KB1	KB2	KB3	GB1	KR1	KR3
DWAF station	K1H002	K1H004	K1H005	K2H003	K6H002	K6H011
ACHNABUN	0.65	6.13	0.78	0.00	0.64	32.11
ACHNMINU	22.24	15.70	0.83	0.64	2.63	19.18
ACHNOBLO	6.84	10.21	7.73	0.48	49.21	5.74
BRACSP01	21.39	0.00	0.00	2.41	0.32	0.00
CCNESP01	0.00	13.26	0.00	0.32	0.00	0.00
EUTIINCI	29.92	0.00	0.00	1.12	0.00	0.00
FALATERA	0.00	0.00	0.00	0.00	10.78	0.00
NAVIGREG	0.48	15.72	45.16	0.00	0.00	4.53
NAVIHEIM	0.00	4.10	0.00	0.16	1.00	12.26
NITZPALE	0.65	6.17	2.42	62.12	1.79	1.55
NITZPUMI	0.82	15.80	2.49	11.76	0.00	0.32
STNESP1	0.33	0.65	11.72	0.00	0.00	0.15
EC	13.5	23.3	19.3	12.9	14.4	29.6
NH4	0.02	0.022	0.05	0.056	0.03	0.018
NO2+NO3	0.646	0.099	0.059	0.171	0.047	0.042
pH	4.72	7.33	6.94	4.9	6.66	7.26
PO4	0.016	0.027	0.076	0.078	0.014	0.002

River: Olifants																									
habitat: epilithon																									
slide	774	767	761	754	747	739	687	676	699	670	733	727	706	719	712	804	829	835	797	783	790	693	809	816	823
site	O2	O3	O4	O5	O6	O7	O8	O9	O10	O11	KO1	KO2	KO3	KO4	KO5	W1	W2	W3	W4	W5	W6	W7	B1	B2	B3
ACHNENGE	0.00	0.00	0.00	0.00	0.00	0.49	11.33	0.00	0.00	0.00	0.71	0.61	0.15	0.16	4.50	0.00	0.00	0.00	0.00	0.49	0.00	0.00	0.00	0.00	0.00
ACHNMINU	78.60	48.73	63.29	8.03	74.07	33.92	4.88	85.11	84.76	78.72	65.72	70.56	66.62	5.11	11.33	72.54	70.78	93.08	84.12	60.60	83.64	74.91	21.90	12.25	68.30
ACHNKRYO	0.00	0.00	0.00	18.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.75	0.00	0.00	0.00	0.00	2.97	0.15
AMRAPEDI	0.00	0.00	0.29	0.11	0.00	0.81	0.63	0.00	0.00	0.00	0.57	0.00	0.00	1.46	1.33	4.34	0.23	0.78	0.00	1.49	0.00	0.00	4.76	35.88	0.33
CYCLMENI	0.00	4.11	0.00	0.00	0.00	4.37	7.22	0.00	0.05	0.40	0.16	0.00	0.59	0.16	1.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	21.43	36.07	0.71
CYLAMIC2	0.00	0.00	0.62	0.00	0.28	0.16	0.00	0.00	0.00	0.00	0.00	2.06	0.00	0.00	0.00	0.00	18.00	3.52	0.00	0.00	0.00	0.32	0.00	0.23	10.09
DIATVULG	0.00	0.00	0.00	0.00	0.00	0.16	4.92	0.00	0.14	1.33	0.74	0.55	0.46	65.93	1.50	0.00	0.00	0.00	0.00	5.76	0.00	0.00	0.00	0.00	0.00
NAVIFRUG	0.00	0.00	0.00	59.85	0.05	2.91	0.31	0.00	0.10	0.00	0.00	0.00	0.17	1.88	2.17	0.00	0.00	0.00	1.74	0.00	0.00	0.00	2.86	3.47	0.15
NITZDISS	6.69	8.40	0.00	0.00	2.84	9.39	13.33	0.00	0.13	0.00	3.44	1.42	1.14	0.44	2.00	1.69	1.04	0.36	5.45	14.76	0.34	0.23	5.24	0.95	1.65
NITZFRUS	0.00	0.77	0.00	0.93	4.30	17.45	3.68	0.00	0.00	0.16	2.00	0.31	0.00	0.31	7.17	6.51	0.00	0.00	0.00	1.14	0.00	0.00	0.95	1.38	0.00
NITZPACE	0.00	3.97	0.00	0.44	14.10	1.45	21.17	0.00	0.00	0.00	2.95	0.45	1.19	0.00	17.33	0.72	0.37	0.47	0.00	2.99	0.00	0.00	34.76	3.31	0.54
NITZPALE	1.19	3.87	0.14	2.79	1.75	1.30	8.46	0.00	0.57	1.61	5.18	1.26	15.46	1.55	23.50	0.97	0.00	0.00	0.50	1.43	0.11	0.18	2.38	0.00	0.00
Water Quality																									
Ca^{2+} ($mg.l^{-1}$)	28	112	34	41	94	79	35	53	47	39	73	25	30	51	34	168	34	21	15	12	34	39	29	25	19
Cl^- ($mg.l^{-1}$)	0	44	0	107	40	40	0	29	0	0	26	0	0	47	31	222	0	0	0	0	0	0	0	0	0
Conductivity ($mS.m^{-1}$)	40.9	138.5	43.7	94.6	109.4	96.6	45.7	78.4	60.7	54.4	91.9	36.2	40.4	74.3	52.9	299.0	42.2	26.5	21.6	18.1	27.6	32.4	39.9	31.6	25.8
F^- ($mg.l^{-1}$)	0.4	0.5	0.5	0.4	0.5	0.4	0.3	0.3	0.4	0.3	0.4	0.3	0.3	0.4	0.3	0.2	0.4	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.2
K^+ ($mg.l^{-1}$)	4.4	7.6	4.9	15.6	9.8	8.4	6.5	8.0	5.3	5.2	11.8	4.9	5.0	15.1	9.6	3.8	2.7	1.7	2.6	2.1	2.2	2.2	10.8	5.8	3.8
Mg^{2+} ($mg.l^{-1}$)	18	85	20	23	66	53	18	21	14	14	55	17	18	21	16	255	22	16	12	9	6	7	20	18	15
Na^+ ($mg.l^{-1}$)	33	77	25	109	49	43	28	74	52	49	41	16	21	68	46	196	21	9	12	9	9	12	22	14	11
NH_4^+ ($mg.l^{-1}$)	0.00	0.00	0.05	0.45	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.06	0.00	0.00
$NO_2^-+NO_3^-$ ($mg.l^{-1}$)	0.09	0.09	0.12	24.27	4.77	3.60	1.73	4.36	3.38	1.81	0.26	0.23	0.08	9.59	2.92	0.09	0.22	0.41	0.12	0.09	0.14	0.42	0.15	0.18	0.16
PO_4^{3-} ($mg.l^{-1}$)	0.048	0.018	0.005	6.679	0.497	0.129	0.119	0.013	0.012	0.012	0.008	0.014	0.007	2.628	1.337	0.008	0.008	0.013	0.020	0.000	0.018	0.032	1.100	0.638	0.007
OxigenSat (%)	125	165	95	62	202	118	130	95	104	100	125	108	160	171	92	101	85	104	114	96	113	106	101	114	102
pH	8.36	8.52	7.99	6.95	9.36	9.00	9.57	7.35	7.74	7.78	8.37	8.17	9.08	8.83	8.97	8.24	7.72	8.21	7.65	8.07	7.72	7.92	8.05	8.42	7.85
SiO_2 ($mg.l^{-1}$)	2.2	0.7	0.5	4.0	0.5	0.0	0.0	1.9	1.8	1.5	0.0	1.7	0.9	1.4	0.0	1.6	3.9	3.5	1.7	1.2	1.7	3.3	2.6	4.4	2.1
SO_4^{2-} ($mg.l^{-1}$)	33	585	106	157	479	398	130	266	205	173	334	93	111	150	116	1240	82	24	23	21	93	103	17	14	15
Alkalinity (as $CaCO_3$ in $mg.l^{-1}$)	161	149	106	43	58	51	76	31	32	44	103	65	78	131	101	358	129	110	78	62	36	41	173	144	113
TDS ($mg.l^{-1}$)	337	1094	337	634	832	701	335	509	399	364	667	245	295	563	393	2524	333	217	170	137	198	222	333	269	214

River: Olifants																									
habitat: epilithon																									
slide	774	767	761	754	747	739	687	676	699	670	733	727	706	719	712	804	829	835	797	783	790	693	809	816	823
site	O2	O3	O4	O5	O6	O7	O8	O9	O10	O11	KO1	KO2	KO3	KO4	KO5	W1	W2	W3	W4	W5	W6	W7	B1	B2	B3
Temp	10.9	11.4	12.9	13.5	14.7	12.7	12.5	10.0	10.7	13.0	9.0	10.7	11.6	11.4	8.3	10.7	10.5	12.0	15.0	12.4	14.1	12.0	11.9	11.6	12.2

River: Olifants																										
habitat: epipelon																										
Slide	780	777	770	767	757	750	742	690	684	703	673	736	730	709	723	715	806	832	837	800	786	794	696	812	819	826
Site	O1	O2	O3	O4	O5	O6	O7	O8	O9	O10	O11	KO1	KO2	KO3	KO4	KO5	W1	W2	W3	W4	W5	W6	W7	B1	B2	B3
ACHNENGE	0.00	0.00	0.00	0.33	0.00	2.50	1.60	16.85	0.00	0.16	7.79	0.33	0.00	0.00	0.23	23.28	0.16	0.00	0.59	0.00	0.49	0.00	0.00	0.00	0.00	0.31
ACHNMINU	1.72	3.49	9.67	27.23	1.53	20.04	9.83	0.78	64.66	42.79	44.68	12.74	16.75	5.02	1.92	3.33	11.54	16.78	21.61	39.97	1.72	44.66	33.39	0.00	0.99	15.7
CALOSCHU	20.81	10.52	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CCNEPEDI	0.00	0.00	0.00	0.00	0.00	1.32	1.45	3.57	0.00	0.16	0.00	0.97	0.00	0.00	14.19	9.11	0.48	0.40	0.00	0.00	0.00	0.00	0.00	0.00	2.31	0.30
CCNEPLAC	0.00	0.66	0.00	1.12	4.14	2.62	1.33	3.08	0.00	4.02	0.82	0.00	0.80	0.47	16.29	8.77	0.48	0.00	1.14	0.67	0.95	0.80	0.64	0.16	1.98	2.22
CYLATURG	0.16	1.00	0.00	0.93	0.44	0.80	0.33	0.71	1.13	14.27	10.35	0.00	4.75	4.05	0.23	0.15	0.47	4.79	7.59	0.00	7.26	8.44	27.82	0.00	0.46	4.40
DIATVULG	0.00	1.00	0.00	0.00	14.94	0.00	0.80	2.95	0.00	0.30	1.62	31.25	1.87	1.26	9.72	2.02	0.00	0.00	0.61	2.51	21.09	0.64	0.00	0.31	13.84	0.64
FRAGCAva	0.00	0.00	0.00	0.65	0.00	0.00	0.32	0.00	18.97	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.49	0.00	0.00	0.00	0.00
GONECLja	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	1.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.98	0.00	12.11	14.26	0.00	0.00	3.81
NAVICAPI	0.00	1.00	0.00	0.64	0.64	1.15	1.45	9.58	0.00	1.87	2.56	11.28	0.80	31.07	9.78	4.50	0.32	17.51	13.54	3.42	17.68	8.18	3.21	13.2	25.88	19.1
NAVICRex	1.10	1.99	0.96	0.78	3.64	6.50	4.72	0.88	0.16	3.41	3.33	1.13	0.79	9.17	9.11	3.01	18.06	3.71	3.68	0.31	0.00	0.00	0.00	1.81	0.00	0.31
NAVIMENI	0.16	0.66	0.16	4.24	1.09	5.15	13.19	0.32	0.00	0.00	0.00	0.00	0.98	0.47	0.23	2.01	0.00	16.00	2.38	2.29	0.00	0.00	0.00	25.2	15.45	8.80
NAVIPERI	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NAVITRIV	0.00	0.33	0.49	0.31	2.56	0.00	0.00	0.00	0.00	0.00	0.00	0.48	0.16	14.82	0.96	0.16	1.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NITZDISS	1.45	4.48	17.49	0.95	0.00	11.53	15.31	9.26	0.33	0.51	0.16	0.48	0.16	1.23	0.17	1.72	0.48	1.53	2.70	13.69	19.78	0.97	0.48	9.38	2.54	4.99
NITZGRAC	2.33	1.32	17.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.08	0.00	0.00	0.31	0.17	0.00	0.49	0.33	0.00	0.00
NITZGRAF	7.54	13.63	13.97	26.37	0.00	2.47	2.10	2.44	0.00	0.13	0.00	12.97	30.58	0.15	0.00	0.00	13.34	1.04	2.67	6.02	3.32	6.29	0.00	1.91	0.46	8.66
NITZPACE	17.81	8.39	1.93	0.94	0.95	2.15	1.28	16.17	0.62	0.76	0.17	2.29	0.32	0.31	0.00	2.12	0.60	0.49	0.32	1.42	0.49	0.00	0.00	3.73	2.90	0.31
NITZPALE	6.00	6.79	4.99	4.23	24.19	5.54	3.74	14.36	2.28	3.32	6.08	4.23	3.37	12.14	5.88	13.92	3.07	1.85	3.78	0.49	0.99	0.47	0.48	0.97	1.64	0.31
NITZRECT	0.00	0.00	2.42	1.71	1.08	1.28	0.98	0.00	0.00	0.00	0.00	1.95	8.57	0.79	0.83	0.00	1.24	1.41	1.51	1.75	7.88	1.93	0.00	15.9	15.50	3.88
SYNEULNA	0.00	0.00	0.00	0.00	0.22	0.50	0.80	0.00	1.98	0.85	0.17	0.00	10.45	0.16	0.00	0.00	0.00	0.00	0.60	2.22	1.86	1.63	1.12	0.32	0.00	0.00
Water Quality																										
Ca^{2+} ($mg.l^{-1}$)	26	28	112	34	41	94	79	35	53	47	39	73	25	30	51	34	168	34	21	15	12	34	39	29	25	19
Cl^- ($mg.l^{-1}$)	39	0	44	0	107	40	40	0	29	0	0	26	0	0	47	31	222	0	0	0	0	0	0	0	0	0
Conductivity	43.7	40.9	138.5	43.7	94.6	109.4	96.6	45.7	78.4	60.7	54.4	91.9	36.2	40.4	74.3	52.9	299.0	42.2	26.5	21.6	18.1	27.6	32.4	39.9	31.6	25.8

River: Olifants
habitat: epipelon

Slide	780	777	770	767	757	750	742	690	684	703	673	736	730	709	723	715	806	832	837	800	786	794	696	812	819	826
Site	O1	O2	O3	O4	O5	O6	O7	O8	O9	O10	O11	KO1	KO2	KO3	KO4	KO5	W1	W2	W3	W4	W5	W6	W7	B1	B2	B3
Cl^- ($mg.l^{-1}$)	39	0	44	0	107	40	40	0	29	0	0	26	0	0	47	31	222	0	0	0	0	0	0	0	0	0
Conductivity ($mS.m^{-1}$)	43.7	40.9	138.5	43.7	94.6	109.4	96.6	45.7	78.4	60.7	54.4	91.9	36.2	40.4	74.3	52.9	299.0	42.2	26.5	21.6	18.1	27.6	32.4	39.9	31.6	25.8
F^- ($mg.l^{-1}$)	0.3	0.4	0.5	0.5	0.4	0.5	0.4	0.3	0.3	0.4	0.3	0.4	0.3	0.3	0.4	0.3	0.2	0.4	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.2
K^+ ($mg.l^{-1}$)	2.7	4.4	7.6	4.9	15.6	9.8	8.4	6.5	8.0	5.3	5.2	11.8	4.9	5.0	15.1	9.6	3.8	2.7	1.7	2.6	2.1	2.2	2.2	10.8	5.8	3.8
Mg^{2+} ($mg.l^{-1}$)	16	18	85	20	23	66	53	18	21	14	14	55	17	18	21	16	255	22	16	12	9	6	7	20	18	15
Na^+ ($mg.l^{-1}$)	45	33	77	25	109	49	43	28	74	52	49	41	16	21	68	46	196	21	9	12	9	9	12	22	14	11
NH_4^+ ($mg.l^{-1}$)	0.06	0.00	0.00	0.05	0.45	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.06	0.00	0.00
NO_2^-+NO_3^- ($mg.l^{-1}$)	0.15	0.09	0.09	0.12	24.27	4.77	3.60	1.73	4.36	3.38	1.81	0.26	0.23	0.08	9.59	2.92	0.09	0.22	0.41	0.12	0.09	0.14	0.42	0.15	0.18	0.16
PO_4^{3-} ($mg.l^{-1}$)	0.040	0.048	0.018	0.005	6.679	0.497	0.129	0.119	0.013	0.012	0.012	0.008	0.014	0.007	2.628	1.337	0.008	0.008	0.013	0.020	0.00	0.018	0.032	1.10	0.638	0.01
OxigenSat (%)	115	125	165	95	62	202	118	130	95	104	100	125	108	160	171	92	101	85	104	114	96	113	106	101	114	102
pH	8.79	8.36	8.52	7.99	6.95	9.36	9.00	9.57	7.35	7.74	7.78	8.37	8.17	9.08	8.83	8.97	8.24	7.72	8.21	7.65	8.07	7.72	7.92	8.05	8.42	7.85
SiO_2 ($mg.l^{-1}$)	4.5	2.2	0.7	0.5	4.0	0.5	0.0	0.0	1.9	1.8	1.5	0.0	1.7	0.9	1.4	0.0	1.6	3.9	3.5	1.7	1.2	1.7	3.3	2.6	4.4	2.1
SO_4^{2-} ($mg.l^{-1}$)	24	33	585	106	157	479	398	130	266	205	173	334	93	111	150	116	1240	82	24	23	21	93	103	17	14	15
Alkalinity (as $CaCO_3$ in $mg.l^{-1}$)	166	161	149	106	43	58	51	76	31	32	44	103	65	78	131	101	358	129	110	78	62	36	41	173	144	113
TDS ($mg.l^{-1}$)	356	337	1094	337	634	832	701	335	509	399	364	667	245	295	563	393	2524	333	217	170	137	198	222	333	269	214
Temp	11.4	10.9	11.4	12.9	13.5	14.7	12.7	12.5	10.0	10.7	13.0	9.0	10.7	11.6	11.4	8.3	10.7	10.5	12.0	15.0	12.4	14.1	12.0	11.9	11.6	12.2

River: Swartkops
Habitat: epilithon

Slide	1088	1096	1099	1109	1120	1123	1173	1174	1177	1179	1182	1204	1205	1208	1231	1232	1235	1258	1259	1262	1284	1287	1289	1292	1315
Site	E09	B09	A09	E10	B10	A10	E11	D11	C11	B11	A11	E12	B12	A12	E13	B13	A13	E14	B14	A14	F15	E15	B15	A15	E16
ACHNABUN	0.00	0.62	13.99	0.00	0.50	8.32	0.00	0.00	0.00	0.65	17.70	0.00	1.05	22.85	0.00	8.71	33.63	0.00	2.64	19.93	0.00	0.00	1.35	29.19	0.00
ACHNDELI	0.00	0.00	0.00	2.26	0.00	0.00	5.10	0.00	0.00	0.00	0.00	1.91	0.00	0.00	2.48	0.00	0.00	0.00	0.00	0.00	4.94	0.00	0.00	0.00	0.00
ACHNENGE	10.26	0.00	0.00	0.45	0.00	0.32	2.04	15.20	23.83	0.66	0.30	0.00	0.00	0.00	3.96	0.00	0.00	1.95	0.00	0.00	46.47	0.47	0.49	0.00	0.19
ACHNMICR	0.00	19.32	10.95	0.00	5.48	4.29	0.00	0.00	0.22	5.18	2.81	0.00	8.09	3.14	0.00	20.99	1.93	0.00	14.91	7.13	0.00	0.00	5.37	4.44	0.00
ACHNMINU	0.00	49.02	39.67	0.00	46.51	20.76	0.00	0.16	0.00	41.13	28.00	0.00	58.77	40.09	0.00	45.86	39.53	0.00	56.82	48.25	0.00	2.84	27.83	39.94	0.00
ACHNABLO	0.00	3.36	11.76	0.00	10.13	11.99	0.00	0.33	0.33	15.30	30.38	0.48	15.50	16.73	0.00	8.38	6.46	0.00	3.70	6.00	0.00	0.00	31.58	12.33	0.00
AMRAHELE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.32	0.00	0.00	0.00	0.00
BRACBREB	0.00	4.10	3.08	0.00	0.15	0.64	0.00	0.00	0.00	1.84	0.76	0.00	2.65	0.82	0.99	4.26	2.44	0.00	10.86	1.54	0.00	0.00	10.15	1.97	0.00

River: Swartkops

Habitat: epilithon

Slide	1088	1096	1099	1109	1120	1123	1173	1174	1177	1179	1182	1204	1205	1208	1231	1232	1235	1258	1259	1262	1284	1287	1289	1292	1315
Site	E09	B09	A09	E10	B10	A10	E11	D11	C11	B11	A11	E12	B12	A12	E13	B13	A13	E14	B14	A14	F15	E15	B15	A15	E16
FRAGELLI	0.00	0.16	0.00	0.00	0.00	13.19	0.00	5.59	6.42	0.00	0.00	0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00
NAVIFRUG	0.00	0.00	0.00	3.17	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.96	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
NAVIGREG	0.00	7.13	0.00	0.00	12.14	0.00	0.00	4.36	0.43	6.00	0.16	0.00	6.06	0.16	0.50	3.78	0.00	0.00	3.61	0.00	0.10	0.00	15.46	0.00	0.00
NAVIHESI	0.00	6.92	4.69	0.00	3.00	2.24	0.00	0.00	0.00	2.12	2.96	0.00	0.74	5.44	0.00	0.00	6.65	0.00	0.25	4.74	0.19	0.00	0.79	5.65	0.00
NAVIMOLL	0.00	0.00	0.00	3.62	0.00	0.00	1.53	1.78	0.00	0.00	0.00	1.91	0.00	0.00	8.91	0.96	0.63	21.46	0.74	0.00	0.00	8.06	0.00	0.00	0.00
NAVIPHYL	5.13	0.00	0.00	6.79	0.00	0.00	19.39	0.33	0.00	0.00	0.33	14.83	0.00	0.00	43.07	0.72	0.47	23.90	0.00	0.00	0.00	6.16	0.00	0.00	0.19
NAVISELU	0.00	0.00	0.00	0.00	0.00	4.80	0.00	0.00	6.11	0.00	0.00	0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.15	0.00	0.00	0.00	0.00
NITZDESE	17.95	0.00	0.00	7.69	0.00	0.00	2.55	0.00	0.00	0.00	0.00	6.22	0.00	0.00	0.99	0.00	0.00	0.98	0.00	0.00	0.00	7.58	0.16	0.00	7.75
NITZELal	7.69	0.00	0.00	1.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.99	0.00	0.00	0.00	0.00	0.00	0.00	11.37	0.00	0.00	68.60
NITZFRUS	12.82	0.33	0.16	36.20	0.00	0.00	41.84	43.26	33.05	0.44	0.82	26.79	0.00	0.00	28.71	0.00	0.00	32.68	0.00	0.00	11.15	8.06	0.15	0.00	11.05
NITZPALE	25.64	0.44	0.67	3.17	0.47	1.20	0.00	4.20	0.00	0.00	0.00	0.00	0.26	0.00	0.00	0.00	0.00	0.98	0.00	0.00	0.00	1.90	0.29	0.00	0.00
NITZSOLI	0.00	0.00	0.00	0.45	0.00	0.00	1.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.99	0.26	0.00	0.00	0.00	0.00	0.00	4.27	0.00	0.00	4.46
SYNETABU	0.00	0.00	0.00	11.31	0.00	0.00	7.14	0.00	0.00	0.00	0.00	24.40	0.00	0.00	0.99	0.15	0.00	5.85	0.00	0.00	0.13	39.81	0.00	0.00	0.19
SYNEULNA	0.00	0.00	0.23	0.00	16.14	0.16	0.00	0.32	0.00	21.65	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.25	0.00	0.00	0.00	0.16	0.00	0.00
Water Quality																									
Ca^{2+} ($mg.l^{-1}$)	50	7	3	47	10	3	53	40	23	10	3	75	9	3	47	16	2	41	7	3	54	72	11	2	73
Cl^- ($mg.l^{-1}$)	809	99	35	745	140	40	985	680	259	124	40	1285	116	43	891	234	42	773	101	42	936	1365	144	44	1322
Conductivity ($mS.m^{-1}$)	469.0	47.0	18.7	307.0	57.7	17.6	843.0	252.0	124.3	51.6	17.5	732.0	50.4	18.2	561.0	100.9	18.4	641.0	46.0	18.1	349.0	492.0	60.1	18.6	400.0
F^- ($mg.l^{-1}$)	0.2	0.0	0.0	0.2	0.1	0.0	0.3	0.2	0.2	0.1	0.0	0.3	0.1	0.0	0.2	0.2	0.1	0.2	0.2	0.1	0.3	0.3	0.1	0.1	0.3
K^+ ($mg.l^{-1}$)	14.0	1.5	0.7	17.3	1.8	0.7	24.4	28.3	47.0	1.9	0.8	26.1	1.9	0.7	19.4	2.3	0.9	17.1	1.5	0.6	19.4	20.7	2.0	0.7	19.1
Mg^{2+} ($mg.l^{-1}$)	62	8	3	60	13	4	82	59	26	13	3	105	12	4	77	24	4	68	10	4	74	112	14	4	102
Na^+ ($mg.l^{-1}$)	495	61	26	434	85	25	610	393	169	73	25	759	67	25	520	147	27	465	68	24	576	821	87	28	780
NH_4^+ ($mg.l^{-1}$)	0.00	0.00	0.00	1.99	0.00	0.00	0.24	3.08	0.0	0.04	0.0	0.07	0.0	0.0	0.0	0.0	0.0	0.04	0.04	0.0	0.0	0.0	0.0	0.0	0.12
$NO_2^-+NO_3^-$ ($mg.l^{-1}$)	2.34	0.00	0.00	5.21	0.17	0.08	0.93	0.53	0.07	0.10	0.06	1.80	0.07	0.0	1.14	0.45	0.0	0.84	0.10	0.0	0.0	6.22	0.05	0.05	2.53
pH	8	7.06	7.27	7.76	7.09	7.2	8.15	8.19	7.8	7.12	7.01	8.25	7.18	7.27	9.18	7.37	7.48	8.51	7.03	7	7.12	8.5	7.29	7.21	8.33
PO_4^{3-} ($mg.l^{-1}$)	0.696	0.007	0.018	3.952	0.012	0.012	0.138	0.150	0.009	0.007	0.039	0.154	0.038	0.006	0.085	0.023	0.026	0.108	0.079	0.018	4.161	1.916	0.013	0.020	0.655
SiO_2 ($mg.l^{-1}$)	3.60	3.00	2.65	3.50	3.20	3.00	1.10	1.30	2.40	2.40	2.70	1.50	2.10	2.50	0.90	3.00	2.30	1.00	1.70	2.10	2.40	0.60	1.50	2.00	2.50
SO_4^{2-} ($mg.l^{-1}$)	194	22	10	134	34	5	182	118	47	27	7	239	28	9	180	77	16	156	28	10	184	269	32	7	263
Alkalinity (as $CaCO_3$ in $mg.l^{-1}$)	154	32	19	165	42	21	235	189	180	43	18	270	40	14	167	51	7	163	28	9	200	226	46	14	196

River: Swartkops
Habitat: epilithon

Slide	1088	1096	1099	1109	1120	1123	1173	1174	1177	1179	1182	1204	1205	1208	1231	1232	1235	1258	1259	1262	1284	1287	1289	1292	1315
Site	E09	B09	A09	E10	B10	A10	E11	D11	C11	B11	A11	E12	B12	A12	E13	B13	A13	E14	B14	A14	F15	E15	B15	A15	E16
TDS (mg.l^{-1})	1825	237	102	1677	335	104	2229	1555	792	302	101	2827	284	102	1943	566	100	1724	250	95	2100	2969	347	104	2812
Temp (°C)	19.7	20.1	21.1	15.6	15.9	16.0	14.5	13.9	14.1	14.0	15.2	16.8	14.9	16.5	17.9	15.1	20.0	19.7	18.6	20.5	20.0	22.1	22.8	25.0	20.8

River: Swartkops
Habitat: epilithon

Slide	1316	1317	1320	1342	1345	1350	1370	1373	1376	1379	1402	1403	1406	1408	1431	1432	1435	1438	1461	1462	1465	1469
Site	F16	B16	A16	B17	A17	E17	F18	E18	B18	A18	E19	F19	B19	A19	E20	F20	B20	A20	E21	F21	B21	A21
ACHNABUN	0.00	2.14	17.18	1.67	19.71	0.00	0.00	0.00	0.56	22.52	0.00	0.00	2.36	15.99	0.00	0.00	0.00	2.23	0.00	0.00	0.31	11.40
ACHNDELI	1.40	0.00	0.00	0.00	0.00	0.00	9.14	3.75	0.00	0.00	0.00	5.68	0.00	0.00	0.00	8.86	0.00	0.15	0.00	12.69	0.00	0.16
ACHNENGE	6.07	0.00	0.16	0.00	0.00	0.00	24.65	4.12	0.00	0.80	0.00	27.88	2.24	1.82	0.00	18.12	1.55	2.30	0.00	30.20	0.00	0.00
ACHNMICR	0.00	2.13	7.02	8.37	1.64	0.00	0.00	0.00	2.95	0.79	0.00	0.00	0.74	1.08	0.00	0.00	1.52	0.44	0.00	0.00	4.29	1.12
ACHNMINU	0.00	32.29	41.74	38.69	41.20	0.00	0.00	0.00	67.58	18.23	0.00	0.00	10.74	25.38	0.00	0.00	22.82	23.99	0.00	0.00	59.08	35.52
ACHNABLO	0.00	6.31	3.30	6.12	5.45	0.00	0.00	0.00	5.70	8.74	0.00	0.00	35.36	4.08	0.00	0.00	17.69	1.14	0.00	0.00	19.73	1.54
AMRAHELE	15.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BRACBREB	0.00	3.62	2.65	4.09	1.58	0.00	0.00	0.00	3.16	3.01	0.00	0.00	1.76	1.94	0.00	0.00	3.34	1.86	0.00	0.00	0.33	3.88
CYMBMIC1	0.00	0.44	4.92	2.04	4.72	0.00	0.00	0.00	0.71	6.50	0.00	0.00	0.75	4.17	0.00	0.00	0.92	10.89	0.00	0.00	0.67	14.22
FALEUMPA	29.44	0.00	0.00	0.00	0.00	0.00	6.37	0.00	0.00	1.43	0.00	12.35	0.00	0.00	0.00	12.04	0.00	0.00	0.00	15.91	0.00	0.00
FRAGELLI	5.14	0.28	0.00	1.85	0.00	0.00	31.03	0.00	0.43	0.00	0.00	24.02	0.00	0.00	0.00	27.37	3.36	0.71	0.00	11.20	0.00	0.00
NAVIFRUG	0.47	0.00	0.00	0.00	0.00	0.00	0.00	2.25	0.00	0.00	8.43	0.00	0.00	0.00	19.03	0.00	0.00	0.00	0.26	0.00	0.00	0.00
NAVIGREG	0.00	7.84	0.16	11.84	0.00	0.00	0.27	0.00	5.16	0.97	0.00	0.00	6.75	0.17	0.00	0.39	14.96	0.00	0.00	0.00	4.05	0.00
NAVIHESI	0.00	0.63	8.89	3.57	5.57	0.00	0.00	0.00	0.00	21.50	0.00	0.86	0.75	36.23	0.00	0.00	0.88	47.48	0.00	0.00	0.16	22.89
NAVIMOLL	0.00	0.00	0.00	0.00	0.85	5.16	0.00	0.75	0.00	0.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.89	0.00	0.00	0.00
NAVIPHYL	0.00	0.31	0.00	0.00	1.28	0.00	0.34	3.00	0.00	0.00	3.21	0.00	0.00	0.00	1.33	0.08	0.00	0.00	5.00	0.00	0.00	0.00
NAVISELU	12.15	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.00	0.92	0.50	0.00	0.00	1.27	0.00	0.58	0.00	1.84	0.00	0.00
NITZDESE	0.00	0.63	0.00	0.00	0.00	9.86	1.19	7.12	0.00	0.17	8.43	0.44	0.50	0.15	2.65	0.34	0.00	0.00	2.11	0.00	0.00	0.00
NITZELal	0.00	29.00	0.61	0.00	3.85	22.54	0.00	7.87	0.00	0.00	2.41	0.51	0.00	0.00	2.65	0.00	0.00	0.00	0.00	0.00	0.00	1.24
NITZFRUS	17.29	3.20	2.61	0.00	0.85	13.62	12.49	58.05	0.29	3.59	61.85	9.82	0.00	0.00	70.35	14.29	0.81	0.42	79.74	13.99	2.15	1.45
NITZPALE	0.00	0.46	0.32	0.00	0.33	1.88	1.85	0.00	2.02	0.32	4.82	0.96	13.05	0.00	0.00	2.71	1.92	1.74	0.00	0.26	0.17	0.65
NITZSOLI	0.00	0.31	0.00	0.00	0.00	13.15	0.31	0.75	0.86	0.31	2.41	0.00	0.00	0.00	1.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SYNETABU	0.00	0.00	0.00	0.00	0.00	17.84	0.27	0.00	0.00	0.00	0.00	0.32	0.00	0.00	0.00	0.41	0.00	0.00	0.00	0.00	0.00	0.00
SYNEULNA	0.00	0.00	0.32	1.50	0.32	0.00	0.00	0.00	0.00	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.16	0.00	0.00	0.00	0.48

River: Swartkops

Habitat: epilithon

Slide	1316	1317	1320	1342	1345	1350	1370	1373	1376	1379	1402	1403	1406	1408	1431	1432	1435	1438	1461	1462	1465	1469
Site	F16	B16	A16	B17	A17	E17	F18	E18	B18	A18	E19	F19	B19	A19	E20	F20	B20	A20	E21	F21	B21	A21
Water Quality																						
Ca^{2+} ($mg.l^{-1}$)	59	12	3	11	3	42	48	62	12	3	52	42	14	3	76	53	10	4	88	60	6	3
Cl^- ($mg.l^{-1}$)	953	136	46	144	45	699	810	1236	152	47	976	791	170	50	1134	826	112	50	1577	930	76	51
Conductivity ($mS.m^{-1}$)	332.0	52.3	17.3	56.0	17.4	454.0	337.0	508.0	65.8	21.7	318.0	284.0	62.1	19.9	417.8	320.0	48.0	21.2	811.0	356.8	26.5	21.0
F^- ($mg.l^{-1}$)	0.3	0.1	0.0	0.2	0.1	0.3	0.3	0.4	0.1	0.1	0.4	0.3	0.1	0.0	0.3	0.3	0.0	0.1	0.4	0.4	0.0	0.1
K^+ ($mg.l^{-1}$)	19.6	2.4	0.8	2.0	0.7	23.2	19.8	26.8	2.3	0.8	27.5	21.6	3.0	0.8	21.4	23.2	2.2	0.7	34.2	24.8	1.3	0.7
Mg^{2+} ($mg.l^{-1}$)	73	14	4	16	4	60	63	96	14	5	78	57	17	5	96	64	11	4	129	69	7	4
Na^+ ($mg.l^{-1}$)	602	79	28	90	28	445	527	744	79	29	613	505	90	30	728	547	65	28	899	563	42	29
NH_4^+ ($mg.l^{-1}$)	0.0	0.0	0.0	0.0	0.0	0.0	0.05	0.80	0.05	0.04	1.86	0.09	0.0	0.0	0.05	0.08	0.0	0.07	0.13	0.0	0.0	0.0
NO_2^-+NO_3^- ($mg.l^{-1}$)	0.0	0.05	0.0	0.0	0.11	0.89	0.0	1.19	0.0	0.0	2.68	0.0	0.0	0.0	2.98	0.0	0.13	0.05	0.62	0.05	0.0	0.0
pH	6.81	7.12	7.29	7.1	7.31	8.65	6.83	8.29	6.89	7.68	7.89	6.85	6.93	7.19	8.87	7	6.94	7.4	8.76	7.12	6.96	7.37
PO_4^{3-} ($mg.l^{-1}$)	2.568	0.040	0.057	0.025	0.023	1.049	4.858	2.179	0.013	0.022	2.972	6.965	0.031	0.022	2.654	5.967	0.020	0.033	0.130	4.293	0.018	0.053
SiO_2 ($mg.l^{-1}$)	2.80	1.20	2.10	2.40	2.20	2.60	2.90	3.20	2.20	2.60	3.80	3.00	2.30	2.60	4.70	5.80	2.60	2.90	2.90	2.50	2.50	2.90
SO_4^{2-} ($mg.l^{-1}$)	194	30	8	33	7	139	165	258	24	8	191	144	21	5	514	285	17	0.0	290	203	11	6
Alkalinity (as $CaCO_3$ in $mg.l^{-1}$)	174	33	11	38	17	177	201	259	42	19	219	190	45	22	199	195	36	20	295	209	26	16
TDS ($mg.l^{-1}$)	2121	312	103	343	109	1631	1892	2752	335	115	2226	1813	371	122	2833	2056	263	115	3380	2118	176	113
Temp (°C)	21.1	23.1	22.4	24.0	27.1	22.4	26.8	30.6	30.0	32.3	22.9	23.3	25.6	23.6	24.8	22.7	23.9	25.1	22.8	18.9	20.7	23.6

River: Swartkops

habitat: epipelon

Slide	1081	1084	1089	1092	1095	1102	1105	1110	1113	1116	1118	1154	1157	1161	1164	1167	1170	1185	1188	1192	1195	1198	1201	1211	1214
Station	F09	E09	D09	C09	B09	F10	E10	D10	C10	B10	A10	F11	E11	D11	C11	B11	A11	F12	E12	D12	C12	B12	A12	F13	E13
ACHNENGE	1.59	1.42	9.16	0.60	0.46	4.40	2.01	11.13	4.83	0.49	0.91	4.86	1.63	10.61	4.11	1.49	0.32	4.10	2.43	2.85	4.52	1.56	0.55	7.33	0.76
ACHNEXIG	1.24	0.31	3.28	3.48	8.80	0.49	0.45	1.96	4.03	0.73	2.88	3.30	0.00	1.93	11.86	2.31	0.16	0.94	0.00	0.30	2.72	1.89	0.00	1.77	0.00
ACHNHUNG	0.32	0.28	0.31	3.95	0.00	0.73	0.00	0.80	0.63	0.00	0.00	0.47	0.33	0.32	0.42	0.00	0.00	0.33	0.00	0.00	1.17	0.00	0.00	2.73	0.00
ACHNMINU	0.00	0.00	0.25	0.38	5.56	0.00	0.00	0.30	0.44	1.22	3.84	0.47	0.00	0.00	2.34	7.84	9.89	1.41	0.00	0.98	2.57	5.75	10.56	0.63	0.00
AMRACOFF	0.00	0.16	1.27	0.00	0.00	0.00	0.34	1.06	0.00	0.00	0.00	0.15	0.00	0.65	0.00	0.00	0.00	0.16	0.32	0.49	0.30	0.00	0.00	0.00	0.00
AMRASUBT	0.00	0.32	0.31	0.23	0.00	0.00	0.61	0.00	0.00	0.00	0.00	3.99	0.16	0.00	0.00	0.00	0.00	0.62	0.00	0.00	0.00	0.00	0.00	0.16	0.75
BALAPARA	9.05	0.00	0.17	8.40	0.00	10.22	0.32	0.80	3.23	0.00	0.00	5.03	1.13	0.00	3.49	0.00	0.00	14.59	0.48	0.00	3.31	0.00	0.00	10.79	0.00

River: Swartkops
habitat: epipelon

Slide	1081	1084	1089	1092	1095	1102	1105	1110	1113	1116	1118	1154	1157	1161	1164	1167	1170	1185	1188	1192	1195	1198	1201	1211	1214
Station	F09	E09	D09	C09	B09	F10	E10	D10	C10	B10	A10	F11	E11	D11	C11	B11	A11	F12	E12	D12	C12	B12	A12	F13	E13
BRACBREB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.74	0.97	0.00	0.00	0.00	0.00	1.35	2.74	0.00	0.00	0.00	0.00	0.91	0.76	0.32	0.00
CYMBOAHU	1.42	0.31	0.00	0.00	0.00	0.00	0.46	0.63	0.00	0.00	0.00	0.29	0.00	0.34	0.00	0.00	0.00	1.42	1.29	0.30	0.00	0.00	0.00	0.32	3.75
DINEPUEL	1.74	0.16	5.18	0.91	2.31	2.34	0.00	1.78	2.51	0.49	0.00	10.13	0.00	5.30	2.65	0.00	0.00	3.83	0.00	4.66	2.05	0.51	0.00	2.42	0.00
ENTOALAT	0.00	0.00	0.00	0.00	0.00	1.66	1.86	0.00	0.00	0.00	0.00	2.93	20.95	0.00	0.00	0.00	0.00	7.06	2.42	0.33	0.00	0.00	0.00	10.98	2.56
FALATERA	1.74	25.43	3.04	1.41	0.00	3.03	34.43	1.79	2.01	0.00	0.00	10.74	22.22	2.37	3.02	0.00	0.00	3.27	12.63	1.76	1.18	0.00	0.33	5.85	21.86
FRAGELLI	46.79	1.54	6.39	26.56	4.63	34.03	3.87	1.95	12.45	1.72	0.44	8.68	0.30	0.62	7.30	0.64	0.00	8.67	2.92	0.00	13.29	0.16	0.00	4.39	0.00
MAGLELLI	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.67	0.00	0.00	0.00	0.00	0.00	2.72	0.00	0.00	0.00	0.00	0.00	1.41	0.00	0.00
NAVICIle	0.79	1.86	0.50	0.00	0.00	0.00	2.46	0.60	0.00	0.00	0.00	0.29	0.00	0.34	0.00	0.00	0.00	0.17	0.00	0.33	0.00	0.00	0.00	0.32	0.00
NAVICONF	0.00	0.00	1.38	3.21	0.00	0.00	0.00	0.17	2.74	0.00	0.00	0.00	0.00	0.32	11.08	0.00	0.00	0.00	0.00	0.00	3.99	0.00	1.63	0.00	0.00
NAVICRex	1.28	6.04	3.13	2.09	0.00	0.97	4.00	2.93	2.51	0.00	0.00	1.43	3.99	3.12	5.12	0.14	0.00	0.97	4.19	3.34	1.90	0.00	0.00	3.54	1.06
NAVIGREG	2.66	1.37	9.53	4.44	43.06	4.20	0.31	11.46	7.12	71.99	26.99	3.28	1.13	12.81	10.67	52.38	0.31	5.84	0.32	19.61	12.72	71.03	1.04	1.11	0.61
NAVIHESI	0.00	0.00	0.00	0.00	5.09	0.00	0.00	0.00	0.00	6.82	21.97	0.17	0.00	0.00	0.00	6.40	33.09	0.00	0.00	0.00	0.00	2.00	32.73	0.00	0.00
NAVIHUca	9.56	1.79	1.15	0.49	0.00	2.91	0.31	0.83	0.00	0.00	0.00	5.49	1.60	2.09	0.65	0.30	0.17	4.11	2.58	0.33	0.00	0.00	0.44	9.13	4.23
NAVIPHYL	0.79	0.78	0.48	0.15	0.00	0.24	3.72	0.33	0.00	0.00	0.00	0.93	17.77	0.64	0.00	0.00	0.00	0.48	29.06	1.73	0.00	0.00	0.14	0.48	35.47
NAVIPSHA	0.00	0.00	0.00	0.40	3.24	0.00	0.34	0.00	0.96	0.00	0.00	0.00	0.33	0.00	0.65	0.00	0.00	0.00	0.00	0.00	1.13	0.00	0.00	0.00	0.00
NAVISELU	0.00	0.00	0.33	0.47	0.00	0.00	0.00	1.64	11.25	0.25	0.25	1.41	0.32	1.43	5.87	0.15	0.31	0.33	0.00	0.00	4.36	0.31	0.33	0.32	0.30
NAVITELO	0.00	0.00	0.00	0.25	0.00	0.00	0.16	0.33	1.48	0.00	0.00	0.00	0.00	0.00	0.47	0.00	0.00	0.66	0.00	0.30	1.24	0.00	0.00	0.65	0.00
NAVIVAND	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.72	0.00	0.00	0.00	0.00	0.00	12.95	0.00	0.00
NAVIVIro	0.00	0.00	2.37	3.64	0.93	0.00	0.46	9.68	0.00	0.00	0.69	0.00	0.16	8.06	0.84	0.97	0.79	0.33	0.00	6.81	0.00	0.25	0.78	0.00	0.00
NITZCAPI	0.47	0.31	0.63	0.76	0.00	0.24	0.00	1.12	0.00	0.00	0.00	1.16	0.31	2.26	0.00	0.00	0.00	0.33	0.00	2.87	0.56	0.00	0.00	0.32	0.00
NITZDESE	1.23	16.25	0.00	0.47	0.00	0.49	13.97	0.50	0.16	0.25	0.44	3.02	4.01	0.67	0.15	0.00	0.00	1.25	7.92	0.00	0.00	0.00	0.00	3.23	4.84
NITZFRUS	8.07	26.52	21.59	2.06	0.00	14.29	14.00	14.72	2.54	0.00	0.00	7.14	8.28	7.15	2.46	0.30	0.16	9.36	5.67	2.51	4.32	0.00	0.00	7.21	3.64
NITZGRAC	0.16	0.00	1.10	1.96	0.00	0.00	0.47	3.63	5.66	0.25	0.44	0.63	0.00	4.42	2.90	0.87	0.00	1.09	0.49	7.53	11.50	1.64	0.00	0.32	1.22
NITZMICE	0.16	0.00	1.59	0.98	5.56	0.00	0.17	1.13	1.23	2.45	1.88	1.08	0.00	0.00	0.00	0.28	1.72	0.62	0.64	0.00	1.86	0.00	3.76	0.00	0.00
NITZPALE	0.64	0.61	4.78	3.12	0.00	5.01	1.54	10.48	6.44	0.25	1.82	2.97	0.60	19.77	5.64	0.00	0.78	1.58	0.32	12.16	4.46	0.70	1.22	3.99	1.66
NITZPACE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.25	14.28	0.00	1.00	0.34	0.00	1.00	0.29	0.00	0.00	1.56	0.32	1.14	9.24	0.31	6.00	0.79	0.90
NITZSOLI	0.00	0.28	0.00	0.00	0.00	0.00	0.00	0.90	0.00	0.00	0.00	0.97	0.77	0.31	0.15	0.00	0.00	0.50	1.29	0.48	0.56	0.00	0.00	1.61	2.13
PLACELGI	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PLACSP01	0.00	1.47	0.00	0.00	0.00	0.68	2.61	0.00	0.00	0.00	0.00	0.78	1.10	0.00	0.00	0.00	0.00	0.00	1.45	0.00	0.00	0.00	0.00	0.32	1.36
RHOPGIBA	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.75	0.00	0.00	0.00	0.00	0.00	10.11	0.00	0.00	0.00	0.00	0.00	2.97	0.00	0.00
SYNETABU	0.63	0.00	0.25	0.88	0.00	1.41	0.46	0.17	0.00	0.00	0.00	0.47	0.81	0.65	0.00	0.00	0.00	3.32	8.72	0.33	0.28	0.00	0.00	1.62	1.36
TRYBANGU	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.33	0.48	0.00	0.00	0.30	0.32	0.15	0.00	0.00	2.86	0.00	1.27	0.00	0.00	0.00	0.95	0.00
TRYBCONS	0.96	4.92	0.17	0.00	0.00	0.00	0.78	0.48	0.00	0.00	0.00	0.92	2.53	1.61	0.00	0.00	0.00	0.33	6.94	13.30	0.00	0.00	0.00	0.00	3.31

Table 5. Comparison of the water quality indications for the epipelic diatom NAVIGREG where it is the dominant and where it occurs at less than 10% of the diatom population

Water quality	NAVIGREG as Dominant		NAVIGREG at less than 10%	
	Max	Min	Max	Min
Ca^{++} ($mg.l^{-1}$)	62.00	3.00	90.00	2.00
Cl^{-} ($mg.l^{-1}$)	698.00	40.00	1577.00	40.00
EC (mS.m-1)	299.00	17.60	903.00	17.30
F^{-} ($mg.l^{-1}$)	0.30	0.00	0.40	0.00
K^{+} ($mg.l^{-1}$)	190.40	0.70	242.60	0.60
Mg++ ($mg.l^{-1}$)	63.00	4.00	129.00	3.00
Na^{+} ($mg.l^{-1}$)	471.00	25.00	899.00	24.00
NH_4^{+} ($mg.l^{-1}$)	0.70	0.00	3.81	0.00
$NO_2^{-}+NO_3^{-}$ ($mg.l^{-1}$)	0.85	0.00	6.22	0.00
pH	8.99	6.89	9.00	6.81
PO4--- ($mg.l^{-1}$)	0.08	0.01	6.97	0.01
SiO_2 ($mg.l^{-1}$)	3.20	0.00	8.90	0.50
SO_4^{--} ($mg.l^{-1}$)	127.00	5.00	514.00	5.00
Alkalinity	530.00	21.00	851.00	7.00
TDS ($mg.l^{-1}$)	2258.00	104.00	3380.00	95.00

Table 6 is presented in an attempt to visualise the effect that water quality had on the sites at which NAVIGREG was found. This species NAVIGREG was always present at site B, indicating that this site had water of good quality, a point brought out in relation to Figure 3, where the water quality was stated to be "virtually pristine". Furthermore, it was present at the same site through all seasons, indicating that season is not a variable to which it responds. The species was only present on one occasion at site A where the water should have been of even higher quality. No reason is immediately available to explain this.

River: Swartkops

habitat: epipelon

Slide	1218	1221	1224	1227	1238	1253	1245	1248	1251	1254	1265	1268	1272	1275	1278	1281	1295	1298	1302	1305	1308	1311	1323	1326
Station	D13	C13	B13	A13	F14	E14	D14	C14	B14	A14	F15	E15	D15	C15	B15	A15	F16	E16	D16	C16	B16	A16	F17	E17
BRACBREB	0.00	0.00	2.06	2.36	0.00	0.00	0.00	0.00	3.36	1.25	0.00	0.00	0.00	0.00	13.92	3.18	0.00	0.00	0.00	0.00	6.24	2.16	0.00	0.00
CYMBOAHU	0.00	0.00	0.00	0.00	0.49	6.28	0.32	0.00	0.00	0.00	0.64	11.50	0.00	0.00	0.00	0.00	0.00	1.66	1.23	0.00	0.00	0.00	0.00	3.76
DINEPUEL	3.77	5.07	0.00	0.00	2.96	0.00	7.38	1.00	0.00	0.00	2.23	0.00	3.84	2.53	0.32	0.00	21.13	0.00	0.93	1.16	1.00	0.00	22.03	0.00
ENTOALAT	0.59	0.00	0.00	0.00	10.32	2.37	0.33	0.00	0.00	0.00	1.28	0.82	0.00	0.00	0.00	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.00	0.00
FALATERA	3.85	4.74	0.00	0.00	0.33	10.22	0.17	1.67	0.00	0.00	6.70	6.92	1.08	5.48	0.00	0.00	12.47	20.85	0.87	4.54	0.00	0.00	8.08	18.33
FRAGELLI	0.80	6.71	0.00	0.00	7.39	0.81	0.66	3.17	0.00	0.00	3.99	0.00	1.55	5.06	0.00	0.00	0.15	0.15	6.24	14.49	0.00	1.35	0.00	0.17
MAGLELLI	0.00	0.00	0.00	0.34	0.00	0.00	0.00	3.03	0.00	1.72	0.00	0.00	0.00	0.00	0.00	1.26	0.00	0.00	0.00	0.00	0.00	1.42	0.00	0.00
NAVICIle	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.00	0.00	0.00	0.00	0.91	0.36	0.00	0.00	0.00	4.11	4.04
NAVICONF	0.00	1.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.84	0.00	1.44	0.00	0.00	0.00	0.32	0.00	0.00	0.00	0.00
NAVICRex	2.46	7.10	0.00	0.00	1.64	2.51	0.29	5.85	0.14	0.47	1.75	2.15	0.80	6.12	0.32	0.32	1.74	1.67	2.98	11.70	0.31	0.93	4.46	4.86
NAVIGREG	23.53	23.28	65.15	1.55	7.02	1.10	23.53	25.52	57.66	0.47	1.44	0.00	8.32	13.64	30.29	0.00	0.67	0.00	5.55	17.02	43.70	0.15	1.66	0.17
NAVIHESI	0.00	0.00	2.43	26.87	0.67	0.00	0.00	0.00	0.57	26.68	0.00	0.00	0.00	0.00	0.22	26.01	0.00	0.00	0.00	0.00	1.12	33.24	0.00	0.00
NAVIHUca	1.38	0.00	0.00	0.00	9.77	1.22	1.90	0.67	0.00	0.00	14.04	0.66	0.31	0.32	0.00	0.00	8.93	0.76	0.00	0.00	0.00	0.00	3.49	0.63
NAVIPHYL	1.75	0.61	0.00	0.00	0.32	23.65	2.62	0.00	0.00	0.48	0.00	8.10	1.08	0.00	0.00	0.00	0.00	7.38	0.73	0.78	0.00	0.00	0.31	1.31
NAVIPSHA	0.00	0.61	6.33	0.00	0.00	0.00	0.00	0.00	2.34	0.00	0.00	0.00	0.00	0.32	2.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NAVISELU	1.27	5.72	0.00	0.00	0.00	0.00	0.17	1.33	0.45	0.00	0.48	0.00	0.15	1.44	0.32	0.28	0.78	0.00	1.24	0.29	0.00	0.00	0.50	0.00
NAVITELO	0.00	0.00	0.00	0.00	0.33	0.00	0.00	1.33	0.00	0.00	0.80	0.00	0.31	1.13	0.00	0.00	0.00	0.32	0.00	0.45	0.15	0.00	2.16	0.47
NAVIVAND	0.00	0.00	0.00	9.90	0.33	0.00	0.81	0.00	0.43	6.58	0.00	0.00	0.00	0.31	0.22	0.33	0.00	0.00	0.00	0.00	0.00	1.40	0.00	0.00
NAVIVIro	2.25	0.00	0.63	1.58	0.00	0.44	1.09	0.83	0.14	0.64	0.00	0.00	0.15	0.48	0.00	0.33	0.00	0.00	0.00	0.48	0.78	0.16	0.00	0.47
NITZCAPI	0.91	0.00	0.00	0.00	0.65	0.00	3.93	0.33	0.29	0.00	0.00	0.00	19.04	0.00	0.00	0.00	0.00	0.00	15.40	0.13	0.00	0.00	0.00	0.16
NITZDESE	0.32	0.99	0.00	1.16	1.32	5.15	0.32	0.00	0.00	0.00	1.59	10.06	1.23	1.12	0.00	0.00	0.00	28.57	3.02	0.00	0.33	0.00	0.33	11.81
NITZFRUS	4.04	1.99	0.00	0.00	2.14	11.34	4.41	2.83	0.00	0.00	3.67	7.71	4.63	5.83	0.64	0.00	1.32	2.17	18.81	2.73	0.62	0.00	0.62	5.33
NITZGRAC	3.37	0.00	0.00	0.00	0.49	0.00	0.29	1.67	0.00	0.00	0.32	0.66	3.99	1.76	1.35	0.00	0.00	1.84	0.78	3.38	0.33	0.00	0.00	0.00
NITZMICE	0.00	2.31	0.80	11.68	0.17	0.32	0.00	0.33	1.25	7.68	0.48	0.00	0.61	2.53	7.36	5.35	0.00	2.11	0.00	2.60	7.32	10.10	0.00	0.31
NITZPALE	7.02	4.10	0.00	1.60	3.77	0.32	8.45	2.83	0.29	1.76	0.16	1.64	13.83	0.96	0.65	4.51	0.00	4.60	2.42	4.26	2.06	3.05	0.00	0.31
NITZPACE	0.00	8.48	0.64	4.03	0.33	0.64	0.29	10.39	0.00	0.80	0.00	0.00	1.69	4.74	4.30	2.09	0.48	0.00	0.28	5.78	0.61	1.26	0.00	0.00
NITZSOLI	0.96	0.38	0.00	0.00	0.65	1.55	1.49	0.17	0.00	0.00	3.03	2.77	2.99	0.48	0.00	0.00	0.00	2.01	2.64	3.02	0.00	0.00	0.33	1.27
PLACELGI	0.00	0.00	0.00	0.96	0.00	0.00	0.00	0.00	0.29	0.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.33	0.00	1.27
PLACSP01	0.32	0.00	0.00	0.00	0.82	4.56	0.00	0.00	0.00	0.00	0.32	5.79	0.00	0.00	0.00	0.00	0.00	3.97	0.00	0.26	0.00	0.60	0.17	21.63
RHOPGIBA	0.00	0.48	0.00	0.48	0.00	0.00	0.00	0.00	0.00	0.77	0.00	0.00	0.00	0.32	0.00	0.33	0.00	0.00	0.00	0.45	0.00	0.00	0.00	0.00
SYNETABU	1.75	0.00	0.00	0.00	0.99	9.33	1.53	1.68	0.00	0.00	1.91	24.36	1.08	7.43	0.00	0.00	0.84	2.02	3.45	2.14	0.00	0.00	5.73	6.90
TRYBANGU	0.00	0.00	0.00	0.00	11.14	0.00	0.16	0.00	0.00	0.00	1.59	0.00	0.15	0.79	0.00	0.00	0.96	0.00	0.69	0.26	0.00	0.00	0.00	0.00
TRYBCONS	16.21	0.32	0.00	0.00	1.63	6.16	17.25	0.00	0.00	0.00	0.48	2.49	15.87	0.00	0.00	0.00	0.16	2.74	4.83	0.00	0.00	0.00	0.00	3.73

River: Swartkops
habitat: epipelon

Slide	1218	1221	1224	1227	1238	1253	1245	1248	1251	1254	1265	1268	1272	1275	1278	1281	1295	1298	1302	1305	1308	1311	1323	1326
Station	D13	C13	B13	A13	F14	E14	D14	C14	B14	A14	F15	E15	D15	C15	B15	A15	F16	E16	D16	C16	B16	A16	F17	E17
Water quality																								
Ca^{2+} ($mg.l^{-1}$)	25	18	16	2	40	41	23	18	7	3	54	72	45	30	11	2	59	73	55	62	12	3	48	42
Cl^- ($mg.l^{-1}$)	362	215	234	42	641	773	360	215	101	42	936	1365	838	332	144	44	953	1322	1004	698	136	46	751	699
Conductivity ($mS.m^{-1}$)	153.1	103.3	100.9	184.1	254	346	152	104.4	46	18.1	349	489	303	167.6	60.1	18.63	332	444	332	299	52.3	17.3	270	233
F ($mg.l^{-1}$)	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.1	0.2	0.1	0.3	0.3	0.2	0.2	0.1	0.1	0.3	0.3	0.2	0.3	0.1	0	0.3	0.3
K^+ ($mg.l^{-1}$)	19.9	24	2.3	0.9	20.5	17.1	18.7	26	1.5	0.6	19.4	20.7	27.8	63.1	2	0.7	19.6	19.1	26.5	190.4	2.4	0.8	17.6	23.2
Mg^{2+} ($mg.l^{-1}$)	35	23	24	4	53	68	34	23	10	4	74	112	72	35	14	4	73	102	83	63	14	4	59	60
Na^+ ($mg.l^{-1}$)	212	146	147	27	405	465	225	146	68	24	576	821	488	223	87	28	602	780	590	471	79	28	461	445
NH_4^+ ($mg.l^{-1}$)	0.17	0	0	0	0.07	0.04	0.7	0	0.04	0	0	0	0.5	0	0	0	0	0.12	0	0.05	0	0	0	0
NO_2^-+NO_3^- ($mg.l^{-1}$)	0.24	0.09	0.45	0	0.74	0.84	0.27	0	0.1	0	0	6.22	0.82	0	0.05	0.05	0	2.53	0	0	0.05	0	0	0.89
pH	8.99	7.79	7.37	7.48	7.38	7.96	8.01	7.49	7.03	7	7.12	8.52	8.59	8.06	7.29	7.21	6.81	8.08	9	8.17	7.12	7.29	7.12	7.88
PO_4^{3-} ($mg.l^{-1}$)	0.036	0.031	0.023	0.026	0.198	0.108	0.074	0.022	0.079	0.018	4.161	1.916	0.086	0.015	0.013	0.02	2.568	0.655	0.063	0.082	0.04	0.057	2.398	1.049
SiO_2 ($mg.l^{-1}$)	1.9	2.3	3	2.3	1.7	1	1.9	1.9	1.7	2.1	2.4	0.6	0.7	0.5	1.5	2	2.8	2.5	0.5	0	1.2	2.1	2.2	2.6
SO_4^{2-} ($mg.l^{-1}$)	95	53	77	16	137	156	83	55	28	10	184	269	143	68	32	7	194	263	174	127	30	8	163	139
Alkalinity (as $CaCO_3$ in $mg.l^{-1}$)	102	103	51	7	147	163	106	110	28	9	200	226	187	243	46	14	174	196	168	530	33	11	176	177
TDS ($mg.l^{-1}$)	875	605	566	100	1479	1724	875	617	250	95	2100	2969	1847	1047	347	104	2121	2812	2136	2258	312	103	1723	1631

River: Swartkops
habitat: epipelon

Slide	1331	1333	1336	1339	1351	1354	1361	1364	1367	1382	1385	1389	1392	1395	1398	1411	1414	1418	1421	1424	1427	1441	1444	1448	1451	1454	1457
Station	D17	C17	B17	A17	F18	E18	C18	B18	A18	F19	E19	D19	C19	B19	A19	F20	E20	D20	C20	B20	A20	F21	E21	D21	C21	B21	A21
ACHNENGE	15.03	0.95	2.56	0.00	9.53	0.44	1.97	4.41	0.00	4.95	0.32	0.52	2.99	0.94	1.45	7.18	0.00	1.56	1.58	1.64	0.80	5.06	0.50	0.33	0.46	1.64	1.21
ACHNEXIG	3.36	0.37	5.08	0.00	4.99	0.00	1.76	8.07	0.00	3.29	0.00	0.32	0.42	0.40	0.16	1.58	0.00	0.17	1.00	3.46	0.00	1.25	0.00	1.50	0.00	2.14	0.31
ACHNHUNG	0.00	2.81	0.00	0.00	1.00	0.00	1.45	0.00	0.00	0.00	0.30	0.55	12.62	0.41	0.00	0.00	0.86	2.67	1.16	0.00	0.00	0.80	1.97	0.00	6.16	0.00	0.00
ACHNMINU	0.64	0.00	6.35	6.85	0.60	0.00	0.18	4.49	12.47	0.33	0.00	0.40	0.00	3.61	4.56	0.47	0.00	0.00	0.46	5.16	6.19	1.31	0.00	0.00	0.00	5.77	7.57
AMRACOFF	0.82	0.00	0.00	0.00	0.00	0.79	0.00	0.00	0.00	0.00	0.32	1.15	0.00	0.00	0.00	0.00	0.31	1.39	0.00	0.00	0.00	0.00	1.97	17.51	0.17	0.00	0.00
AMRASUBT	0.21	0.00	0.00	0.00	2.31	0.48	0.00	0.00	0.00	1.30	0.00	0.00	0.00	0.00	0.00	8.73	0.59	0.00	0.00	0.00	0.00	2.76	2.96	0.00	0.00	0.00	0.00
BALAPARA	0.00	0.73	0.00	0.00	2.95	0.00	10.84	0.00	0.00	1.15	0.15	0.00	0.84	0.00	0.16	0.33	0.16	0.00	0.00	0.00	0.00	0.63	0.00	0.00	0.00	0.00	0.00

River: Swartkops

habitat: epipelon

Slide	1331	1333	1336	1339	1351	1354	1361	1364	1367	1382	1385	1389	1392	1395	1398	1411	1414	1418	1421	1424	1427	1441	1444	1448	1451	1454	1457
Station	D17	C17	B17	A17	F18	E18	C18	B18	A18	F19	E19	D19	C19	B19	A19	F20	E20	D20	C20	B20	A20	F21	E21	D21	C21	B21	A21
BRACBREB	0.00	0.80	3.72	2.62	0.00	0.00	0.00	3.38	4.78	0.00	0.00	0.00	0.00	2.24	1.81	0.00	0.00	0.00	0.00	1.30	1.30	0.00	0.00	0.00	0.00	1.65	1.55
CYMBOAHU	7.75	0.00	0.16	0.36	3.77	0.47	0.00	0.00	0.00	1.83	2.22	0.99	0.00	0.00	0.00	0.98	0.15	3.63	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.00	0.00
DINEPUEL	18.12	3.31	0.58	0.00	0.00	0.00	0.00	0.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.17	0.00	0.33	0.00	0.00
ENTOALAT	0.00	0.00	0.00	0.00	4.15	0.00	0.00	0.00	0.00	0.17	0.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.59	0.49	0.00	0.00	0.00	0.00
FALATERA	3.57	5.49	0.61	0.00	6.65	39.67	1.32	0.32	0.00	0.49	11.99	2.71	1.69	0.00	0.00	0.00	14.00	1.23	1.89	0.00	0.00	1.39	31.68	0.33	5.44	0.00	0.00
FRAGELLI	0.00	14.63	0.93	0.22	4.72	0.00	6.43	0.16	0.00	14.53	1.40	0.00	3.80	0.65	0.00	27.32	0.57	0.19	11.54	1.77	0.00	25.75	0.32	0.00	8.40	2.99	0.63
MAGLELLI	0.00	0.00	0.00	16.23	0.00	0.00	0.00	0.00	5.03	0.00	0.00	0.00	0.00	0.00	1.32	0.00	0.00	0.00	0.00	0.00	1.04	0.00	0.00	0.00	0.00	0.00	0.30
NAVICIle	7.85	0.80	0.00	1.28	0.31	2.90	1.87	0.00	0.00	0.00	2.94	7.69	0.00	0.73	0.00	0.00	4.53	7.62	1.28	1.31	0.00	0.00	3.29	45.86	2.31	0.00	0.30
NAVICONF	0.00	12.86	0.00	0.00	5.41	0.00	2.88	0.00	0.00	32.17	4.17	0.00	3.30	0.55	0.00	25.17	0.64	0.00	1.51	0.33	0.00	18.80	0.17	0.00	3.29	0.00	0.00
NAVICRex	2.56	12.29	0.20	0.00	4.72	6.98	6.93	0.97	0.00	4.90	3.17	2.51	8.11	0.00	0.17	0.76	5.36	3.63	8.51	0.48	0.00	9.15	6.92	6.18	5.62	0.00	0.30
NAVIGREG	2.89	7.60	38.88	0.00	2.61	0.00	1.62	15.94	0.00	2.13	0.15	2.69	7.12	46.44	2.94	1.29	1.66	1.58	1.78	38.85	13.04	0.59	0.00	1.16	0.91	36.98	18.24
NAVIHESI	0.00	0.00	1.44	13.86	0.00	0.00	0.00	1.28	38.26	0.00	0.00	0.00	0.00	1.79	36.85	0.00	0.00	0.00	0.00	0.66	38.96	0.16	0.00	0.00	0.00	2.98	25.89
NAVIHUca	0.00	0.00	0.00	0.00	0.92	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	1.47	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.00
NAVIPHYL	0.43	0.00	0.00	0.00	0.00	12.31	0.00	0.00	0.00	1.14	10.09	1.60	0.00	0.00	0.00	1.28	36.63	0.33	0.00	0.00	0.00	1.38	17.15	0.34	0.00	0.00	0.00
NAVIPSHA	0.00	5.90	0.89	0.00	0.00	0.00	10.32	1.29	0.00	0.17	0.00	0.12	24.98	0.53	0.00	0.00	0.00	2.14	32.48	0.00	0.00	0.00	0.00	0.99	23.38	0.00	0.00
NAVISELU	0.64	3.09	0.65	0.00	0.00	0.00	0.66	0.16	0.00	0.17	0.00	0.12	0.42	0.28	1.16	0.33	0.00	0.33	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NAVITELO	0.00	2.40	0.00	0.00	0.00	0.48	0.54	0.00	0.00	0.33	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38	0.00	0.00	0.14	0.00	0.00	20.67	0.00	0.15
NAVIVAND	0.00	0.73	0.00	2.03	0.00	0.00	0.00	1.13	1.35	0.00	0.00	0.00	0.00	0.00	1.47	0.00	0.00	0.00	0.00	0.00	5.93	0.00	0.00	0.00	0.00	0.33	2.41
NAVIVIro	1.95	0.58	2.99	0.18	0.15	0.00	3.00	14.85	0.36	2.62	0.00	0.00	0.00	5.54	0.17	1.13	0.58	0.00	0.32	6.23	0.72	0.75	0.65	0.34	0.91	1.33	0.62
NITZCAPI	0.00	0.00	0.00	0.00	0.60	0.79	1.98	0.00	0.00	0.00	4.46	27.81	0.84	0.26	0.00	0.00	7.33	21.90	0.00	0.32	0.00	0.00	3.26	6.49	0.00	0.00	0.00
NITZDESE	0.78	0.55	0.00	0.00	2.51	19.12	0.00	0.00	0.36	0.00	23.39	2.22	0.00	0.16	0.00	0.64	7.37	1.02	0.00	0.33	0.00	0.00	9.16	1.32	0.33	0.00	0.00
NITZFRUS	8.30	3.57	1.05	0.00	10.98	0.92	1.83	0.48	0.00	3.43	5.94	5.80	1.15	0.13	0.00	1.96	3.57	19.37	1.56	0.98	0.00	2.75	2.63	2.16	2.18	0.33	0.00
NITZGRAC	0.00	0.00	0.00	0.00	0.91	0.45	1.58	1.45	0.00	0.00	0.00	0.00	0.00	0.83	0.00	0.00	0.00	0.33	0.32	0.80	0.00	0.00	0.17	0.00	0.00	2.15	0.00
NITZMICE	0.00	0.73	1.22	1.57	0.61	0.00	5.24	2.10	2.12	3.27	0.15	0.40	3.85	1.53	4.54	1.14	0.00	0.00	1.35	1.94	1.26	1.21	0.00	0.00	6.69	2.28	8.61
NITZPALE	0.43	0.00	0.00	0.00	3.34	0.95	10.26	7.89	0.00	0.65	2.86	35.62	6.15	8.28	5.21	3.23	0.00	20.47	3.69	12.58	3.07	1.78	0.32	12.15	1.57	3.13	1.56
NITZPACE	0.43	1.80	0.00	0.00	0.30	0.00	3.50	1.63	1.35	1.30	0.00	0.00	0.00	0.91	0.00	0.50	0.30	0.00	0.32	0.99	0.81	0.00	0.00	0.00	1.23	4.96	0.32
NITZSOLI	1.78	1.37	0.00	0.00	0.30	2.93	2.39	0.64	0.00	0.32	3.00	0.64	1.69	0.00	0.00	0.00	2.18	1.32	15.55	0.00	0.00	0.00	0.50	0.34	5.26	0.67	0.00
PLACELGI	0.00	0.00	0.00	8.56	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.13	5.67	0.00	0.00	0.00	0.00	0.00	10.71	0.00	0.00	0.00	0.00	0.00	8.53
PLACSP01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.65	2.55	0.00	0.00	0.00	0.00	0.16	0.58	0.00	0.00	0.00	0.00	0.31	0.65	0.00	0.00	0.00	0.00
RHOPGIBA	0.00	0.00	0.00	1.81	0.00	0.00	0.00	0.00	0.36	0.00	0.00	0.00	0.57	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SYNETABU	0.78	5.00	0.00	0.00	8.00	1.36	5.46	0.00	0.00	1.15	2.38	0.40	0.00	0.00	0.17	0.78	0.89	0.00	1.55	0.00	0.00	2.07	0.82	0.00	0.00	0.16	0.00
TRYBANGU	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TRYBCONS	2.38	0.80	0.00	0.00	0.64	0.33	0.00	0.00	0.00	0.00	1.73	0.32	0.00	0.00	0.00	0.00	1.32	1.03	1.79	0.00	0.00	0.00	3.46	0.83	0.00	0.00	0.00

River: Swartkops

habitat: epipelon

Slide	1331	1333	1336	1339	1351	1354	1361	1364	1367	1382	1385	1389	1392
Station	D17	C17	B17	A17	F18	E18	C18	B18	A18	F19	E19	D19	C19
Water quality													
Ca^{2+} ($mg.l^{-1}$)	25	25	11	3	48	62	39	12	3	42	52	70	77
Cl^- ($mg.l^{-1}$)	319	293	144	45	810	1236	506	152	47	791	976	883	986
Conductivity ($mS.m^{-1}$)	124.2	120.8	56	17.4	337	493	240	65.8	21.7	284	382	316	396
F^- ($mg.l^{-1}$)	0.2	0.2	0.2	0.1	0.3	0.4	0.2	0.1	0.1	0.3	0.4	0.3	0.3
K^+ ($mg.l^{-1}$)	*21.2*	*24.3*	*2*	*0.7*	*19.8*	*26.8*	*98.5*	*2.3*	*0.8*	*21.6*	*27.5*	*32*	*242.6*
Mg^{2+} ($mg.l^{-1}$)	31	29	16	4	63	96	48	14	5	57	78	81	91
Na^+ ($mg.l^{-1}$)	190	181	90	28	527	744	306	79	29	505	613	521	629
NH_4^+ ($mg.l^{-1}$)	*0*	*0*	*0*	*0*	*0.05*	*0.8*	*0*	*0.05*	*0.04*	*0.09*	*1.86*	*0.21*	*0.33*
NO_2^-+NO_3^- ($mg.l^{-1}$)	0.08	0	0	0.11	0	1.19	0	0	0	0	2.68	0	0
pH	7.96	7.73	7.1	7.31	6.83	8.06	8.72	6.89	7.68	6.85	7.69	7.19	8.28
PO_4^{3-} ($mg.l^{-1}$)	0.035	0.022	0.025	0.023	4.858	2.179	0.039	0.013	0.022	6.965	2.972	0.465	0.733
SiO_2 ($mg.l^{-1}$)	2.3	1.5	2.4	2.2	2.9	3.2	0.9	2.2	2.6	3	3.8	5.6	4
SO_4^{2-} ($mg.l^{-1}$)	64	70	33	7	165	258	61	24	8	144	191	99	117
Alkalinity (as $CaCO_3$ in $mg.l^{-1}$)	111	113	38	17	201	259	317	42	19	190	219	301	713
TDS ($mg.l^{-1}$)	787	760	343	109	1892	2752	1445	335	115	1813	2226	2055	3015

Slide	1395	1398	1411	1414	1418	1421	1424	1427	1441	1444	1448	1451	1454	1457
Station	B19	A19	F20	E20	D20	C20	B20	A20	F21	E21	D21	C21	B21	A21
Water quality														
Ca^{2+} ($mg.l^{-1}$)	14	3	53	76	72	90	10	4	60	88	64	42	6	3
Cl^- ($mg.l^{-1}$)	170	50	826	1134	1053	952	112	50	930	1577	1074	422	76	51
Conductivity ($mS.m^{-1}$)	62.1	19.9	320	447.2	422.5	490	48.02	21.21	356.8	903	405.2	202.4	26.5	21
F^- ($mg.l^{-1}$)	0.1	0	0.3	0.3	0.3	0.3	0	0.1	0.4	0.4	0.2	0.2	0	0.1
K^+ ($mg.l^{-1}$)	*3*	*0.8*	*23.2*	*21.4*	*28.4*	*238.4*	*2.2*	*0.7*	*24.8*	*34.2*	*47.6*	*77.3*	*1.3*	*0.7*
Mg^{2+} ($mg.l^{-1}$)	17	5	64	96	88	91	11	4	69	129	94	47	7	4
Na^+ ($mg.l^{-1}$)	90	30	547	728	644	685	65	28	563	899	598	261	42	29
NH_4^+ ($mg.l^{-1}$)	*0*	*0*	*0.08*	*0.05*	*3.81*	*0.08*	*0*	*0.07*	*0*	*0.13*	*0.42*	*0.47*	*0*	*0*
NO_2^-+NO_3^- ($mg.l^{-1}$)	0	0	0	2.98	0.58	0.06	0.13	0.05	0.05	0.62	1.4	0.1	0	0
pH	6.93	7.19	7	8.35	7.4	8.53	6.94	7.4	7.12	7.77	8.15	7.8	6.96	7.37
PO_4^{3-} ($mg.l^{-1}$)	0.031	0.022	5.967	2.654	0.809	0.933	0.02	0.033	4.293	0.13	0.067	0.079	0.018	0.053
SiO_2 ($mg.l^{-1}$)	2.3	2.6	5.8	4.7	4.2	8.9	2.6	2.9	2.5	2.9	2.8	3.1	2.5	2.9
SO_4^{2-} ($mg.l^{-1}$)	21	5	285	514	295	148	17	0	203	290	246	115	11	6
Alkalinity (as $CaCO_3$ in $mg.l^{-1}$)	45	22	195	199	271	851	36	20	209	295	197	220	26	16
TDS ($mg.l^{-1}$)	371	122	2056	2833	2521	3244	263	115	2118	3380	2371	1234	176	113

APPENDIX B

SHORTENED SCIENTIFIC NAMES OF THE DIATOM TAXA

(ACRONYMS)

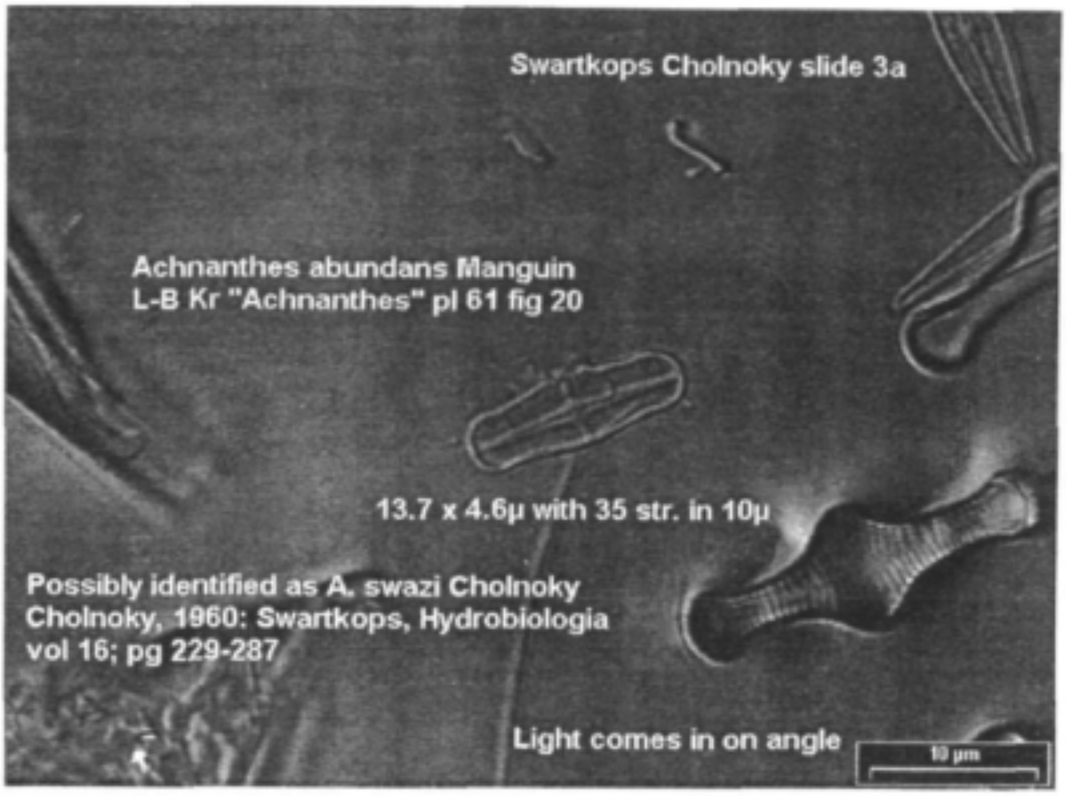
Acronym	Taxon
ACHNABUN	*Achnanthes abundans* Manguin
ACHNAMOE	*Achnanthes amoena* Hustedt
ACHNDAON	*Achnanthes daonensis* Lange-Bertalot
ACHNDELI	*Achnanthes delicatula* (Kutzing)Grunow
ACHNENGE	*Achnanthes engelbrechtii* Cholnoky
ACHNENla	*Achnanthes engelbrechtii* (lanceolate)
ACHNEXIG	*Achnanthes exigua* var. *exigua* Grunow
ACHNHUNG	*Achnanthes hungarica* Grunow
ACHNKRYO	*Achnanthes kryophila* Petersen
ACHNMICR	*Achnanthes microcephala* Kutzing
ACHNMINU	*Achnanthes minutissima* var. *minutissima* Kutzing
ACHNOBLO	*Achnanthes oblongella* Oestrup
ACHNSUAT	*Achnanthes subatomoides* (Hust) L-B & Arch.
AMRACOFF	*Amphora coffeaeformis* (Aghardh) Kutzing
AMRACOGN	*Amphora cognata* Cholnoky
AMRAEXIG	*Amphora exigua* Gregory
AMRAHELE	*Amphora helenensis* Giffen
AMRANORM	*Amphora normanii* Rabenhorst
AMRAPEDI	*Amphora pediculus* (Kutz) Grun.
AMRASUBT	*Amphora cf. subturgida* Hustedt
BALAPARA	*Baccilaria paradoxa* Gmelin
BRACBREB	*Brachysira brebissonii* Ross
CALOSCHU	*Caloneis schumanniana* (Grun) Cleve
CCNEPEDI	*Cocconeis pediculus* Ehrenberg
CCNEPLAC	*Cocconeis placentula* Ehrenberg
CYCLMENI	*Cyclotella meneghiniana* Kutz.
CYLAKAPI	*Cymbella kappii* Cholnoky
CYLAMIC1	*Cymbella microcephala* group 1 Grunow
CYLAMIC2	*Cymbella microcephala* group 2 Grunow
CYLAOAHU	*Cymbella oahuensis* Hustedt
CYLAPUSI	*Cymbella pusilla* Grunow
CYLATUDA	*Cymbella tumida* (Breb) Van Heurck
CYLATURG	*Cymbella turgidula* Grun.
CYLASP07	*Cymbella oahuensis* Hustedt var 1
CYSTDUBI	*Cyclostephanos dubius* (Fricke) Round
DIATVULG	*Diatoma vulgare* var *brevis* Bory
DINEELLI	*Diploneis elliptica* (Kutz) Cleve
DINEPUEL	*Diploneis puella* (Schum) Cleve
ENCYMINU	*Encyonema minutum* (Hilse in Rabenhorst) Mann
ENCYSILE	*Encyonema silesiacum* (Bleisch in Rabenhorst) Mann
ENTOALAT	*Entomoneis alata* (Ehrenberg) Ehrenberg
EUTIFALA	*Eunotia fallax* var *groenlandica* (Grun) L-B & Noerpel
EUTIFORM	*Eunotia formica* Ehrenberg
EUTIIMPL	*Eunotia implicata* Norpel, L-B & Alles
EUTIINCI	*Eunotia incisa* Gregory
EUTIPECT	*Eunotia pectinalis* (Kutz) Raben.
EUTITENE	*Eunotia tenella* (Grun) Hustedt
EUTITRIN	*Eunotia trinacria* Krasske
FALATERA	*Fallacia tenera* (Hustedt) Mann
FALEUMPA	*Fallacia umpatica* (Cholnoky) Mann
FRAGCAPU	*Fragilaria capucina* var. *capucina* (Desmazieres) L-B
FRAGCAru	*Fragilaria capucina* var. *rumpens*(Kutz)L-B

Acronym	Taxon
FRAGCAva	*Fragilaria capucina* var. *vaucheriae* (Kutz) L-B
FRAGELLI	*Fragilaria elliptica* Schumann
FRAGTENE	*Fragilaria tenera* (W. Smith) L-B
FRUSRHOM	*Frustulia rhomboides* (Ehr) de Toni
FRUSRHcr	*Frustulia rhomboides* var *crassinervia* (Breb) Ross.
FRUSROST	*Frustulia rostrata* Hustedt
HANTDIST	*Hantzschia distinctepunctata* Hustedt
GONEACUM	*Gomphonema acuminatum* Ehrenberg
GONEANpr	*Gomphonema angustatum* var. *producta*(Kutz)Rab.
GONEANGU	*Gomphonema angustum* Agardh
GONECLja	*Gomphonema clevei* var. *javanica* Hust.
GONEPAR1	*Gomphonema parvulum* var.1 (Kutzing) Kutzing
GONEPAR3	*Gomphonema parvulum* var.3 (Kutzing) Kutzing
GYROACUM	*Gyrosigma acuminatum* (Kutz) Cleve
MAGLELda	*Mastogloia elliptica* var. dansei (Thwaites) Cleve
MAGLELel	*Mastogloia elliptica* var. elliptica (Agardh) Cleve
NAVICAPI	*Navicula capitatoradiata* Germain
NAVICIle	*Navicula cincta* var. *leptocephala* (Breb) Grunow
NAVICLOA	*Navicula cloacina* L-B &Bonik
NAVICONF	*Navicula confervacea* (Kutz) Grunow
NAVICRCE	*Navicula cryptocephala* Kutzing
NAVICRex	*Navicula cryptocephala* var. exilis Grunow
NAVICRTE	*Navicula cryptotenella* L-B
NAVIDUER	*Navicula duerrenbergiana* Hustedt
NAVIDULC	*Navicula cf dulcis* Krasske
NAVIFRUG	*Navicula frugalis* Hustedt
NAVIGREG	*Navicula gregaria* Donkin
NAVILEPT	*Navicula leptostriata* E.G. Joergensen
NAVIHUca	*Navicula hungarica* var. capitata (Ehrenberg) Cleve
NAVIMENI	*Navicula menisculus* Schumann
NAVIMOLL	*Navicula mollis* (WSmith) Cleve
NAVIPERI	*Navicula peregrina* Ehrenberg
NAVIPERs	*Navicula peregrina* var1 Ehrenberg
NAVIPERM	*Navicula permitis* Hustedt
NAVIPHYL	*Navicula phyllepta* Kutzing
NAVIPSHA	*Navicula pseudohalophila* Cholnoky
NAVIPUPU	*Navicula pupula* var. *pupula* Kutzing
NAVIRIPA	*Navicula riparia* Hustedt
NAVISCHR	*Navicula schroeterii* Meister
NAVISELU	*Navicula seminulum* Grunow
NAVISUTI	*Navicula subtilissima* Cleve
NAVITELO	*Navicula tenelloides* Hustedt
NAVITENT	*Navicula tentata* Cholnoky
NAVITRIV	*Navicula trivialis* Lange-Ber.
NAVIVAND	*Navicula vandamii* Schoeman
NAVIVIli	*Navicula virudula* var *linearis* Hustedt
NAVIVIro	*Navicula virudula* var *rostellata* (Kutz) Cleve
NITZCAPI	*Nitzschia capitellata* Hustedt
NITZCLAU	*Nitzschia clausii* Hantzsch
NITZDESE	*Nitzschia desertorum* Hustedt
NITZDISS	*Nitzschia dissipata* (Kutz) Grunow
NITZELal	*Nitzschia elliptica* var. *alexandrina* Cholnoky
NITZFILI	*Nitzschia filiformis* (W Smith) VanHeurck
NITZFONT	*Nitzschia fonticola* Grunow
NITZFRUS	*Nitzschia frustulum* var. *frustulum* (Kutzing) Grunow

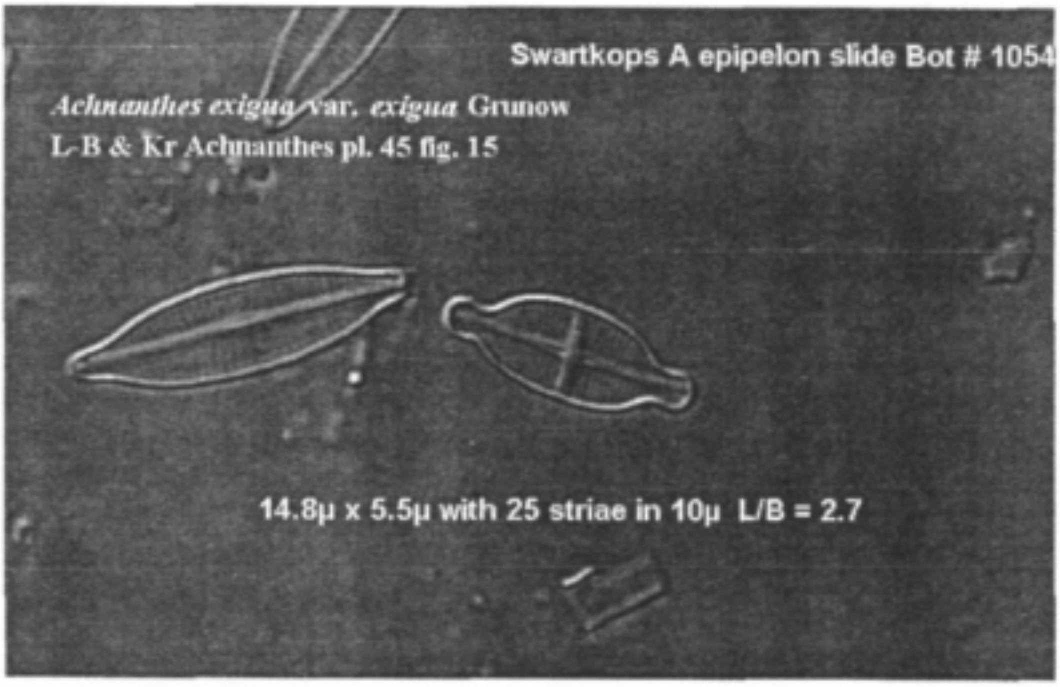
Acronym	Taxon
NITZGRAC	*Nitzschia gracilis* Hantzsch
NITZGRAF	*Nitzschia graciliformis* L-B & Simonsen
NITZLINE	*Nitzschia linearis* var. *linearis* W. Smith
NITZLIte	*Nitzschia linearis* var. *tenuis* (W.Smith) Grun
NITZMICE	*Nitzschia microcephala* Grunow
NITZNANA	*Nitzschia nana* Grunow (sensu Kr & L-B)
NITZPAAE	*Nitzschia paleaeformis* Hustedt
NITZPACE	*Nitzschia paleacea* (Grunow) Grunow
NITZPALE	*Nitzschia palea* (Kutzing) W. Smith
NITZPUMI	*Nitzschia pumila* Hustedt
NITZPURA	*Nitzschia pura* Hustedt
NITZRAUT	*Nitzschia rautenbachii* Cholnoky
NITZRECT	*Nitzschia recta* Hantzsch
NITZSIGM	*Nitzschia sigma* (kutzing) W. Smith
NITZSILI	*Nitzschia siliqua* Archibald
NITZSOLI	*Nitzschia solita* Hustedt
PINNBRAU	*Pinnularia braunii* (Grun) Cleve
PLACELGI	*Placoneis elginensis* var. *elginensis* (Gregory) Mereschkowsky
PLACSP01	*Placoneis* spec1
PLANDUBI	*Planothidium dubium*(Grun) Round & Bukh.
PLANLANC	*Planothidium lanceolatum* (Breb) Round & Bukh.
PLMAACUM	*Pleurosigma acuminatum* (Kutz) Raben.
RHOPGIBA	*Rhopalodia gibba* (Ehrenberg) O. Mueller
RHOPGIBE	*Rhopalodia gibberula* (Ehrenberg) O. Mueller
STNESP01	*Stauroneis* Ehrenberg SPEC 1 WestCape
STNEPACH	*Stauroneis pachycephala* Cleve
STNESPIC	*Stauroneis spicula* Hickie ex Grunow
SURIBREB	*Surirella brebissonii* Krammer & Lange-B
SYNEFAMI	*Synedra familiaris* sensu Krasske
SYNERUMP	*Synedra rumpens* Kutzing
SYNETABU	*Synedra tabulata* (Agardh) Kutzing
SYNETENE	*Synedra tenera* W. Smith
SYNEULNA	*Synedra ulna* (Nitzsch) Ehrenberg
TABEFENE	*Tabellaria fenestrata* (Lyngbye) Kutzing
TABEFLOC	*Tabellaria flocculosa* (Roth) Kutzing
TRYBANGU	*Tryblionella angustata* (W.Smith) Grunow
TRYBCONS	*Tryblionella constricta* (Kutzing) Ralfs
TRYBLEVI	*Tryblionella levidensis* (W.Smith) Grunow

APPENDIX C

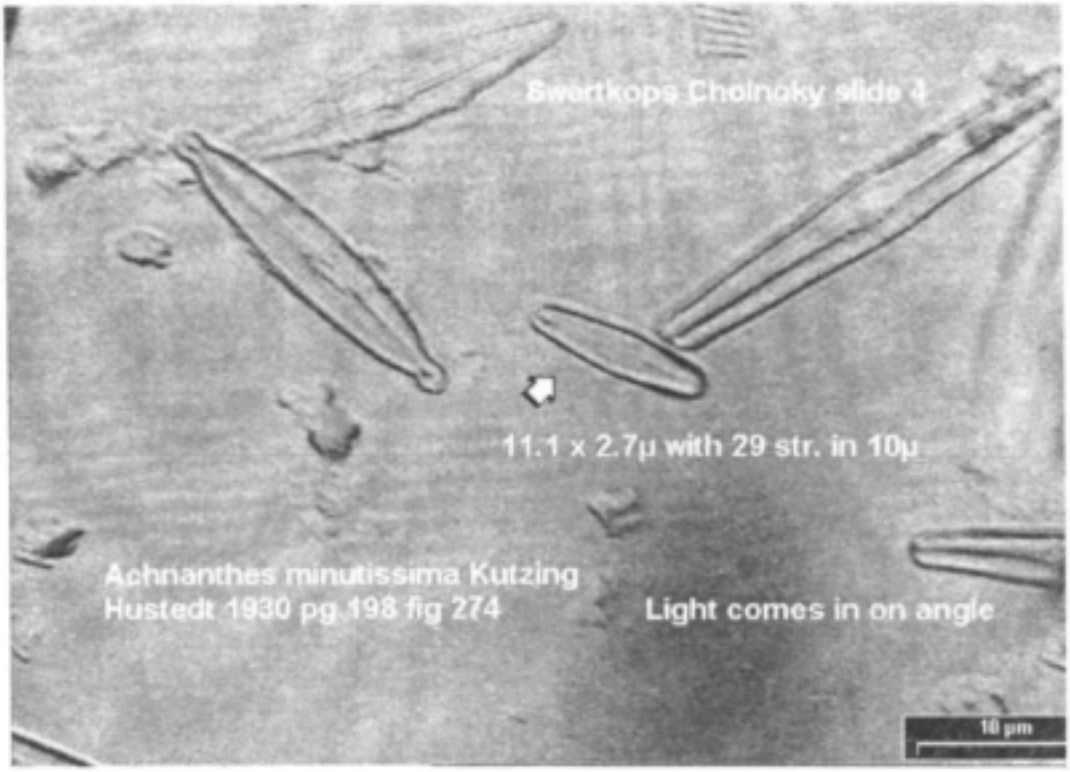
IMAGES OF THE DOMINANT DIATOMS FROM SOUTH AFRICAN RIVERS



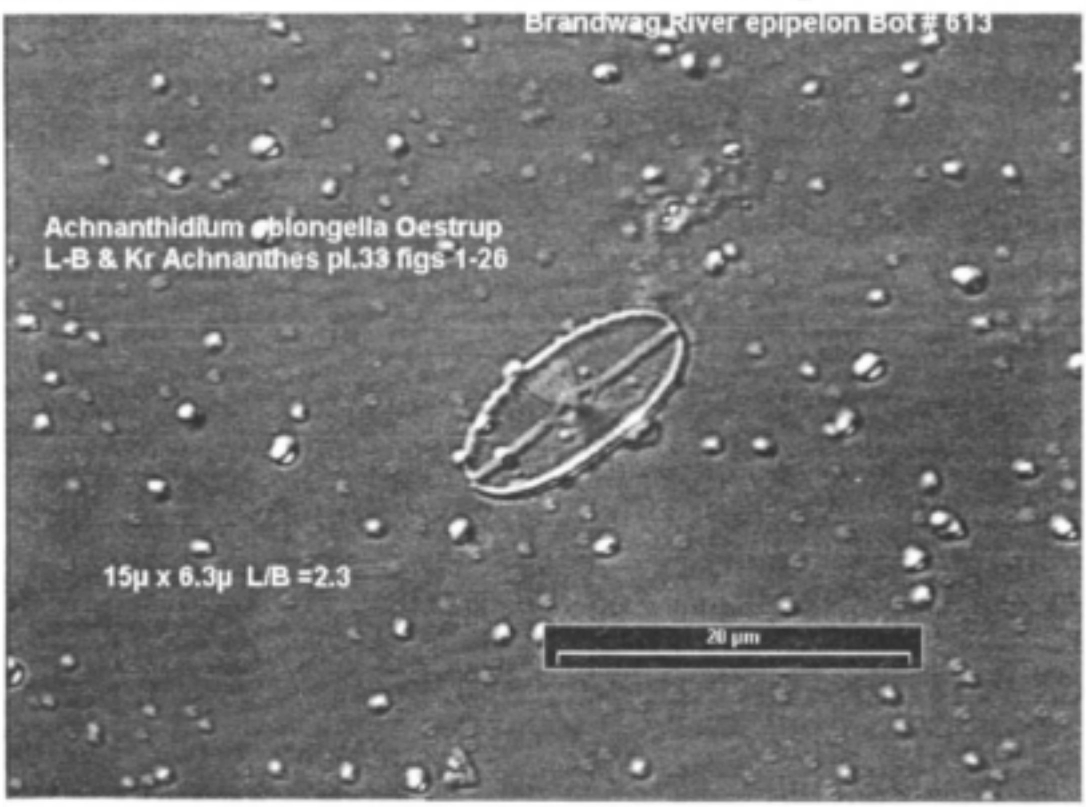
ACHNABUN *Achnanthes abundans* Manguin



ACHNEXIG *Achnanthes exigua* var. *exigua* Grunow

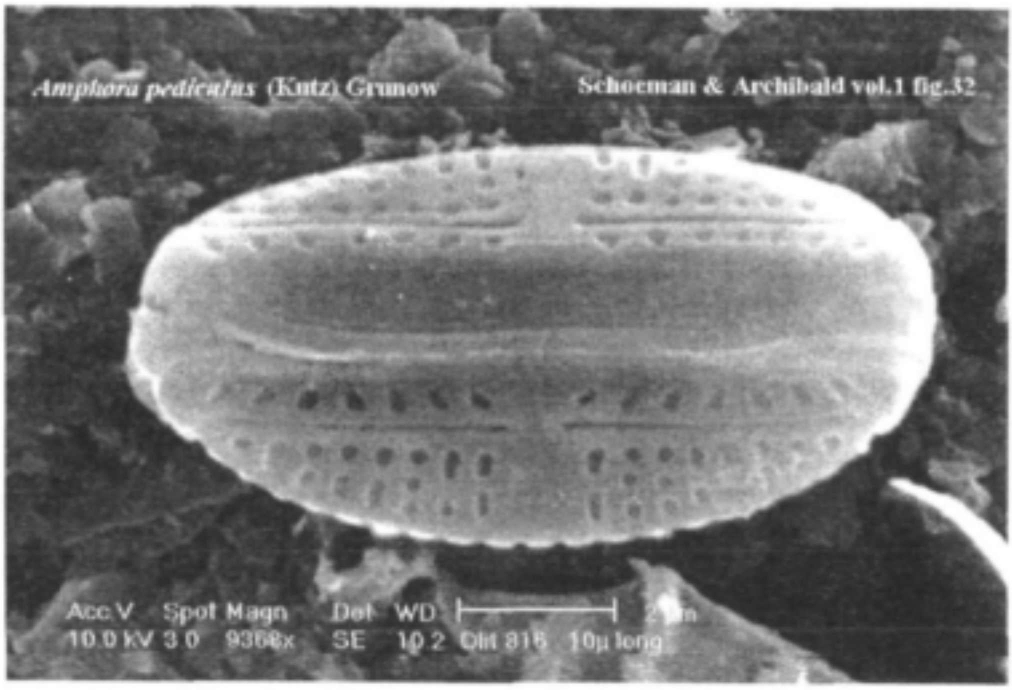


ACHNMImi *Achnanthes minutissima* var. *minutissima* Kutzing

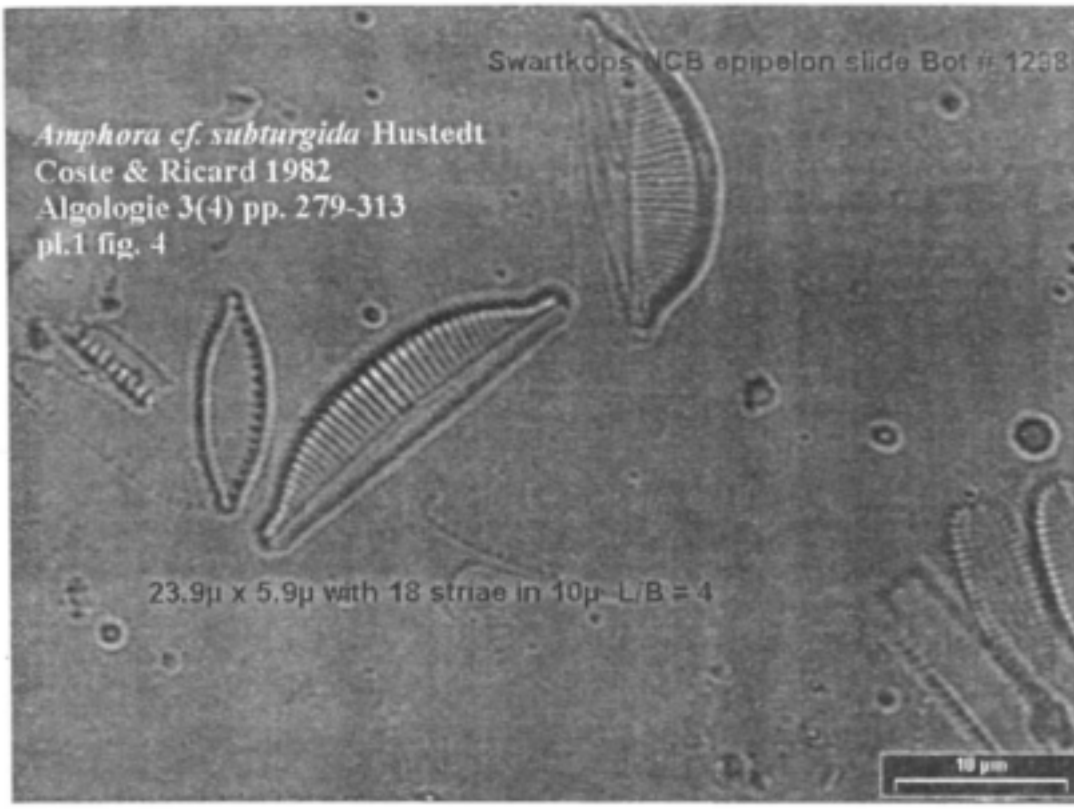


ACHNOBLO *Achnanthes oblongella* Oestrup.

ACHNSUAT *Achnanthes subatomoides* (Hust) L-B & Arch.

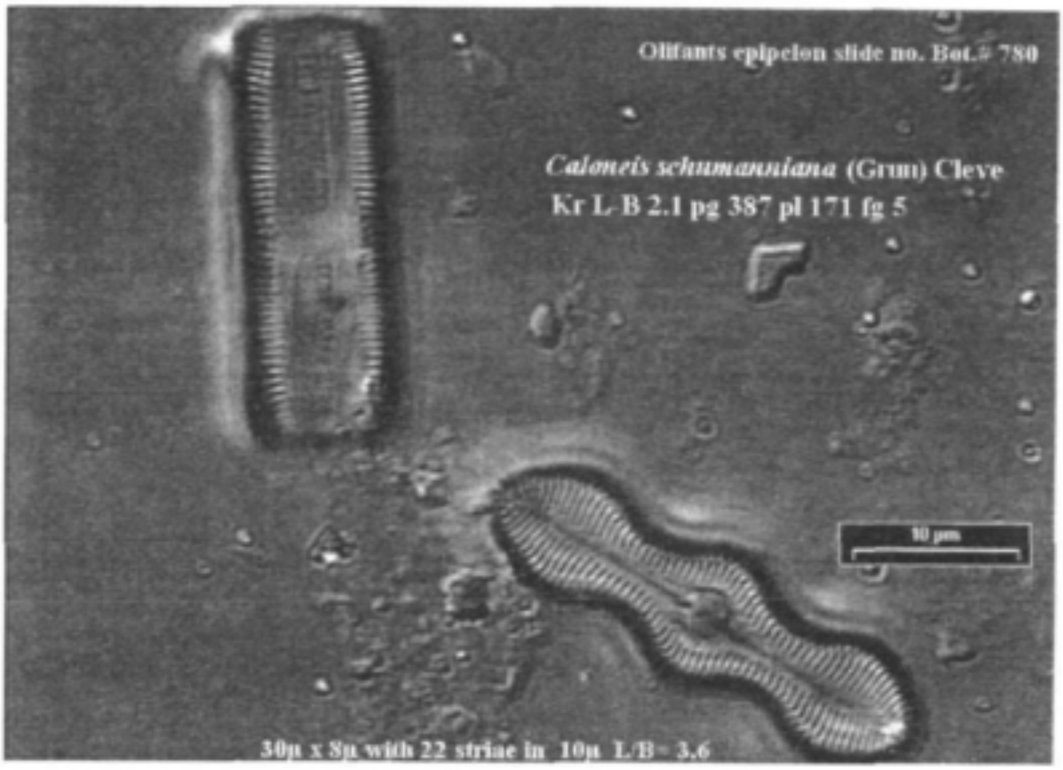


AMRAPEDI *Amphora pediculus* (Kutz) Grun

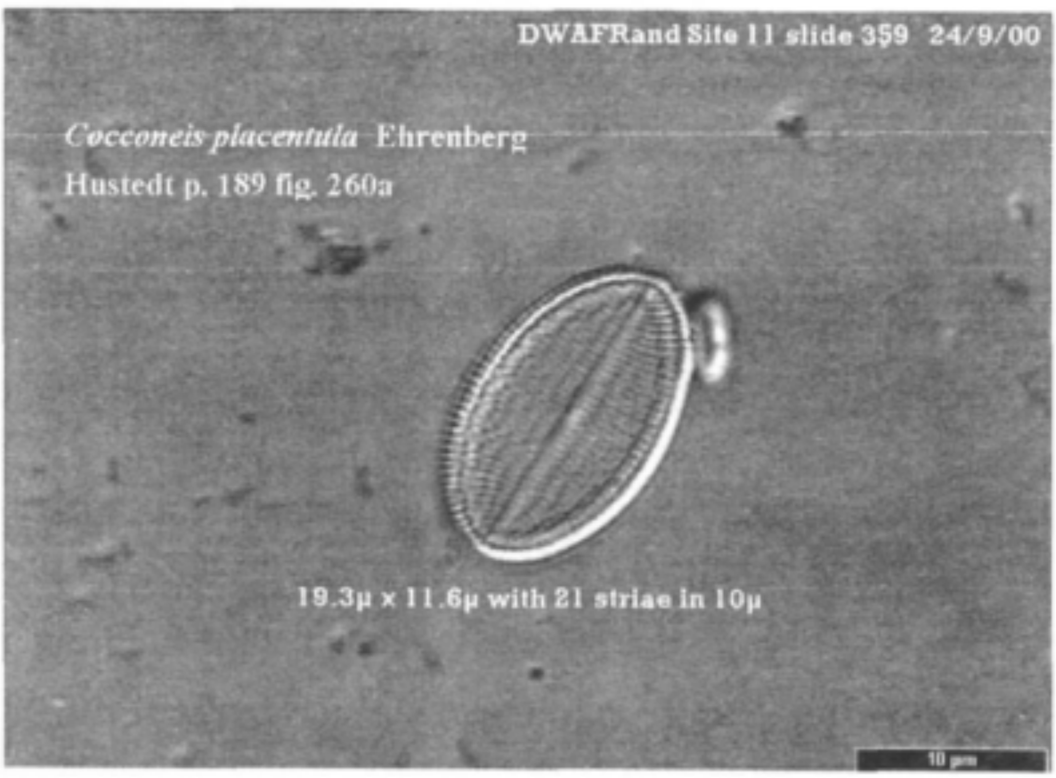


AMRASUBT ***Amphora cf. subturgida*** **Hustedt**

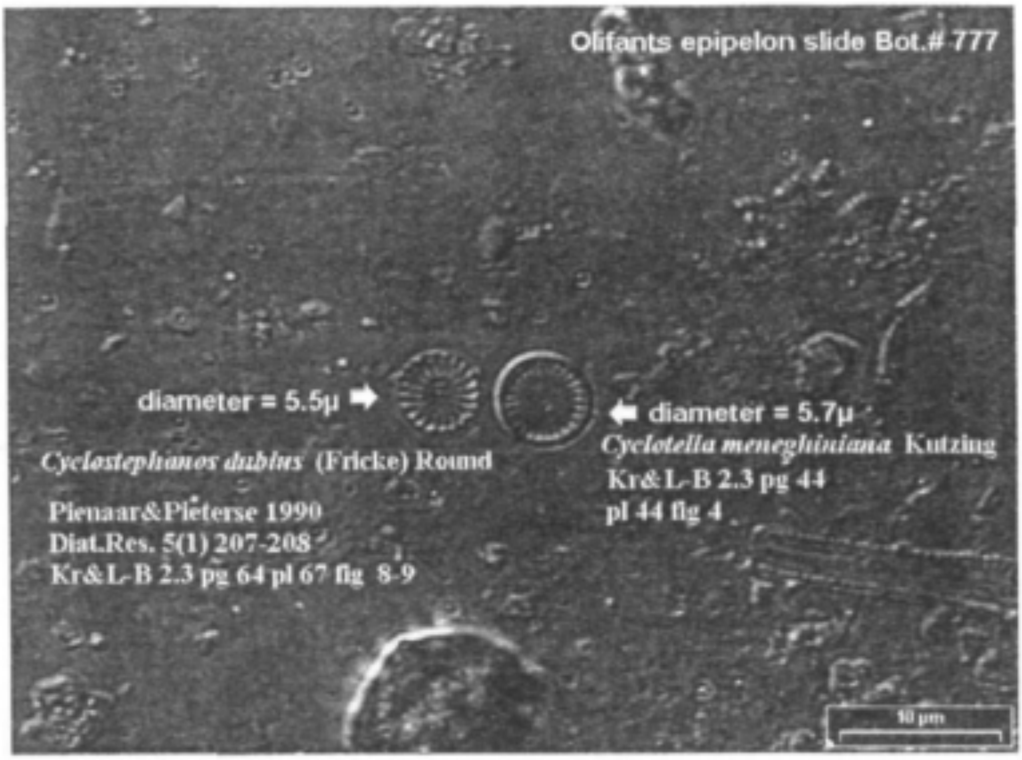
BALAPARA ***Baccilaria paradoxa*** **Gmelin**



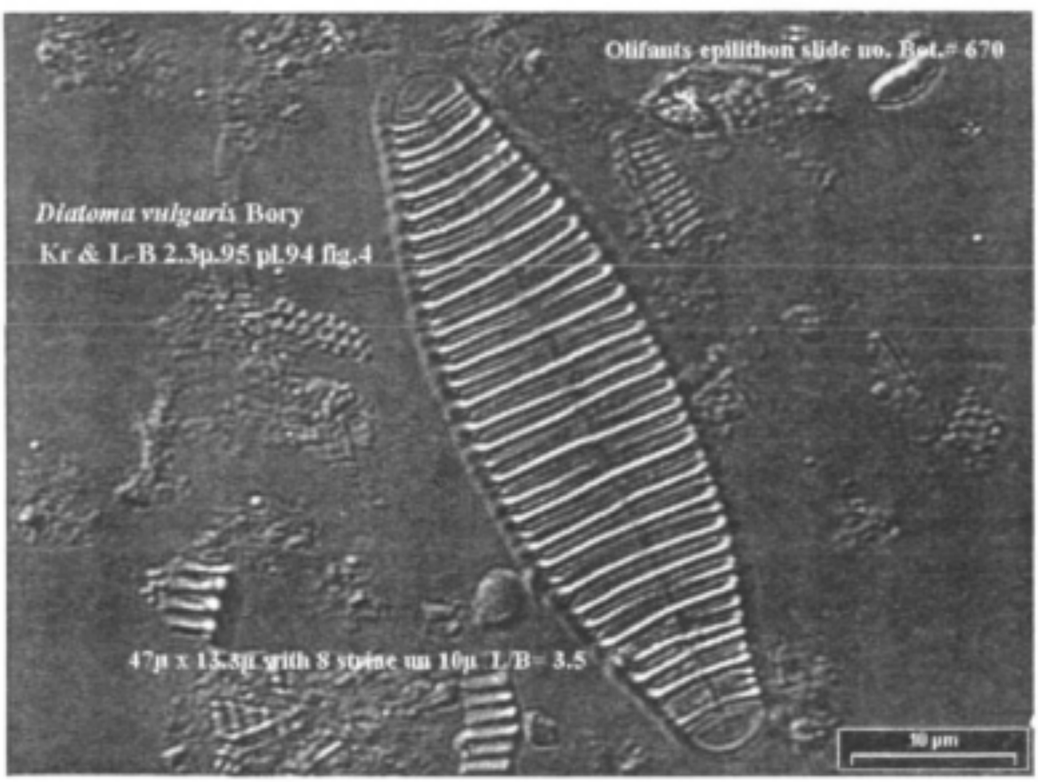
CALOSCHU *Caloneis schumanniana* (Grun) Cleve



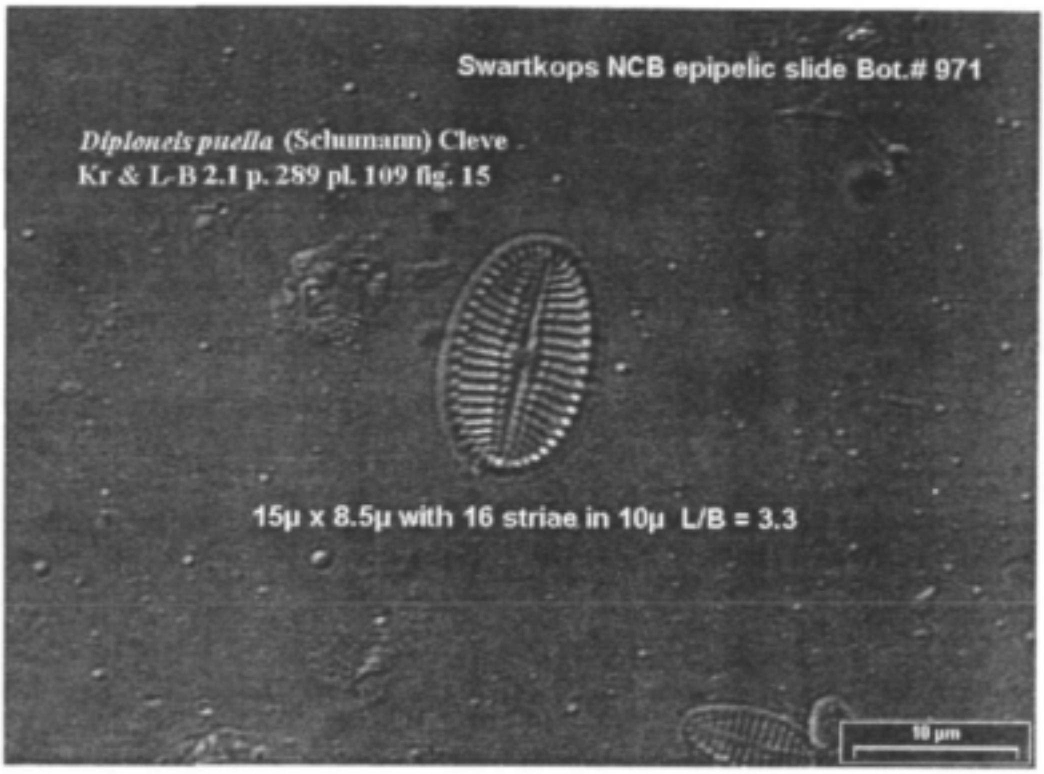
CCNEPLAC *Cocconeis placentula* **Ehrenberg**



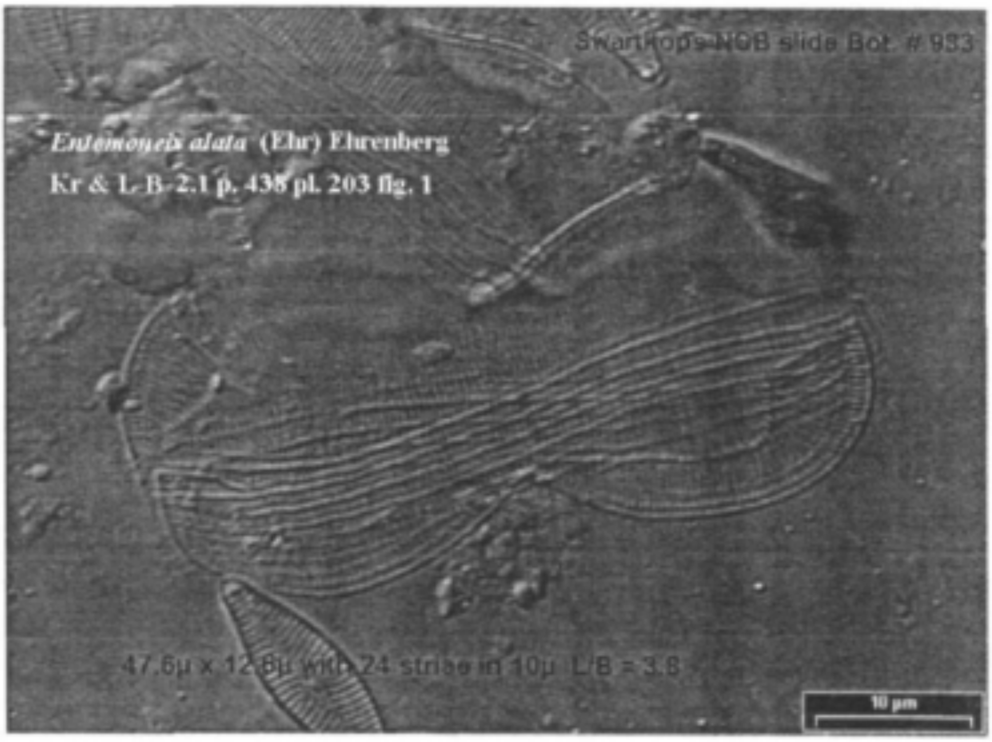
CYCLMENI *Cyclotella meneghiniana* Kutz



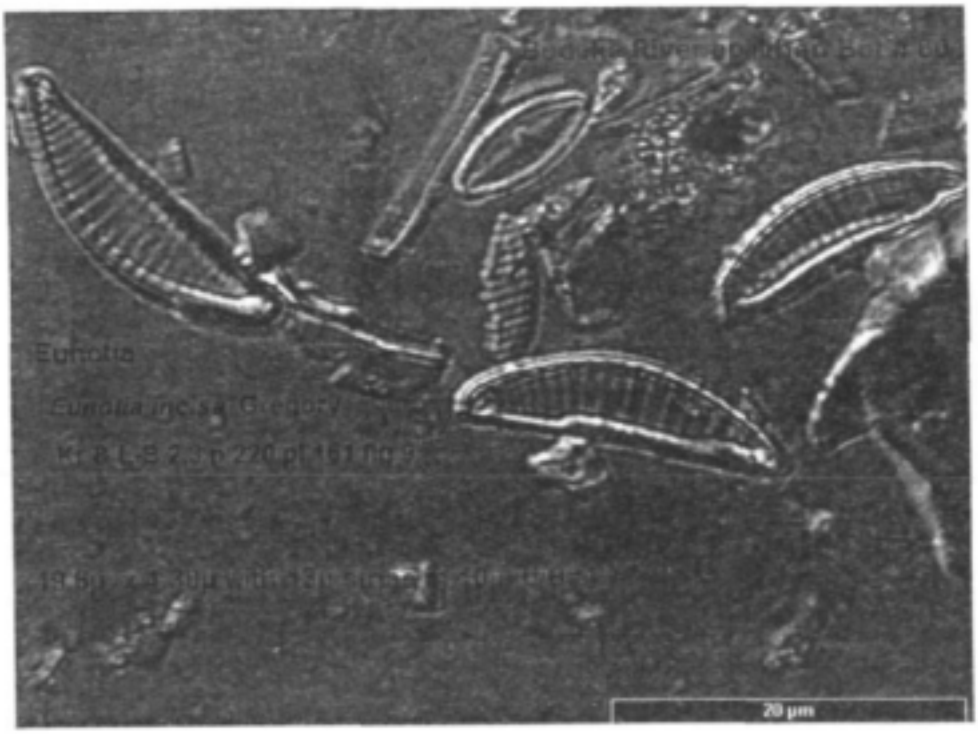
DIATVULG *Diatoma vulgare* var *brevis* Bory



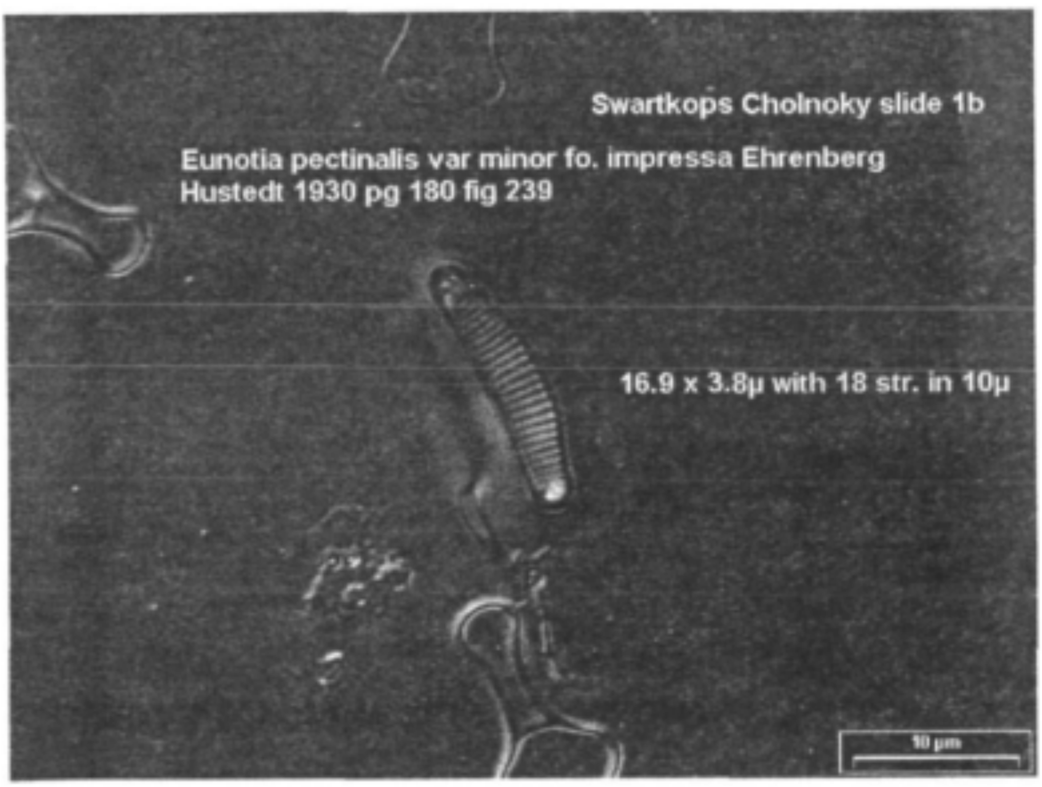
DINEPUEL *Diploneis puella* (Schum) Cleve



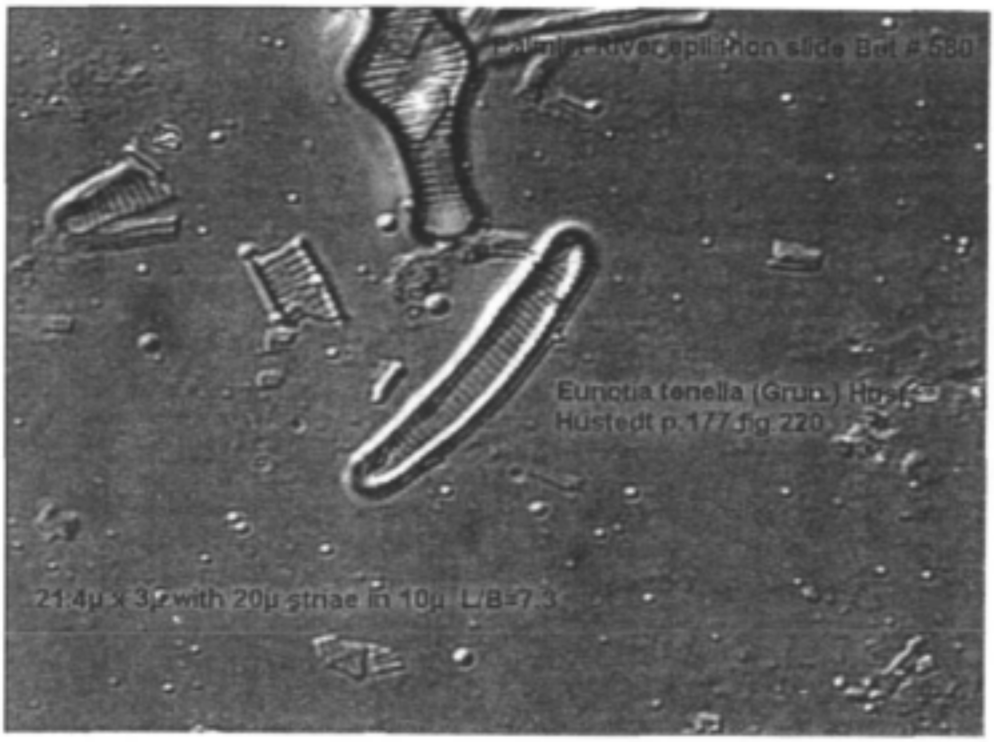
ENTOALAT *Entomoneis alata* (Ehrenberg) Ehrenberg



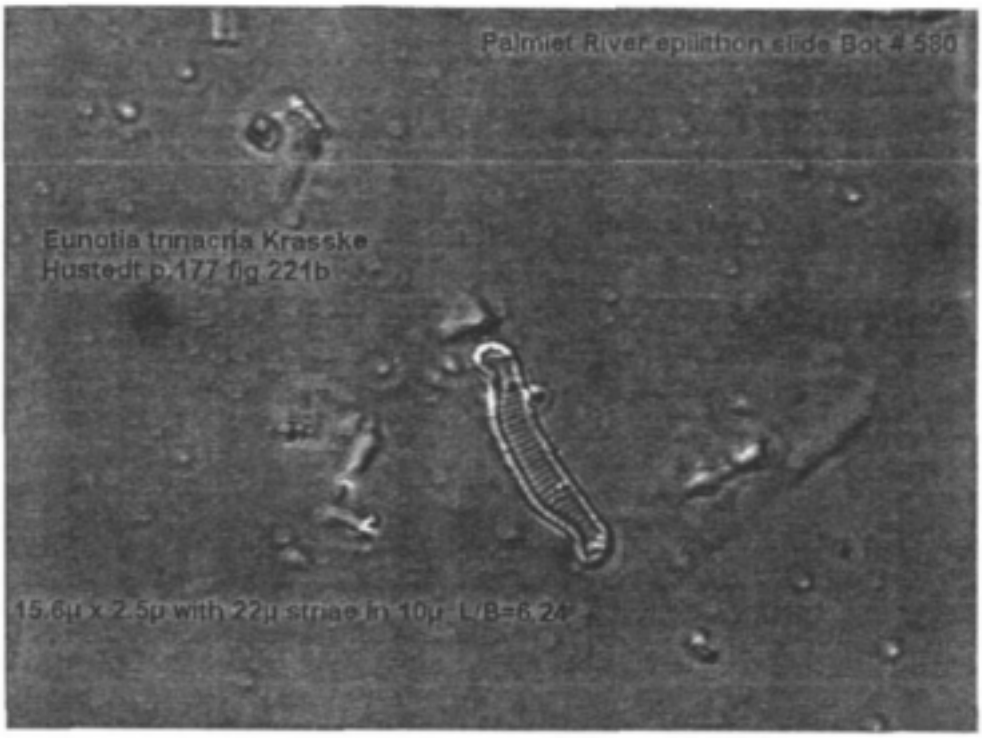
EUTIINCI ***Eunotia incisa*** **Gregory**



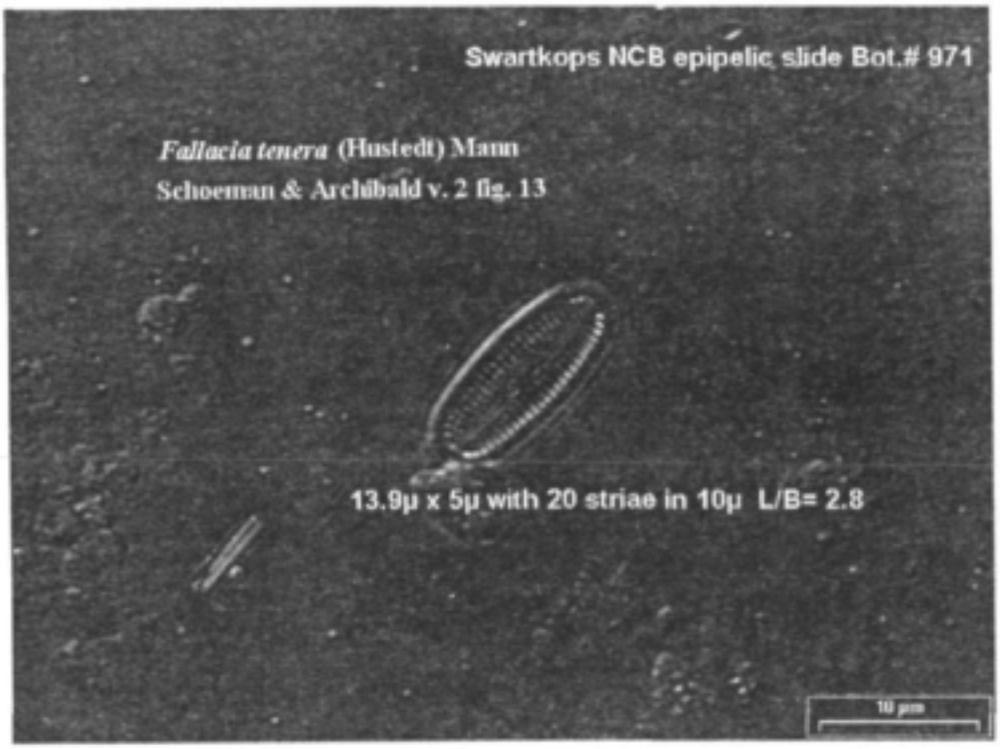
EUTIPECT ***Eunotia pectinalis*** **(Kutz) Raben.**



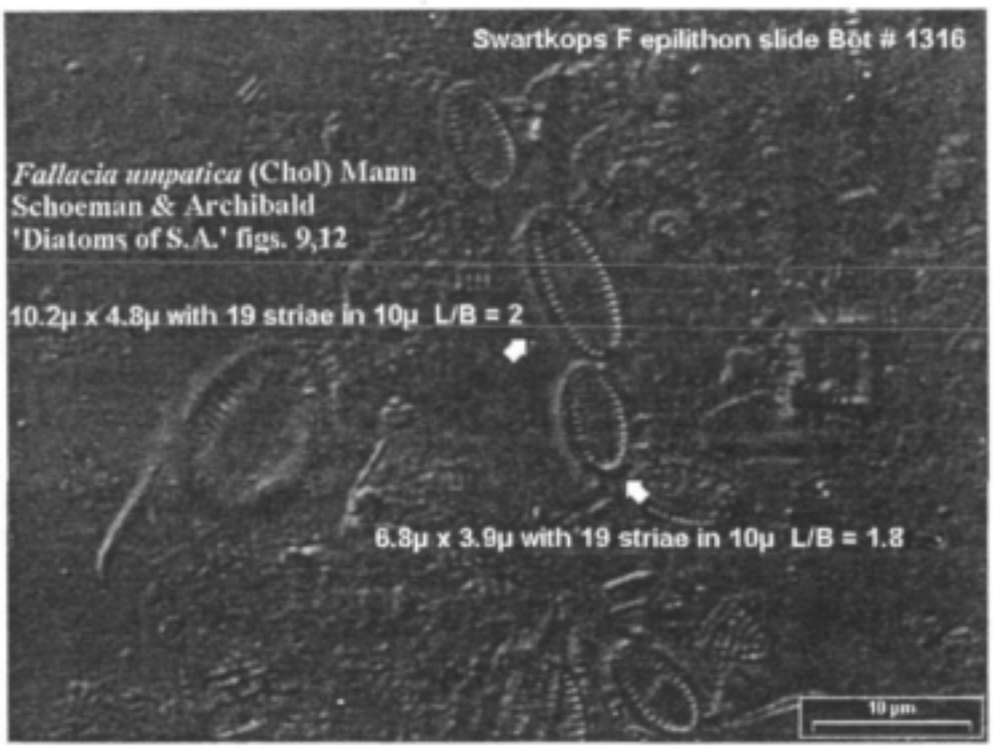
EUTITENE ***Eunotia tenella*** **(Grun) Hustedt**



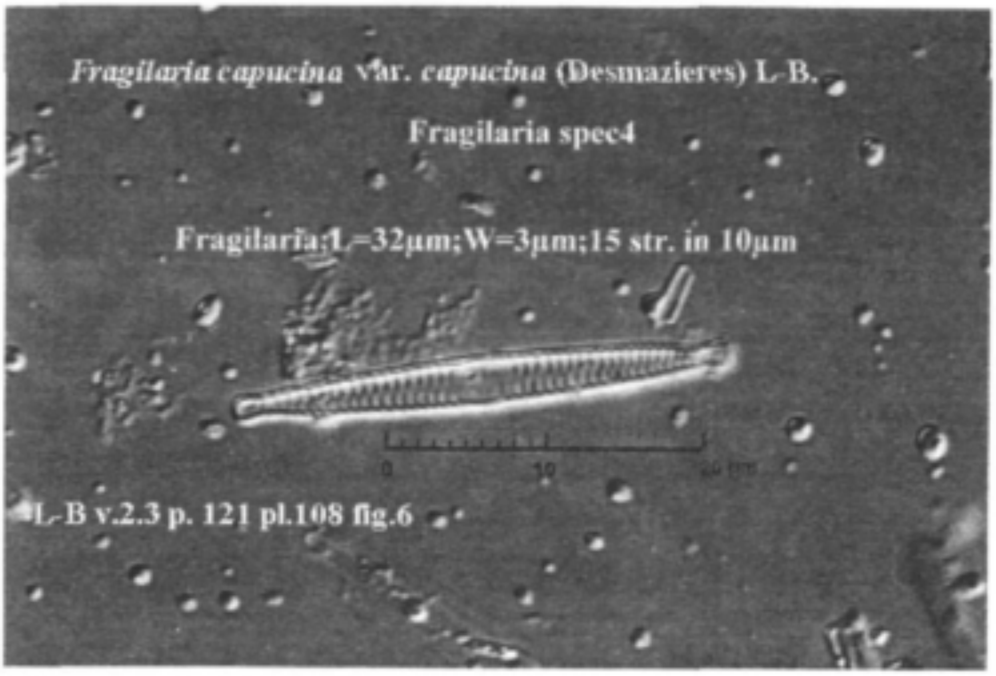
EUTITRIN ***Eunotia trinacria*** **Krasske**



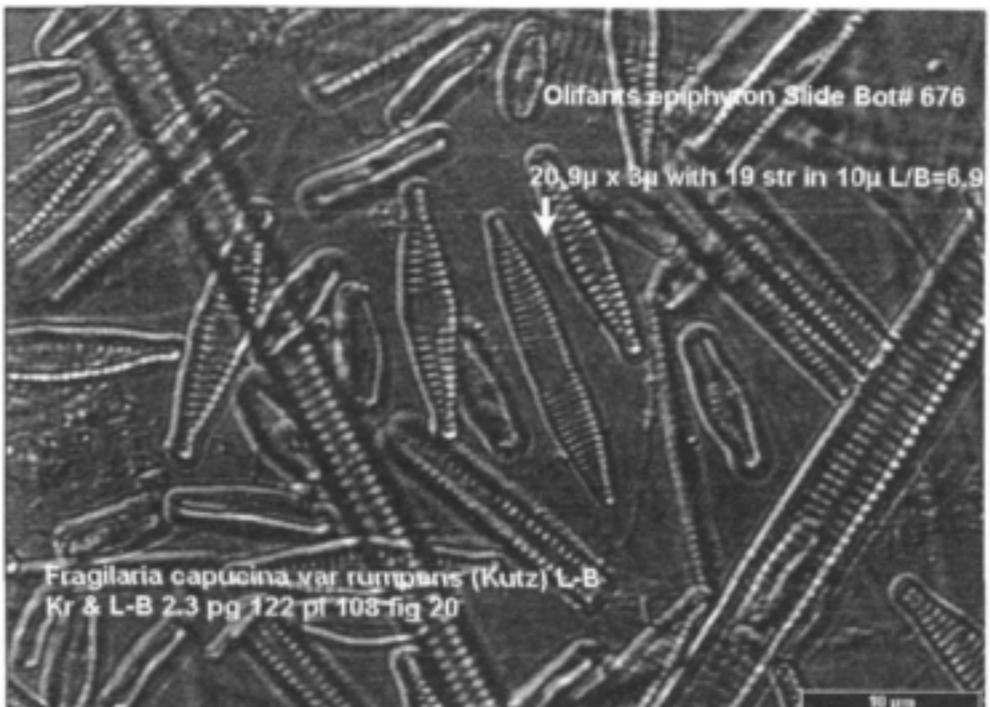
FALATERA *Fallacia tenera* (Hustedt) Mann



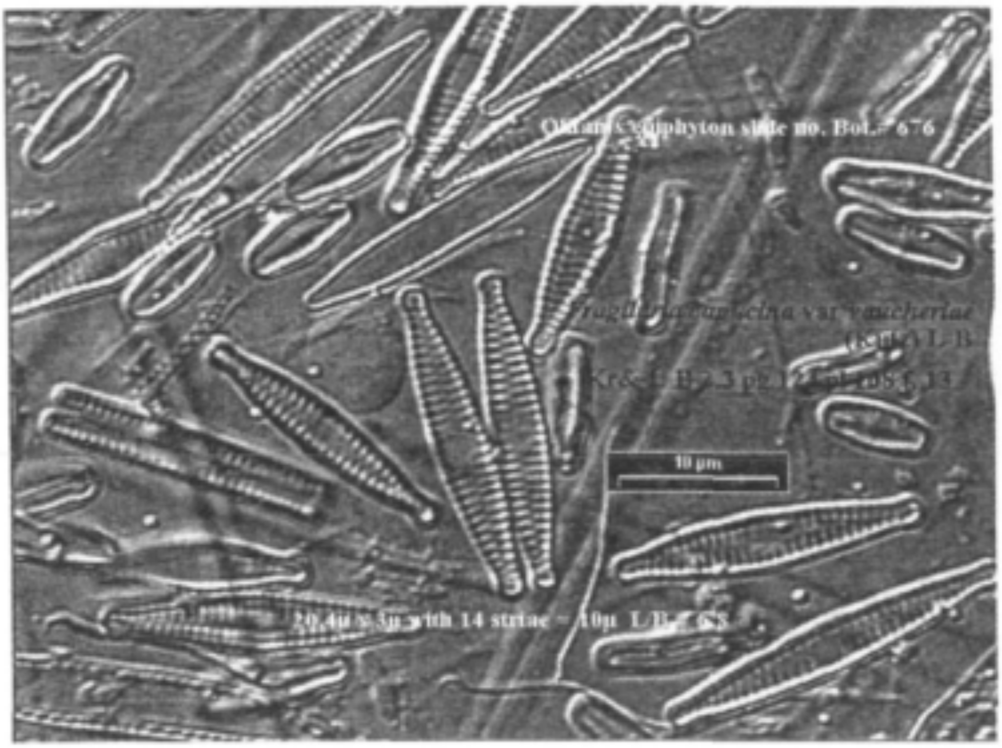
FALEUMPA *Fallacia umpatica* (Cholnoky) Mann



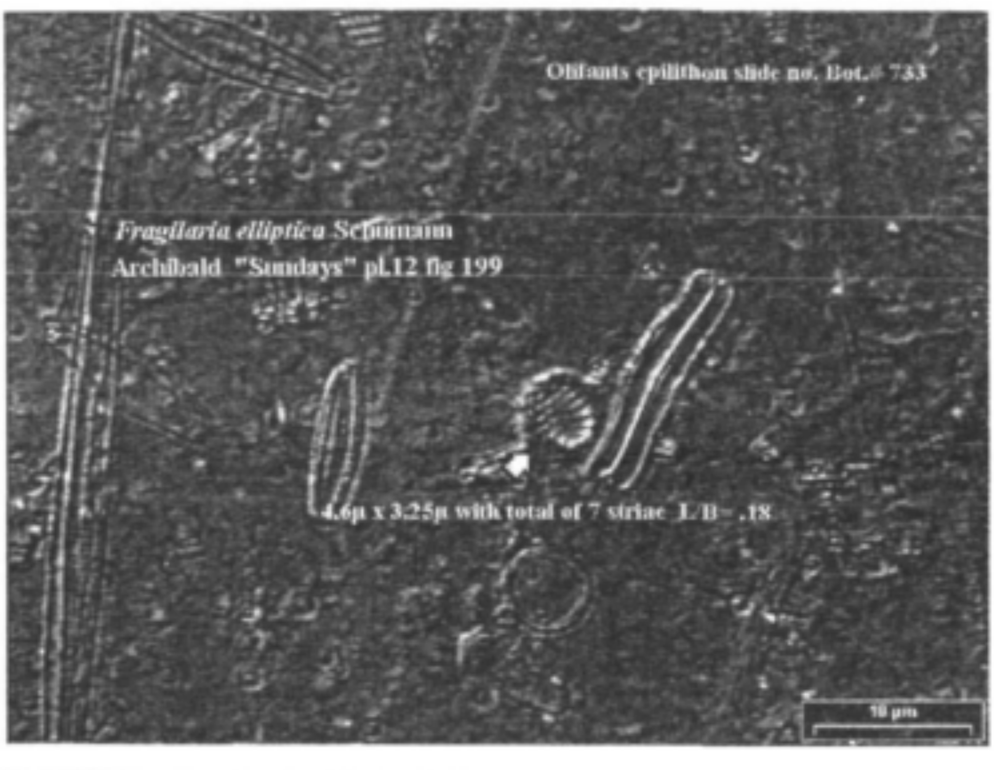
FRAGCAca *Fragilaria capucina* var. *capucina* (Desmazieres) L-B



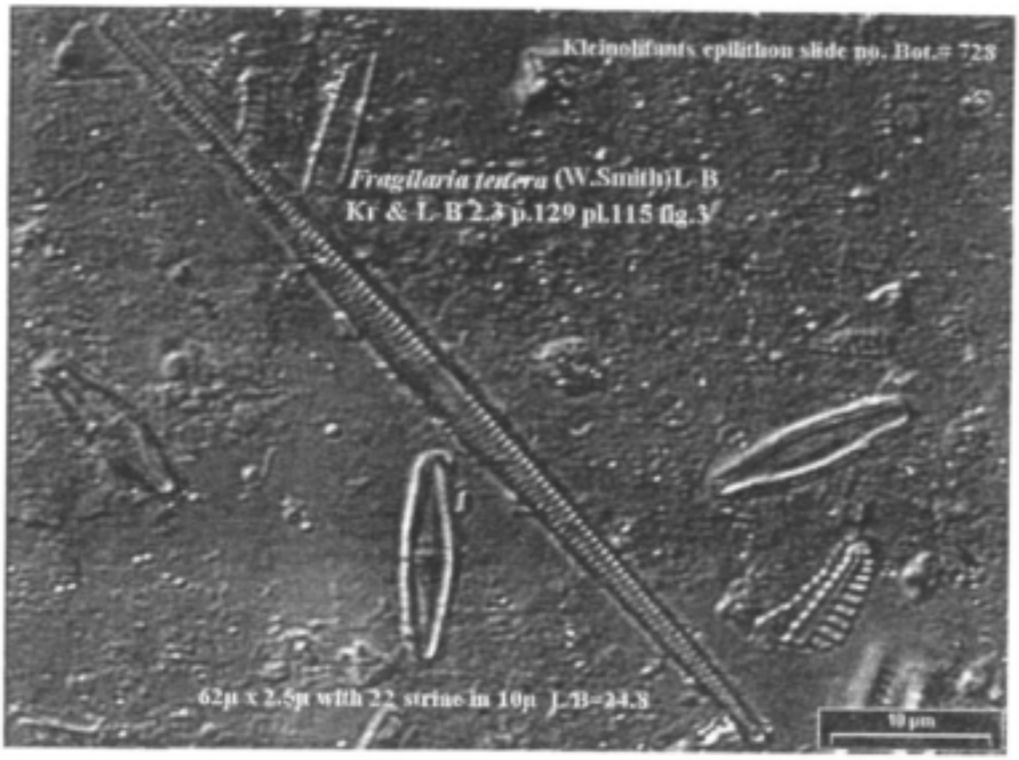
FRAGCAru *Fragilaria capucina* var. *rumpens*(Kutz)L-B



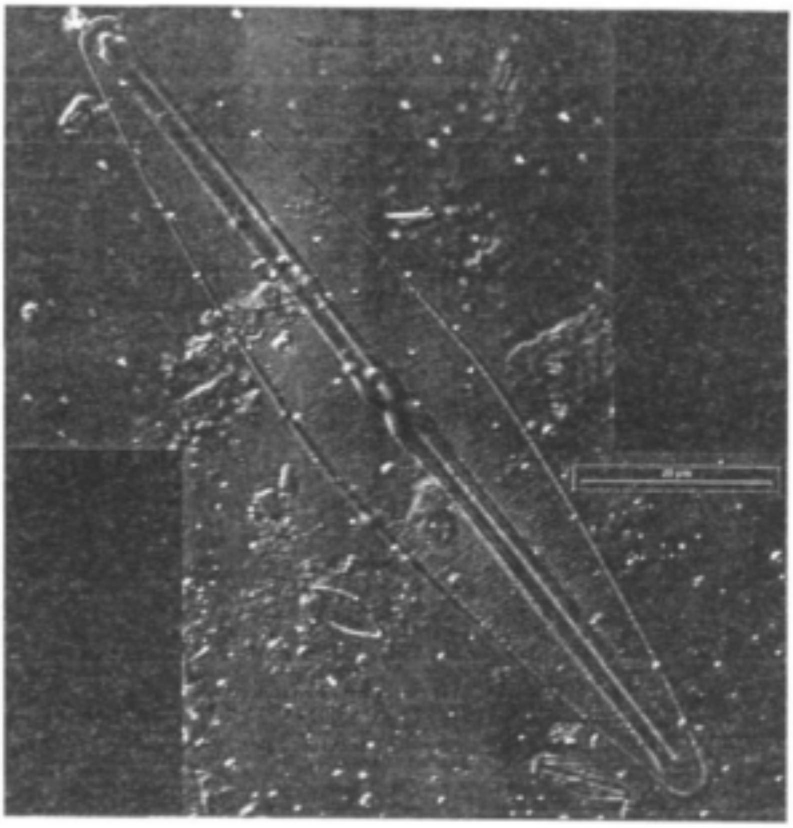
FRAGCAva *Fragilaria capucina* var. *vaucheriae* (Kutz) L-B



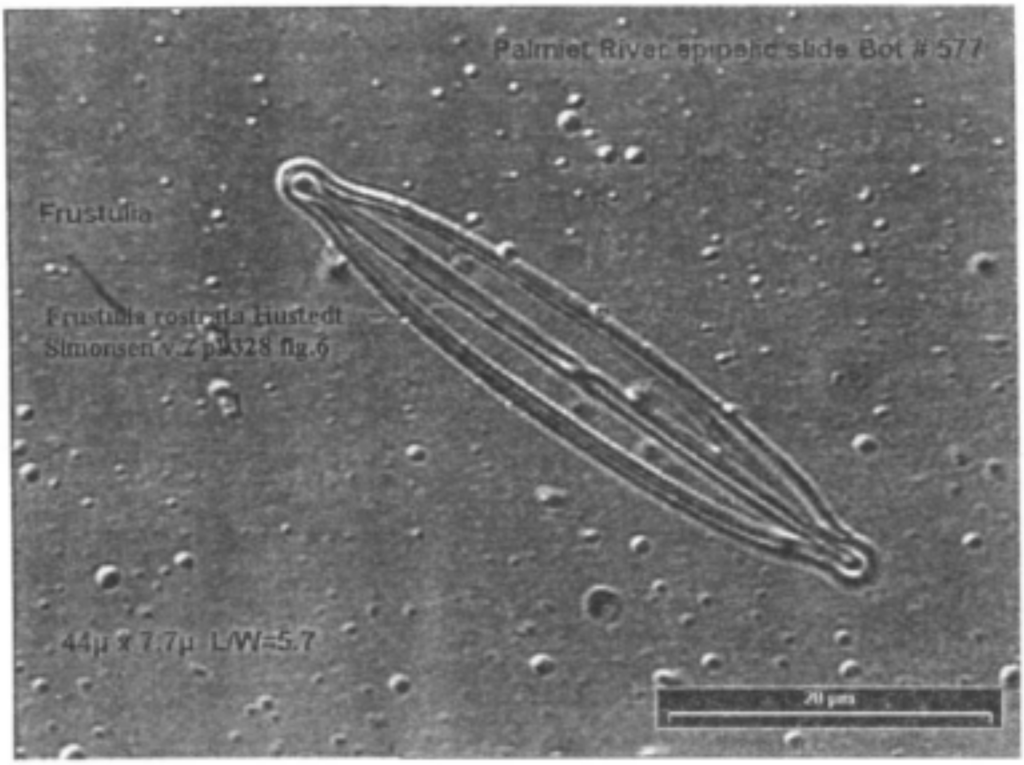
FRAGELLI *Fragilaria elliptica* **Schumann**



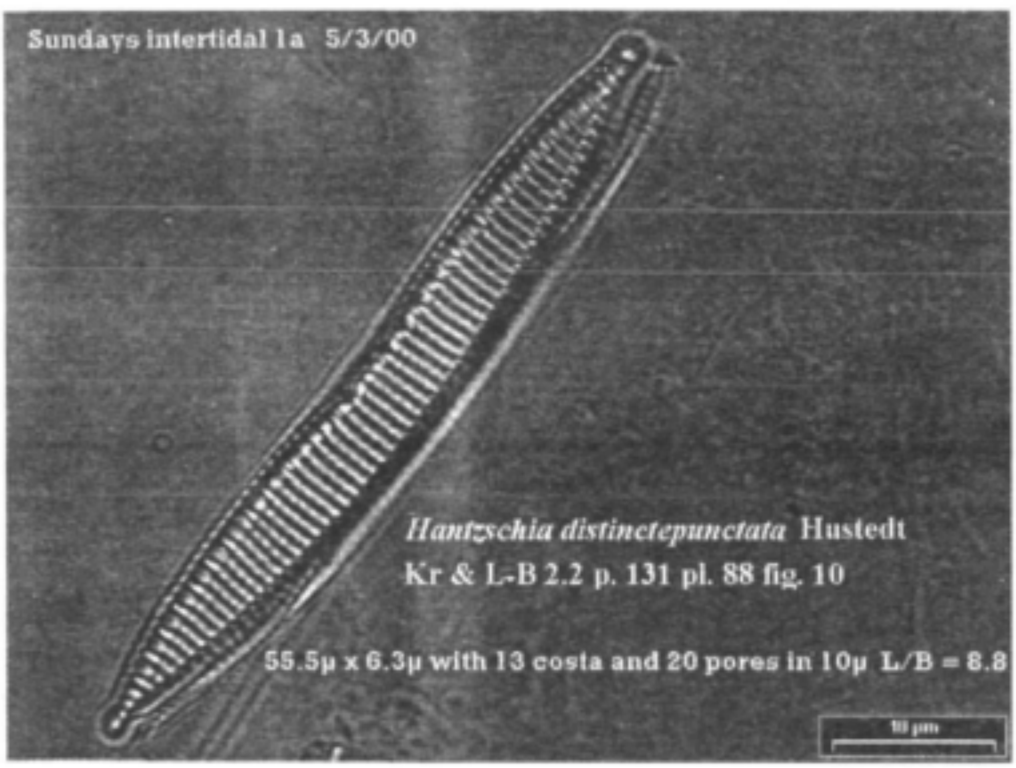
FRAGTENE ***Fragilaria tenera*** **(W. Smith) L-B**



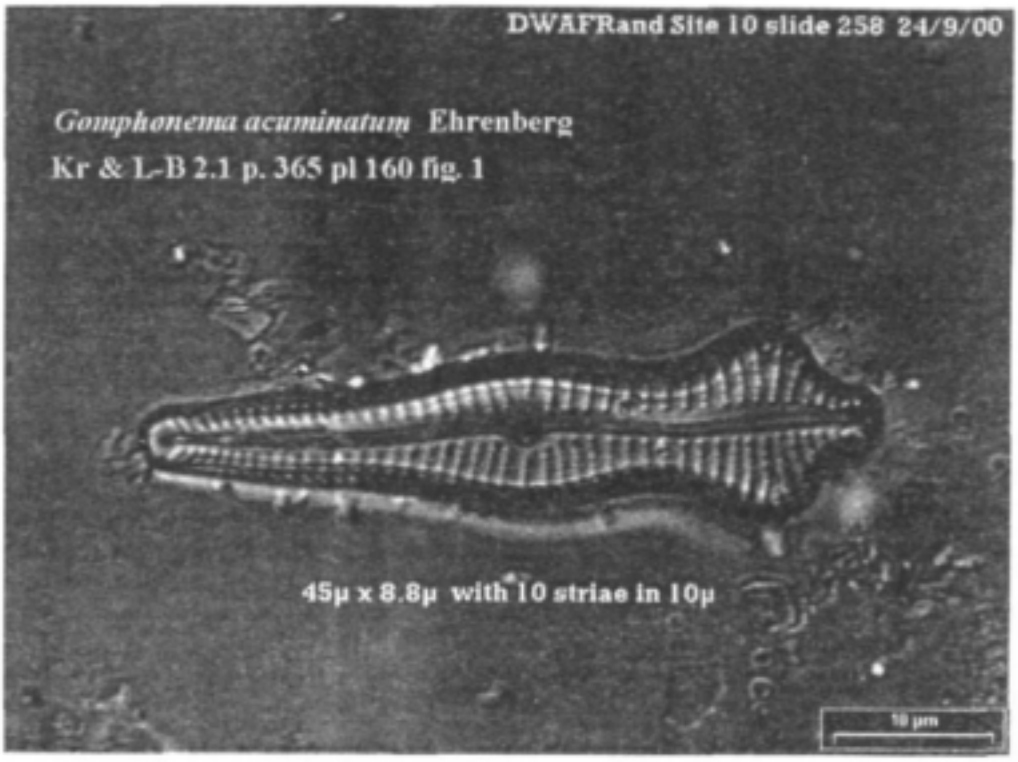
FRUSRHOM ***Frustulia rhomboides*** **(Ehr) de Toni**



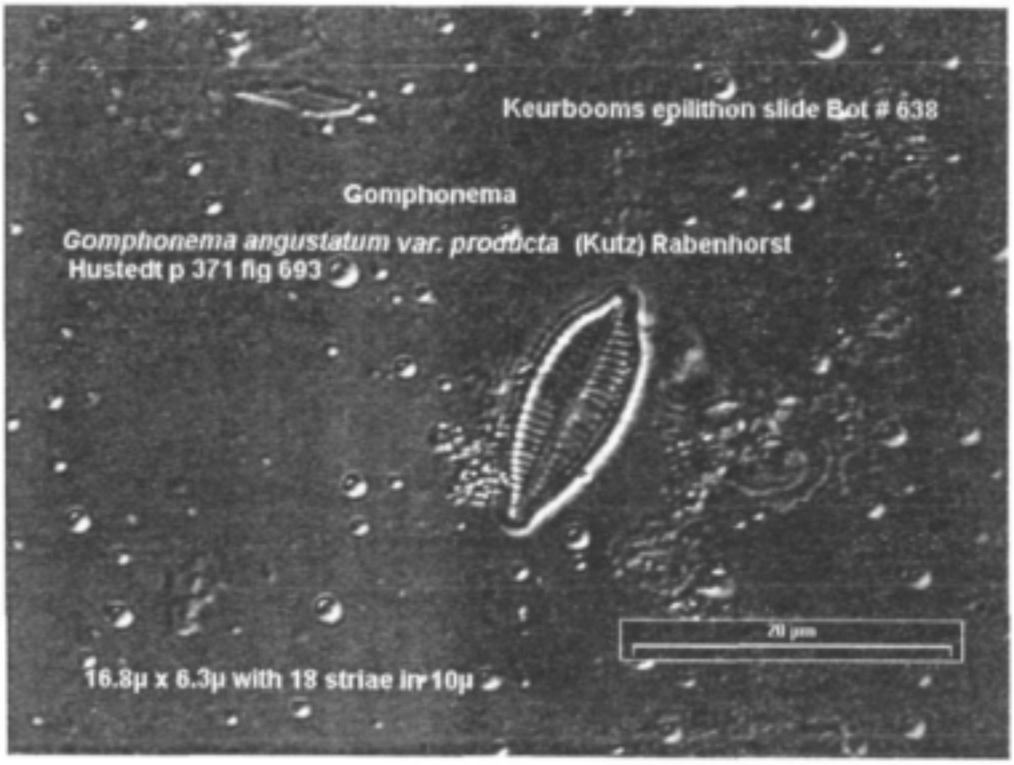
FRUSROST *Frustulia rostrata* Hustedt



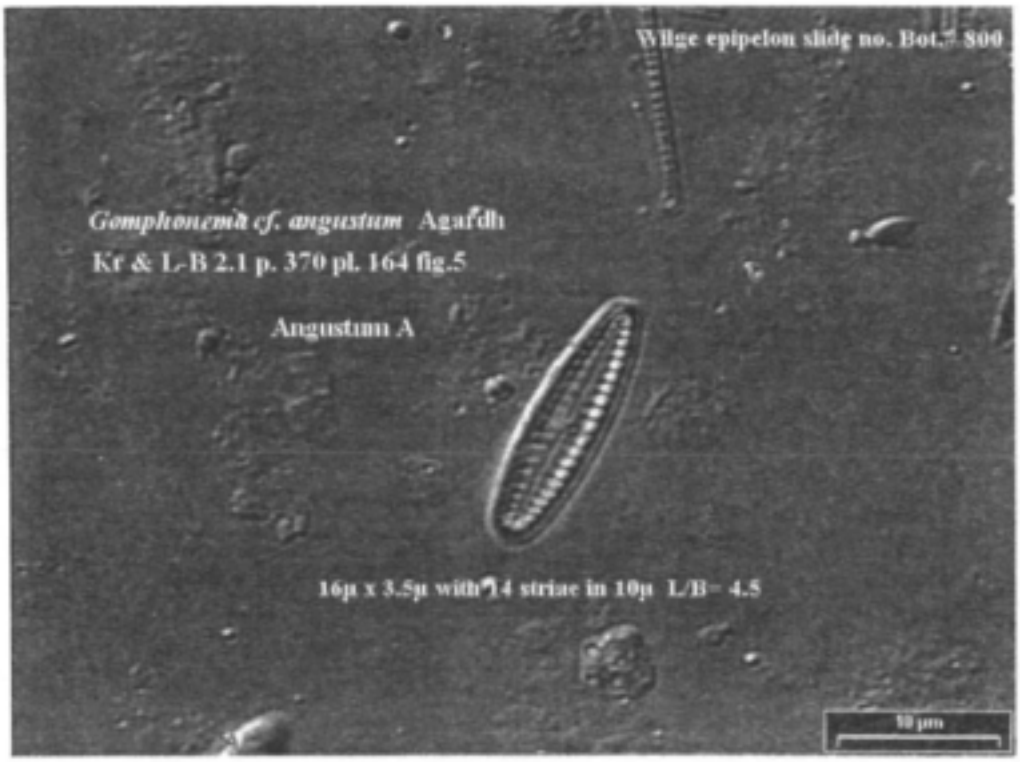
HANTDIST *Hantzschia distinctepunctata* Hustedt



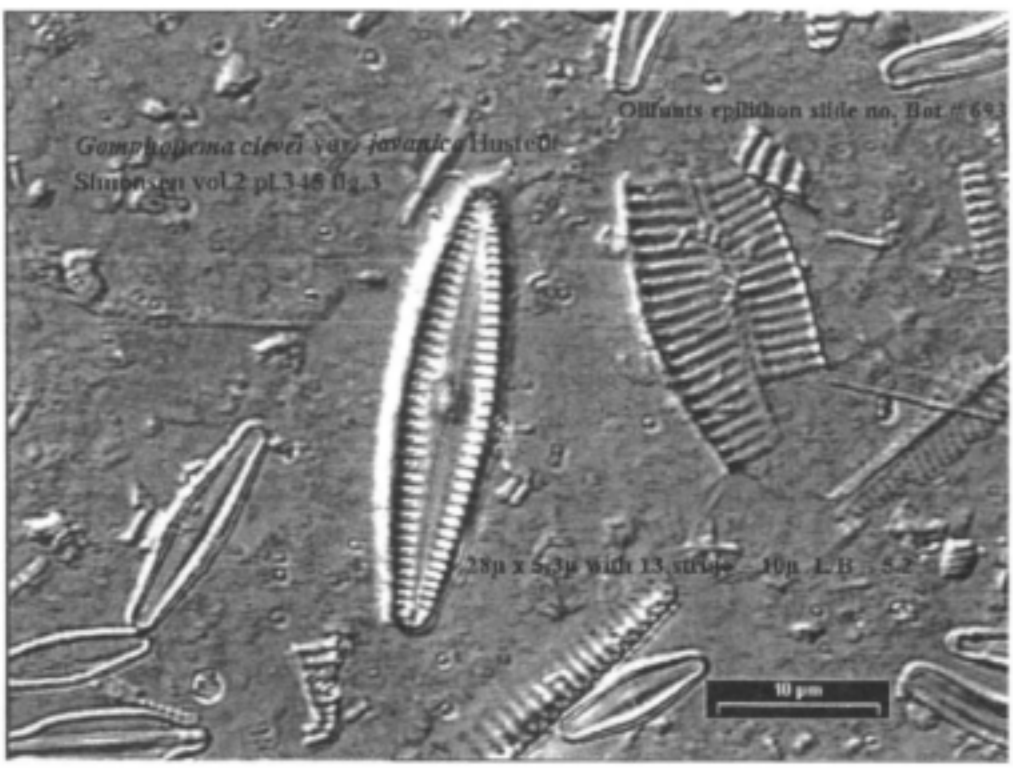
GONEACUM *Gomphonema acuminatum* Ehrenberg



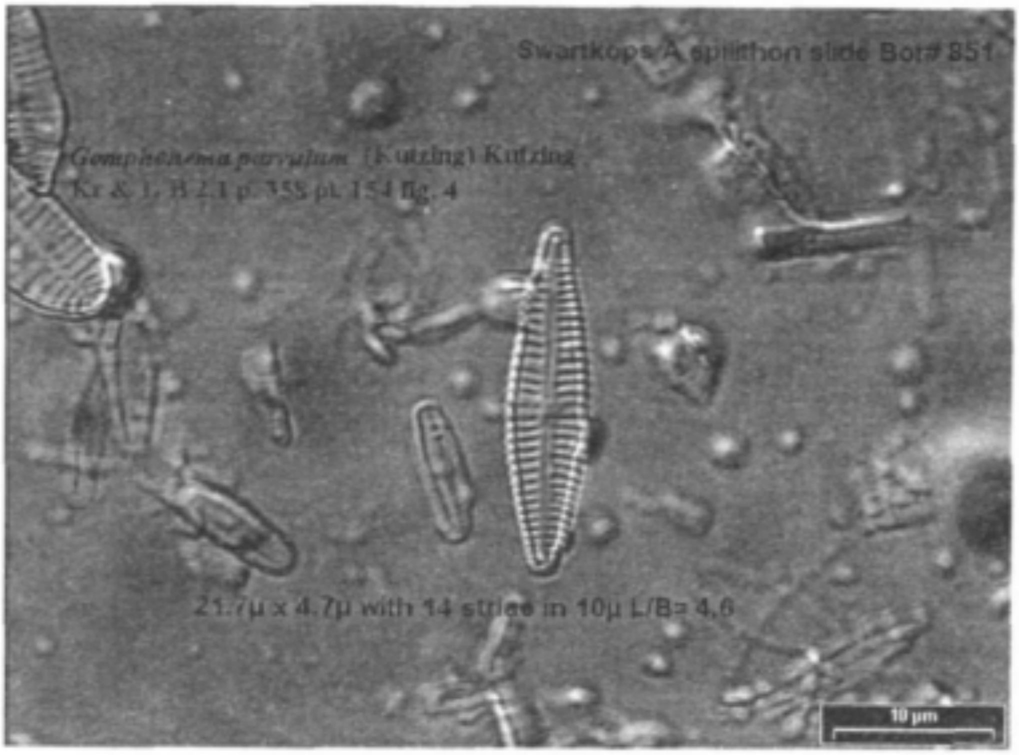
GONEANpr *Gomphonema angustatum* var.*producta*(Kutz)Rab.



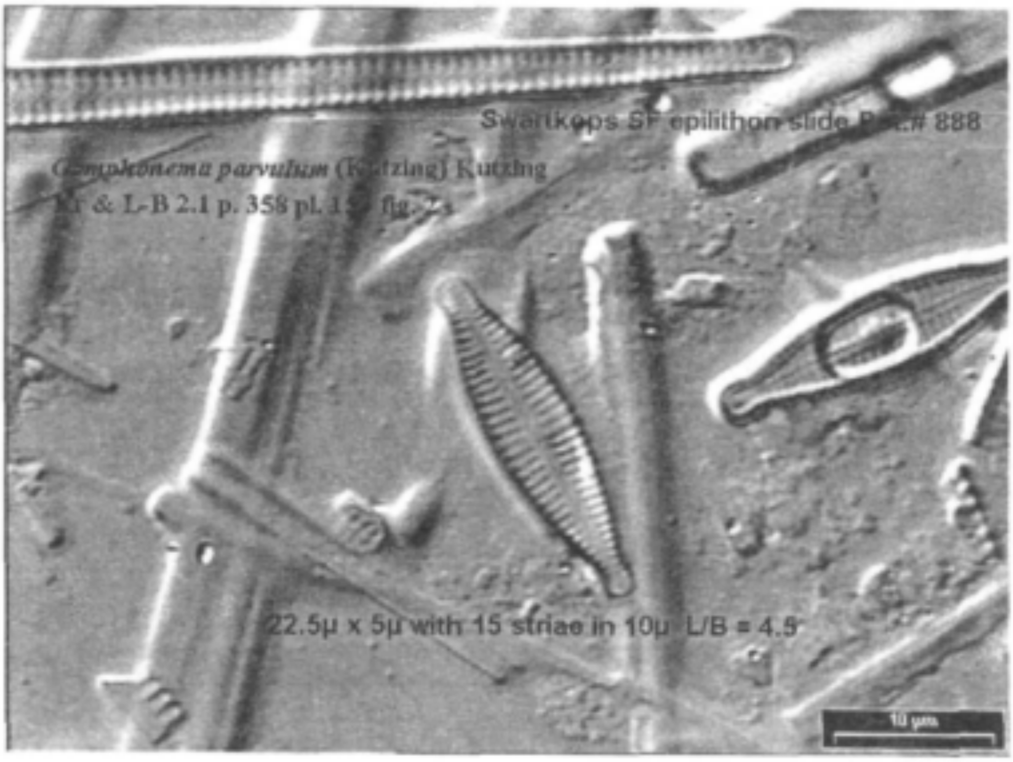
GONEANGU *Gomphonema angustum* Agardh



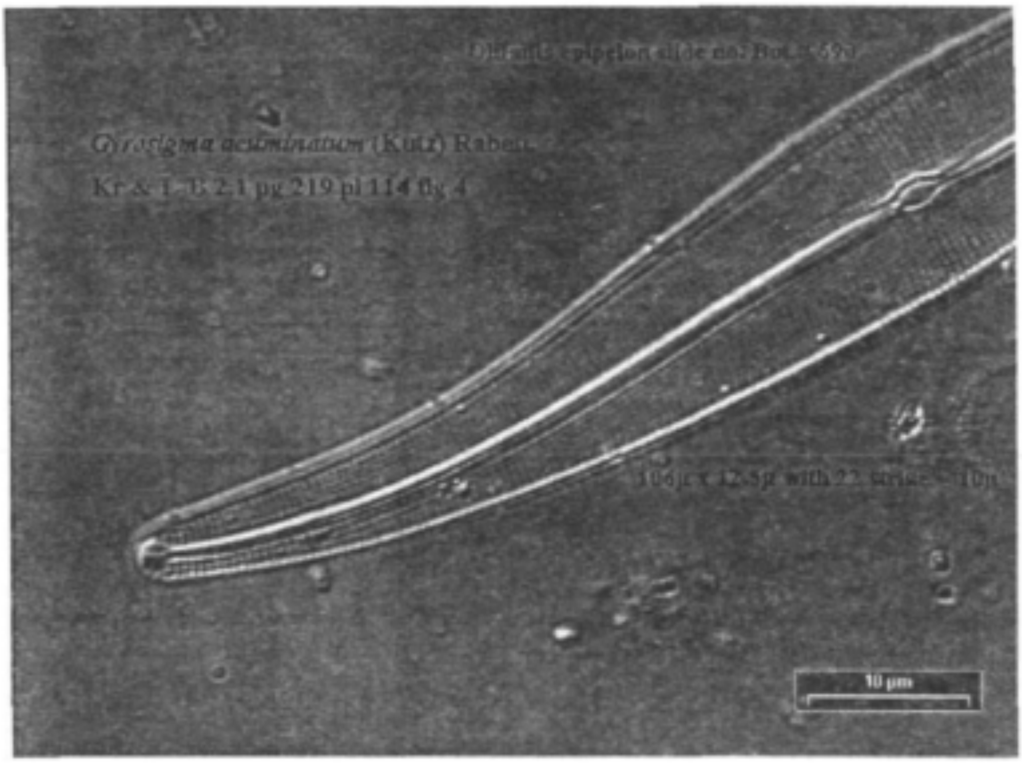
GONECLja *Gomphonema clevei* **var.** *javanica* **Hust.**



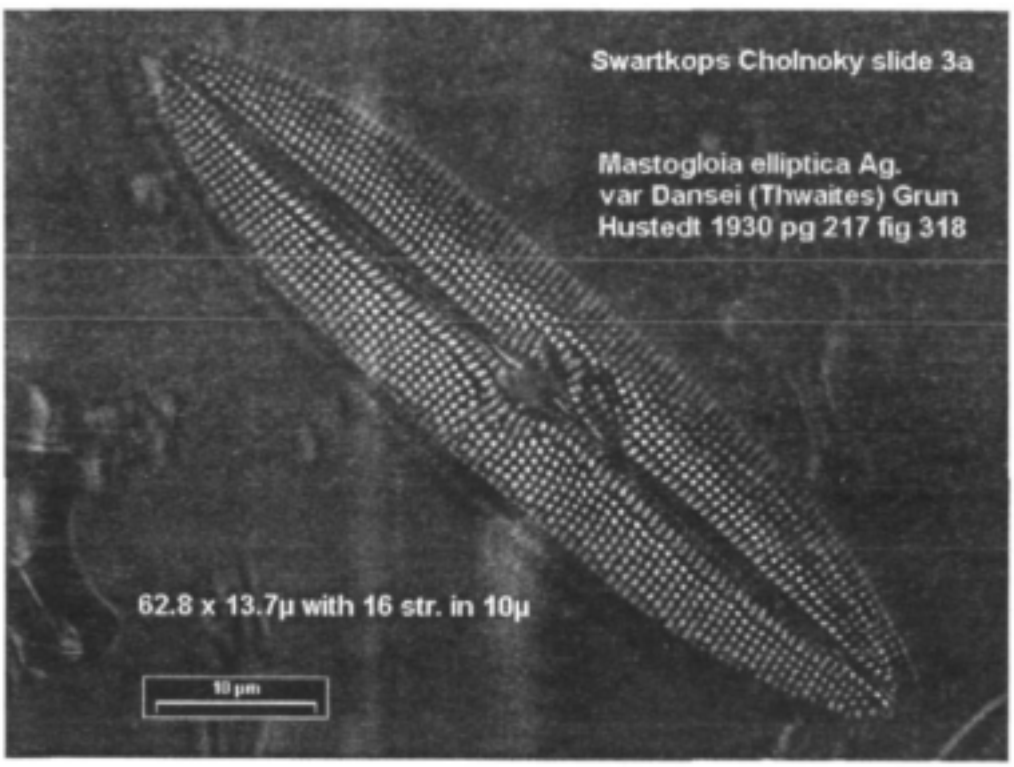
GONEPAR1 *Gomphonema parvulum* var.1 (KUTZING) KUTZING



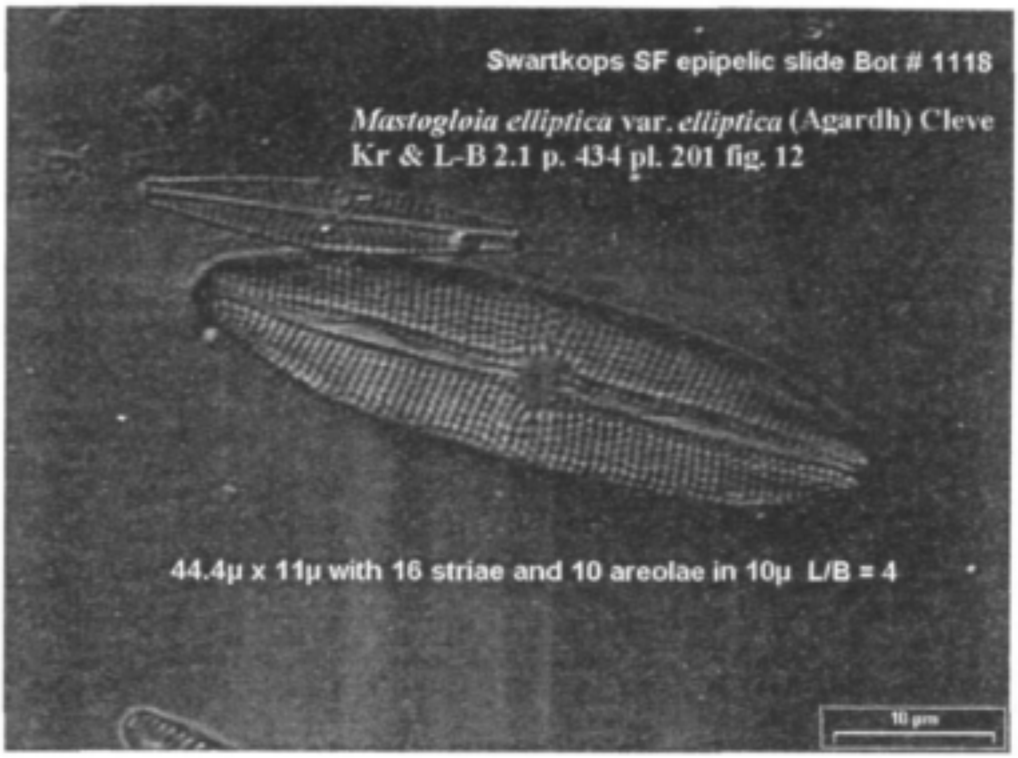
GONEPAR3 *Gomphonema parvulum* var.3 (Kutzing) Kutzing



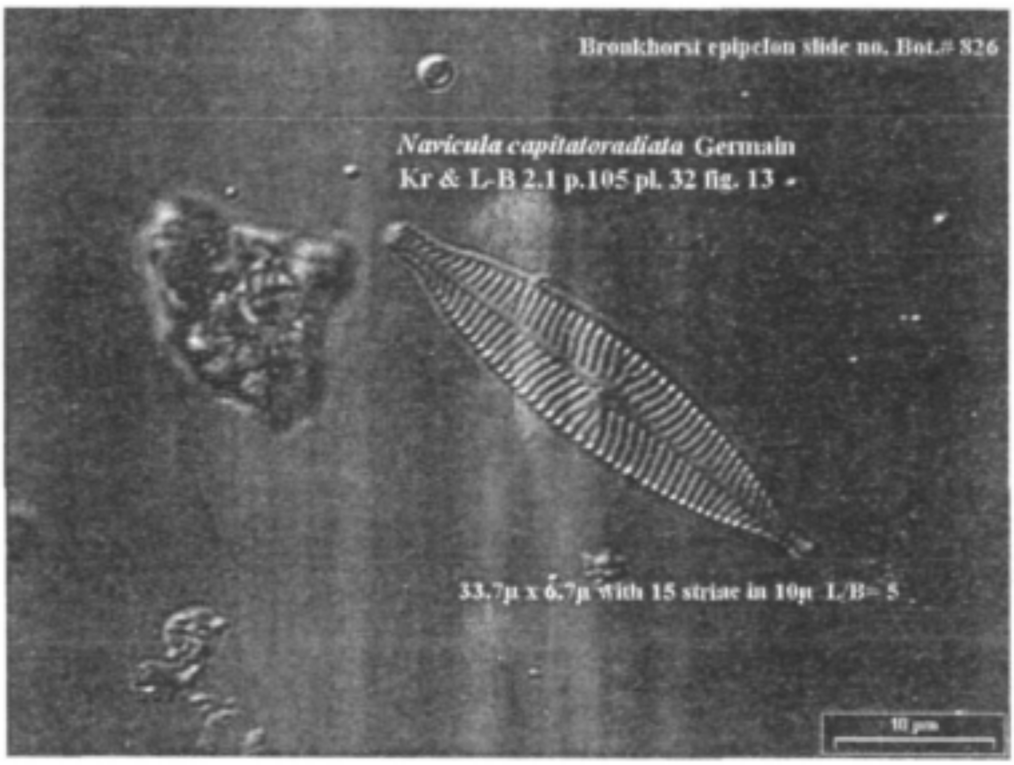
GYROACUM ***Gyrosigma acuminatum*** **(Kutz) Cleve**



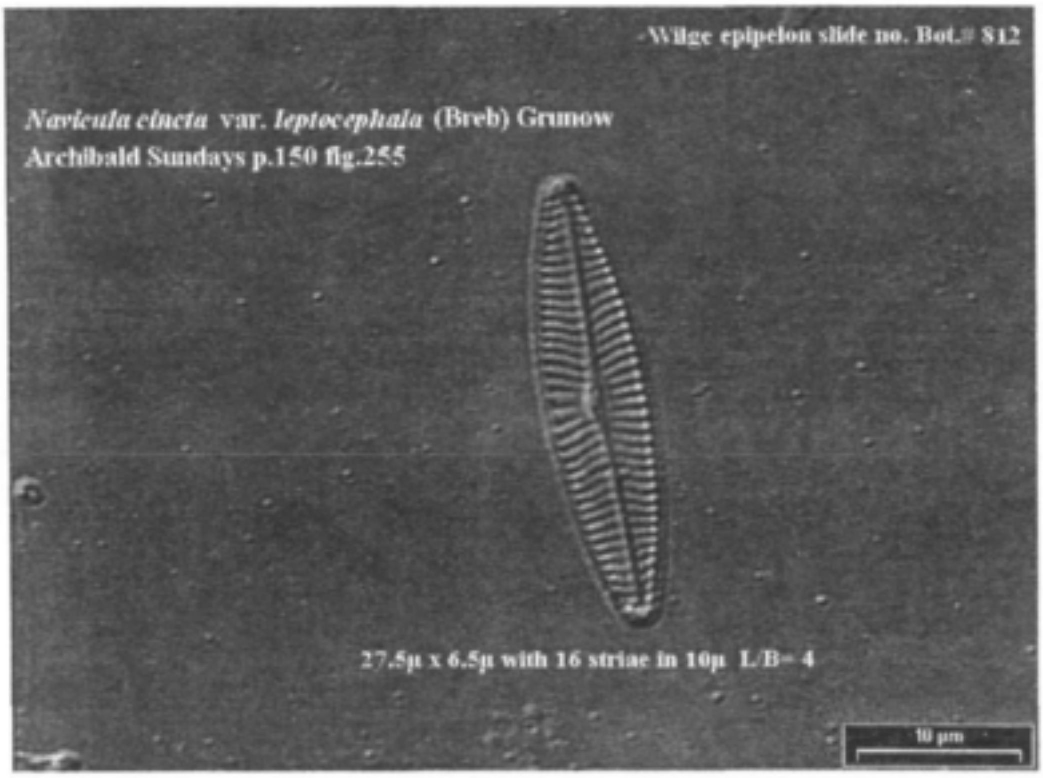
MAGLELda ***Mastogloia elliptica*** **var. dansei (Thwaites) Cleve**



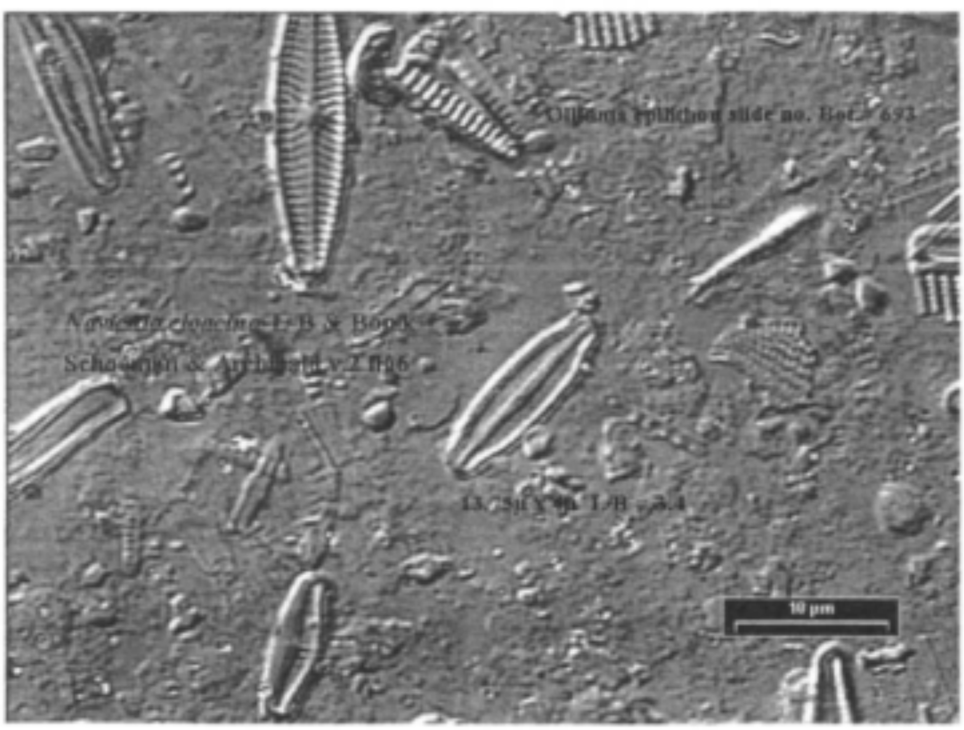
MAGLELel *Mastogloia elliptica* **var. elliptica (Agardh) Cleve**



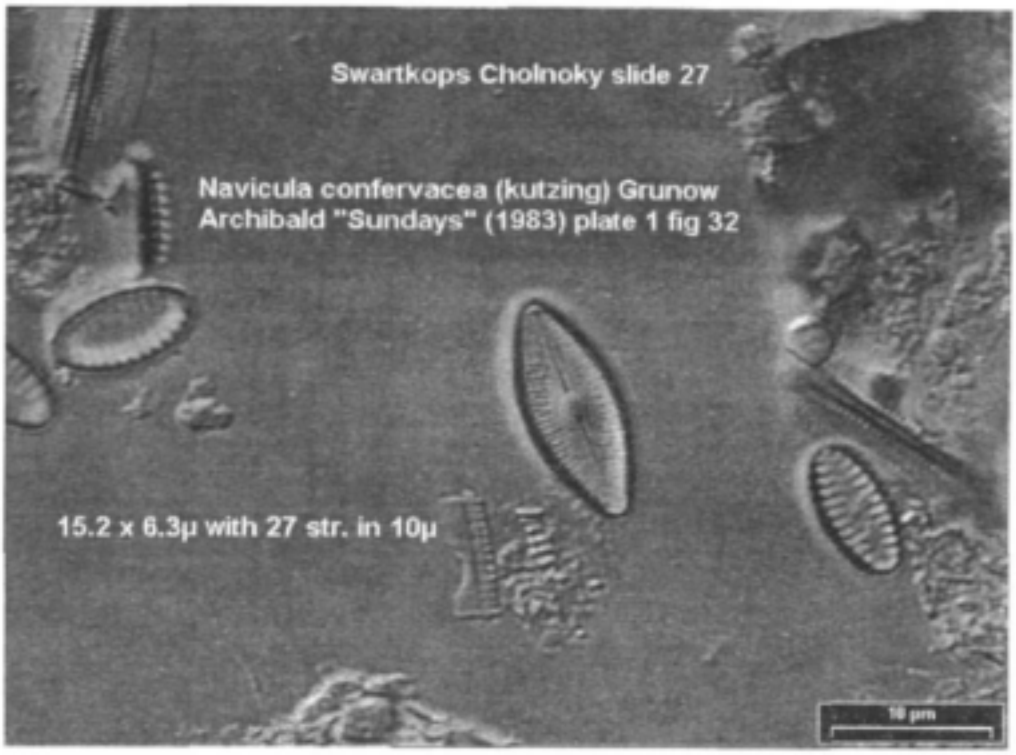
NAVICAPI *Navicula capitatoradiata* **Germain**



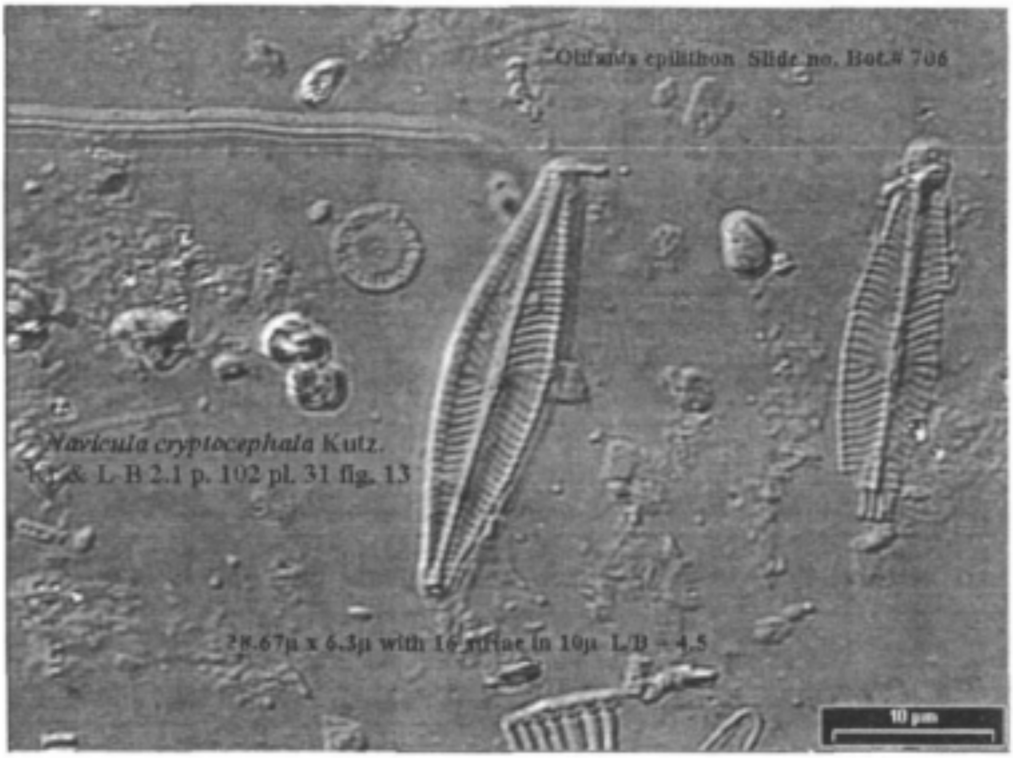
NAVICIle *Navicula cincta* **var.** *leptocephala* **(Breb) Grunow**



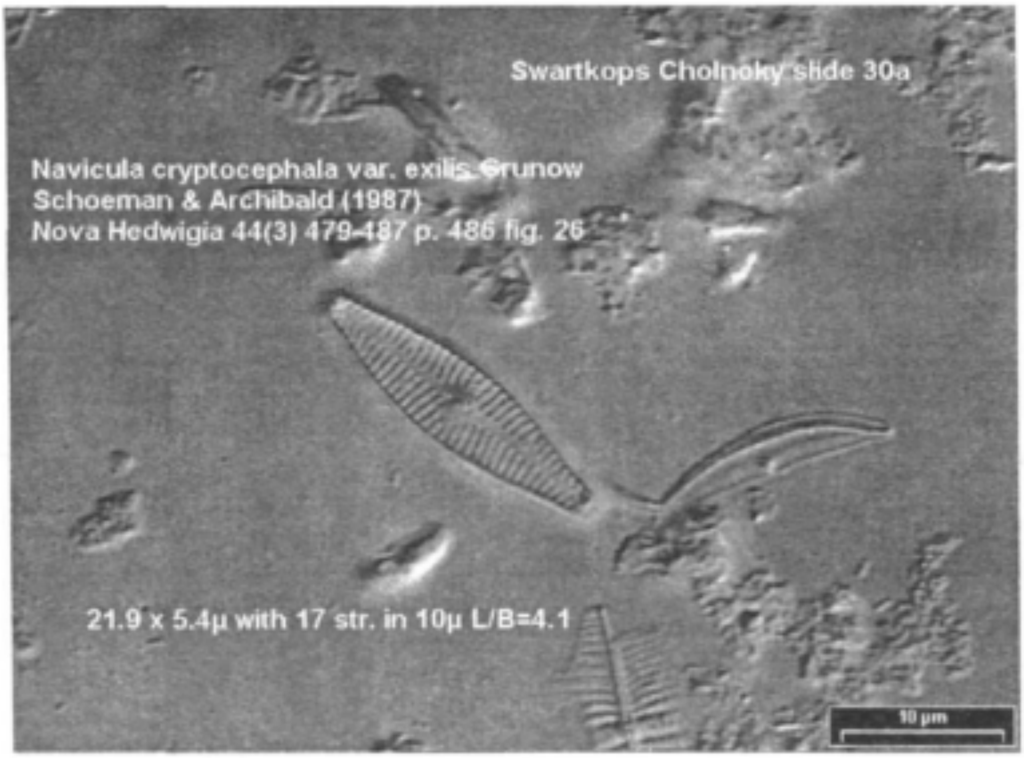
NAVICLOA *Navicula cloacina* L-B &Bonik



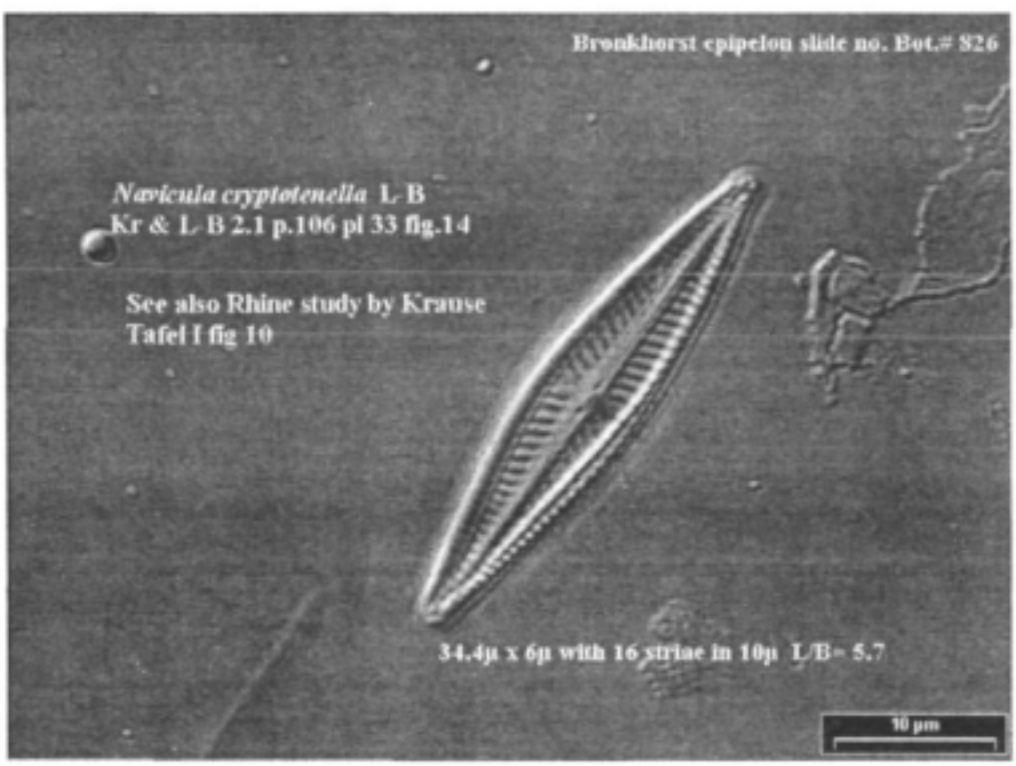
NAVICONF *Navicula confervacea* **(Kutz) Grunow**



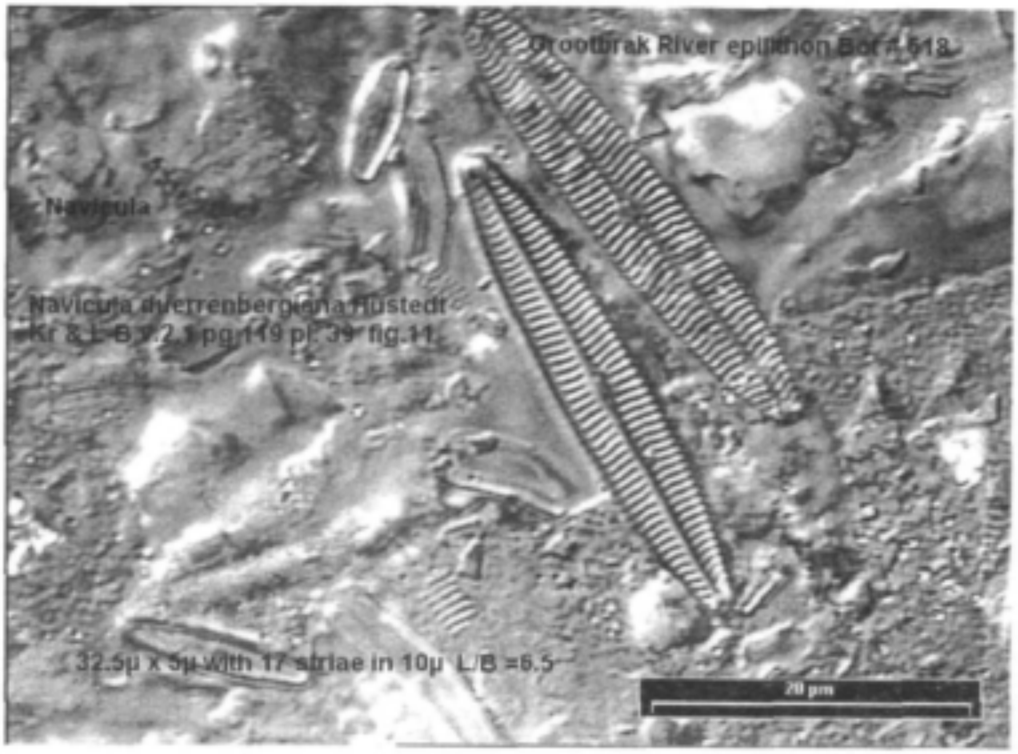
NAVICRCE *Navicula cryptocephala* **Kutzing**



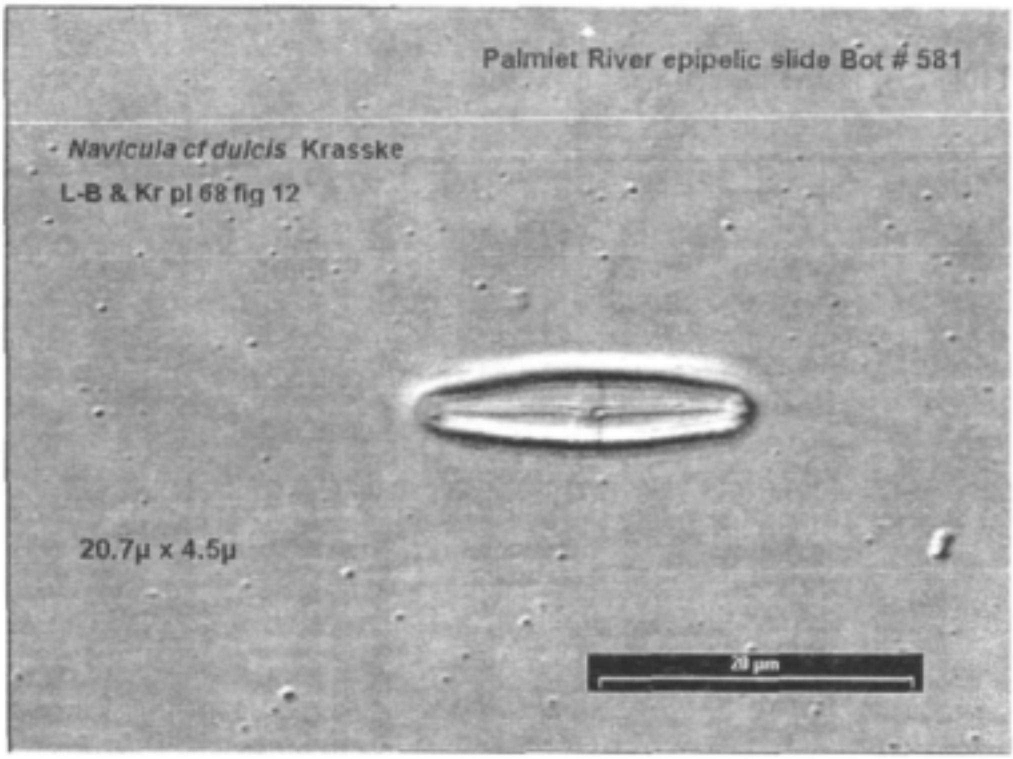
NAVICREX *Navicula cryptocephala* var. exilis GRUNOW



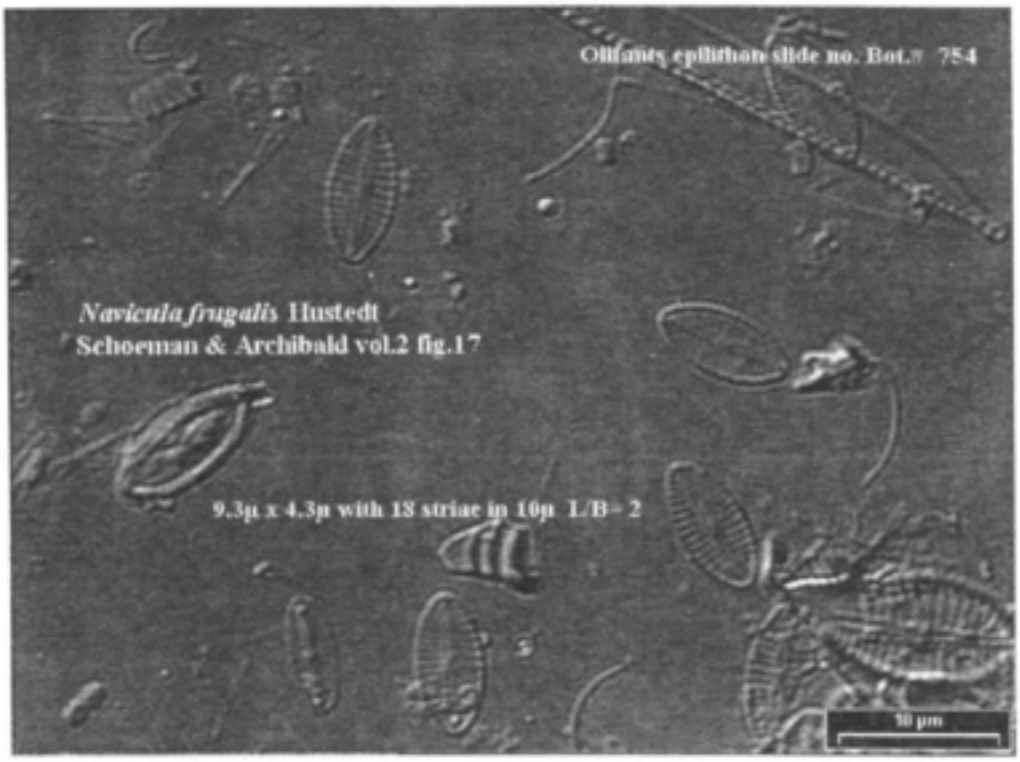
NAVICRTE *Navicula cryptotenella* L-B



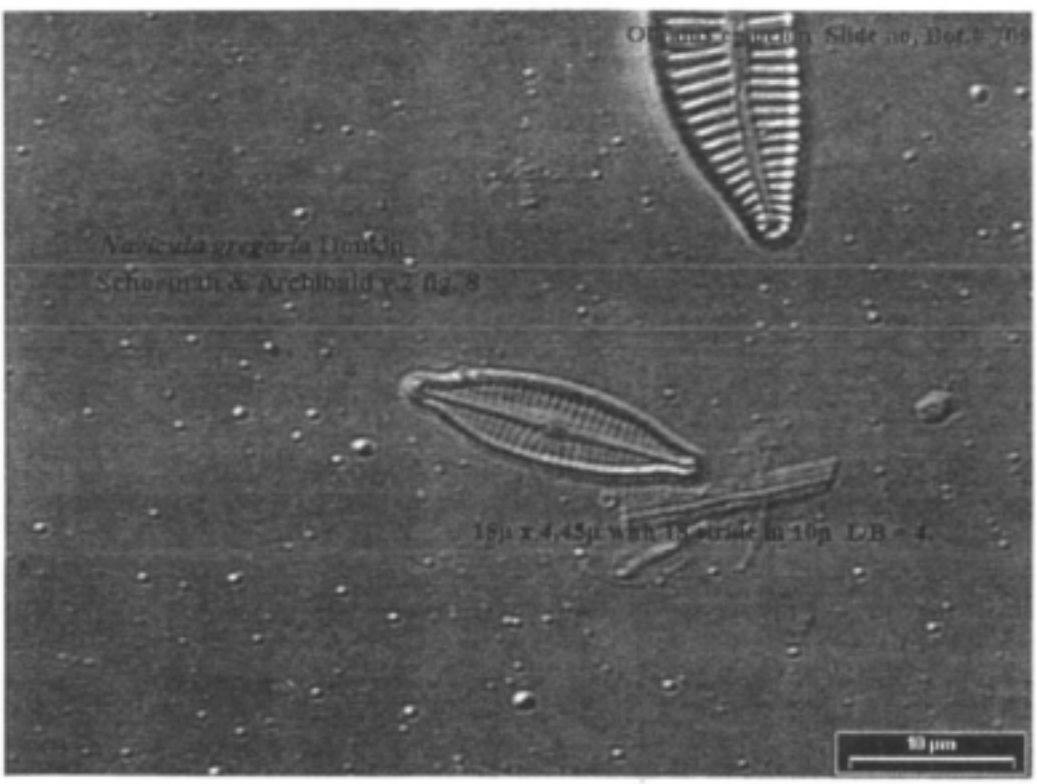
NAVIDUER *Navicula duerrenbergiana* **Hustedt**



NAVIDULC *Navicula cf dulcis* **Krasske**



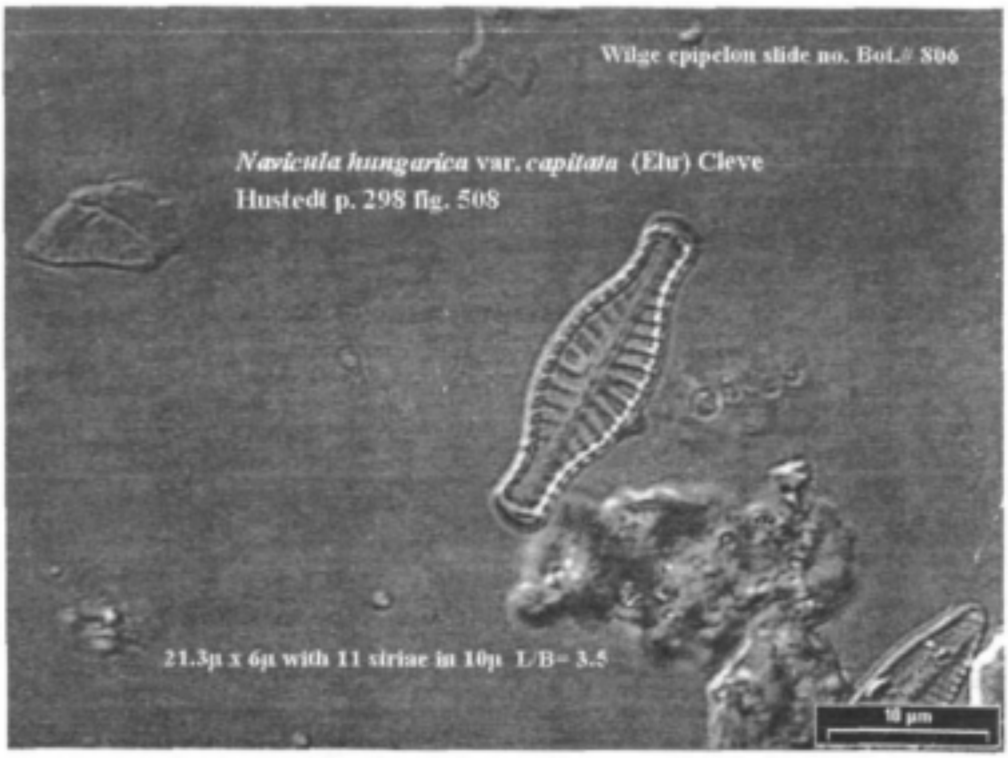
NAVIFRUG *Navicula frugalis* Hustedt



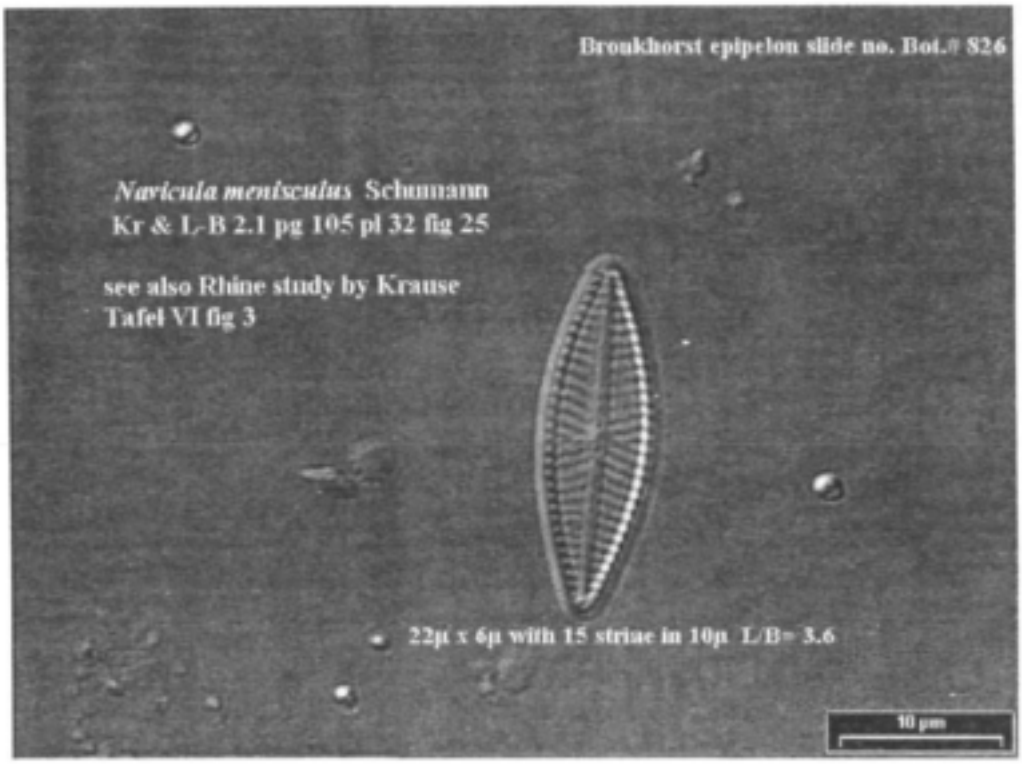
NAVIGREG *Navicula gregaria* Donkin

No image available

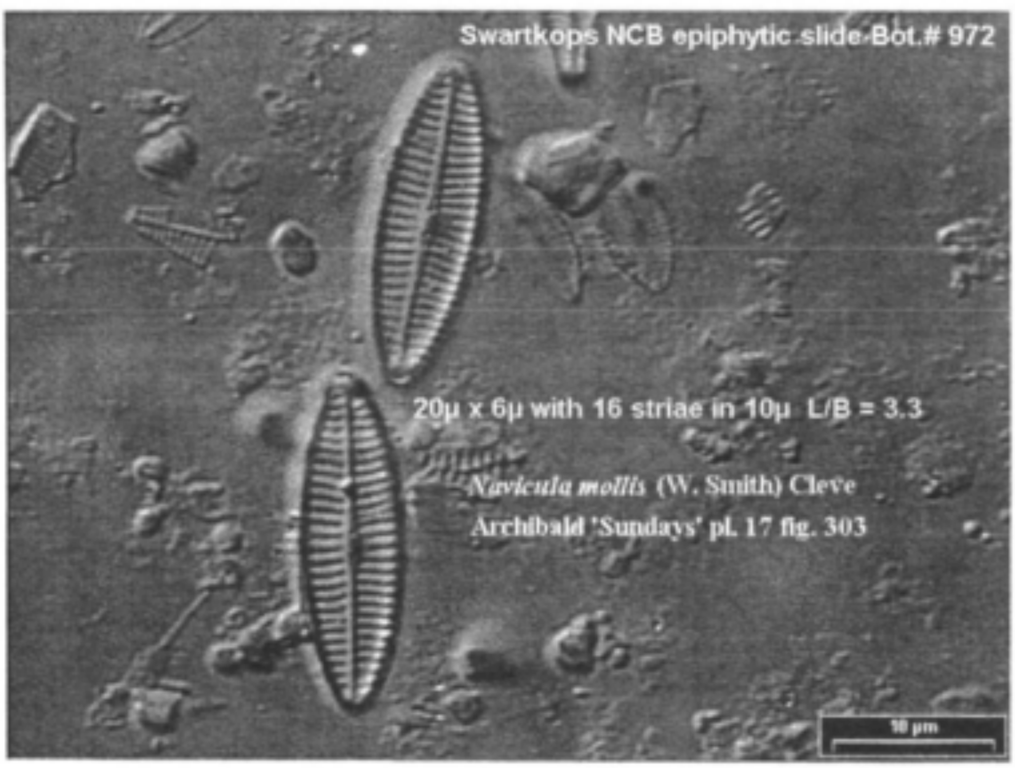
NAVILEPT *Navicula leptostriata* E.G. Joergensen



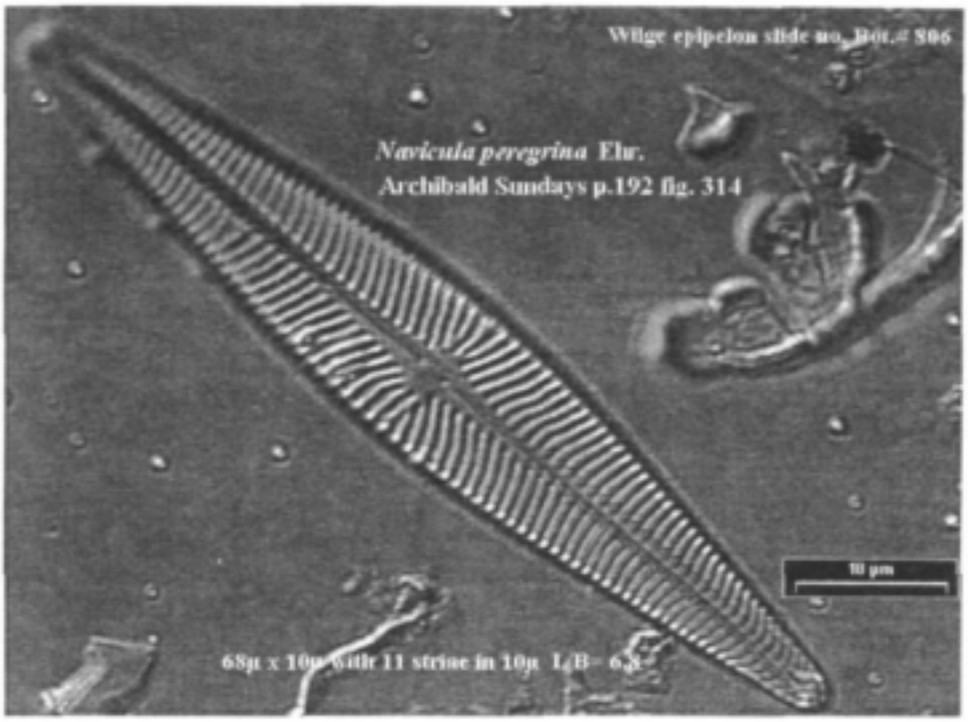
NAVIHUca *Navicula hungarica* var. capitata (Ehrenberg) Cleve



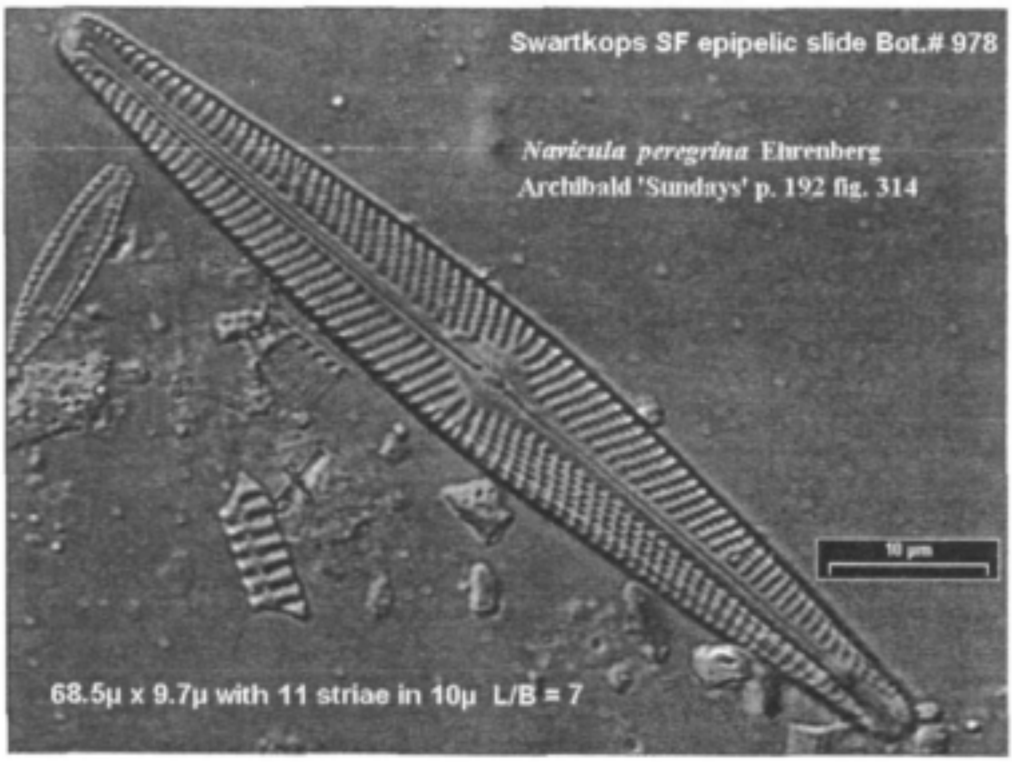
NAVIMENI *Navicula menisculus* Schumann



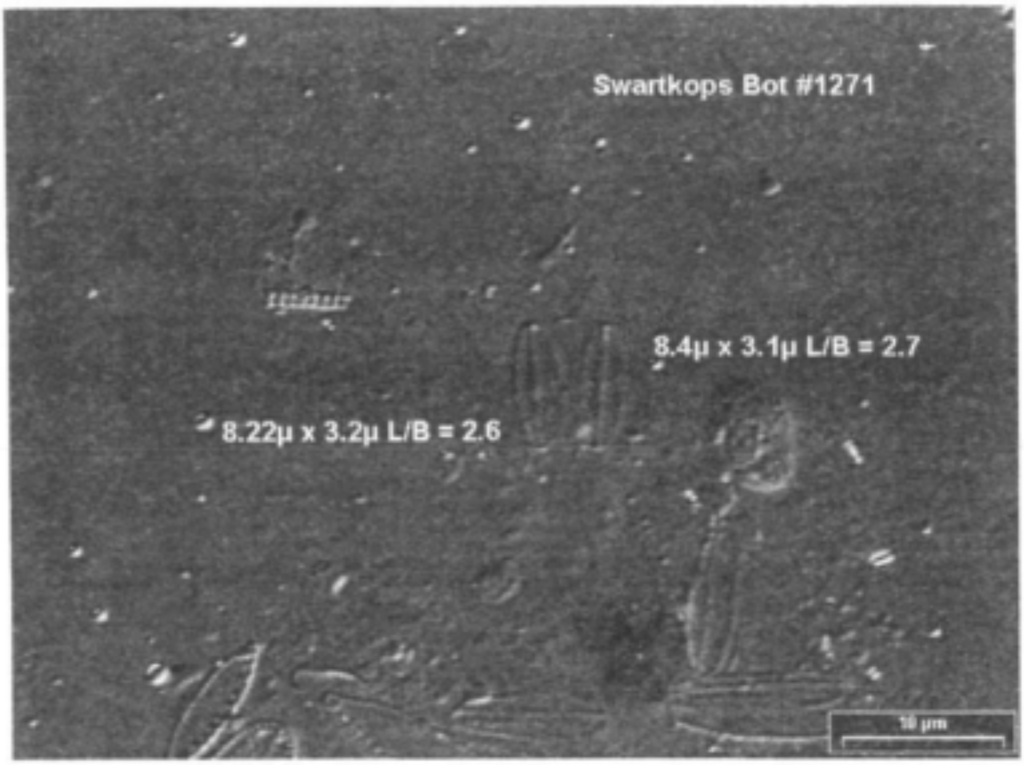
NAVIMOLL *Navicula mollis* (WSmith) Cleve



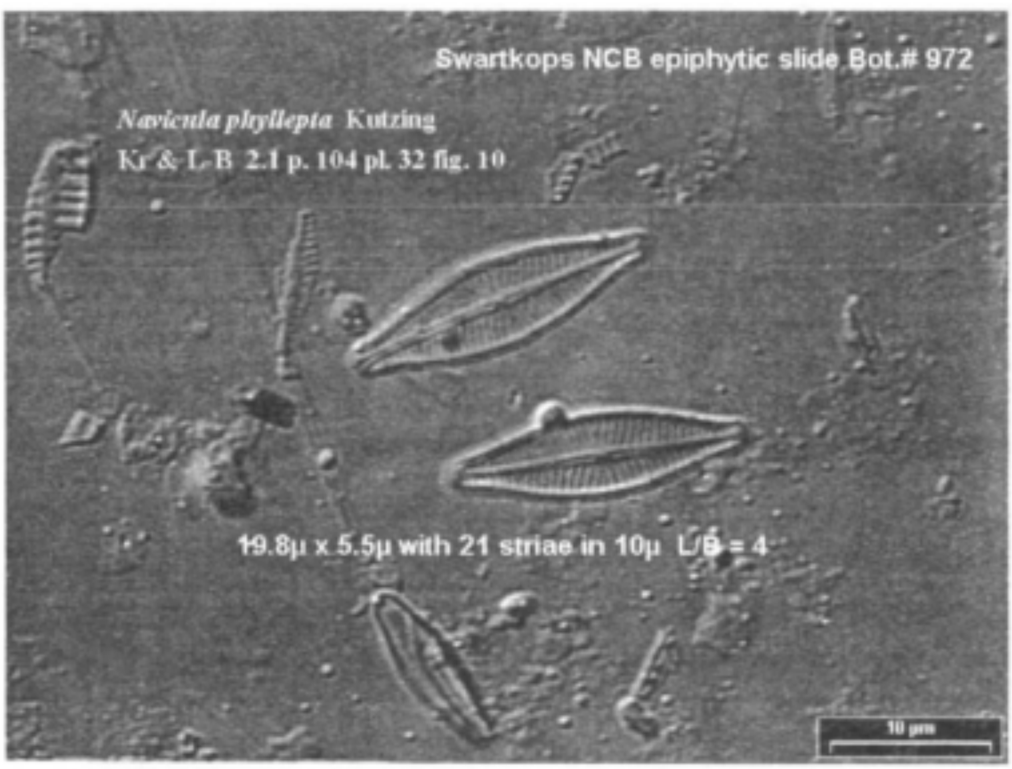
NAVIPERI *Navicula peregrina* Ehrenberg



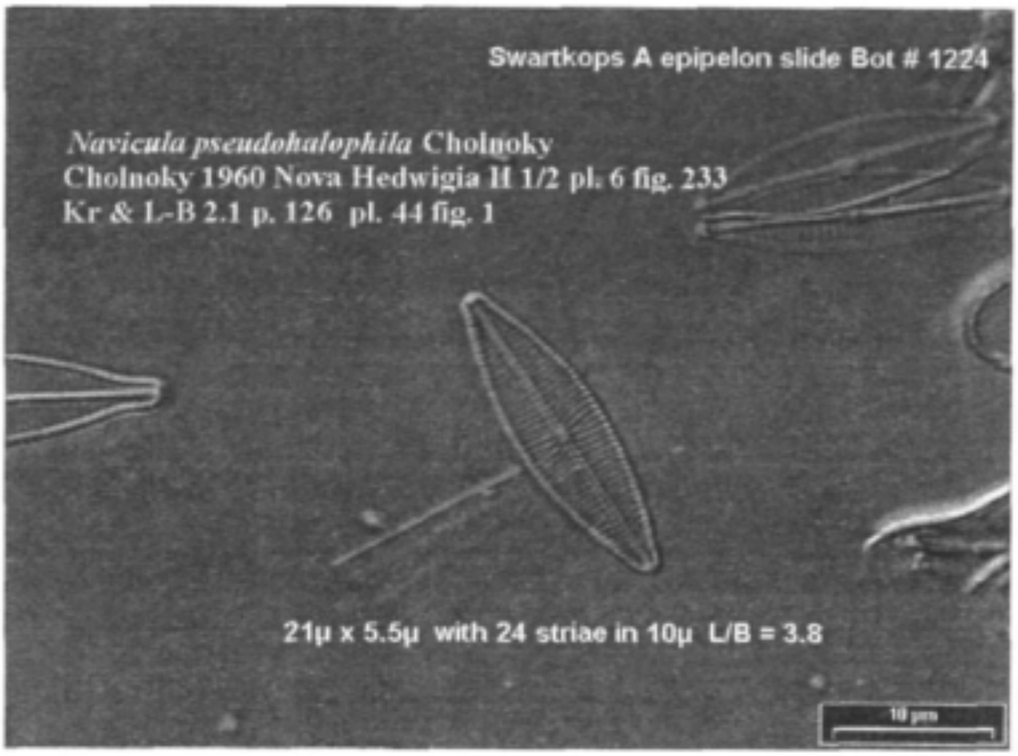
NAVIPERs *Navicula peregrina* var1 Ehrenberg



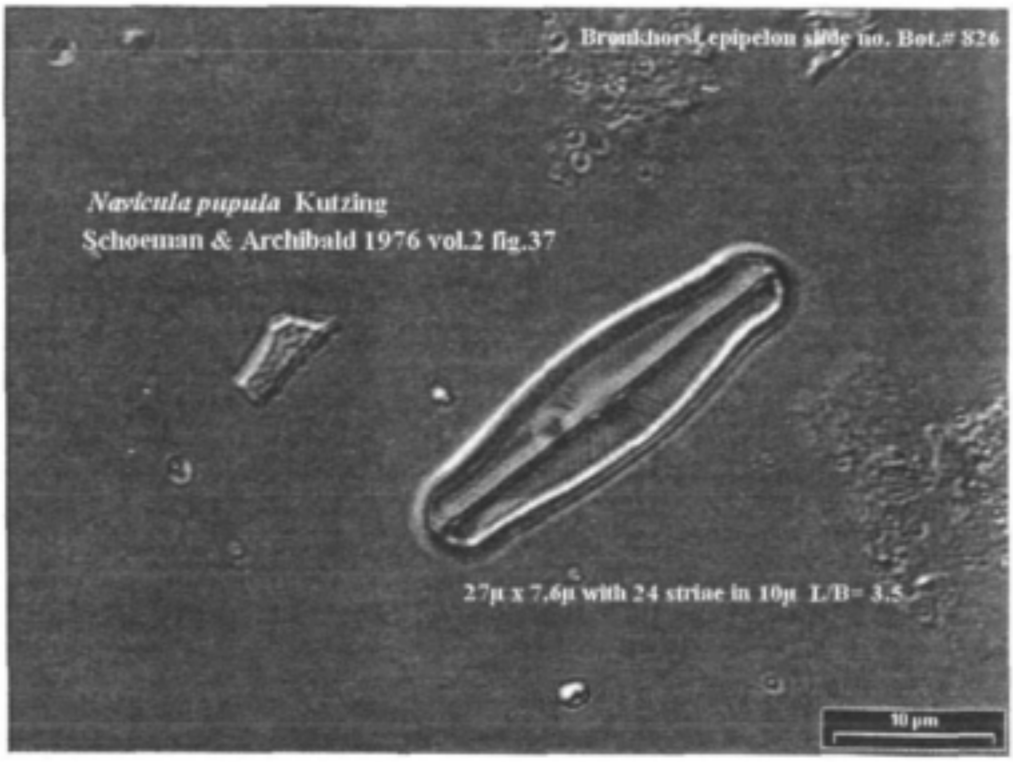
NAVIPERM *Navicula permitis* Hustedt



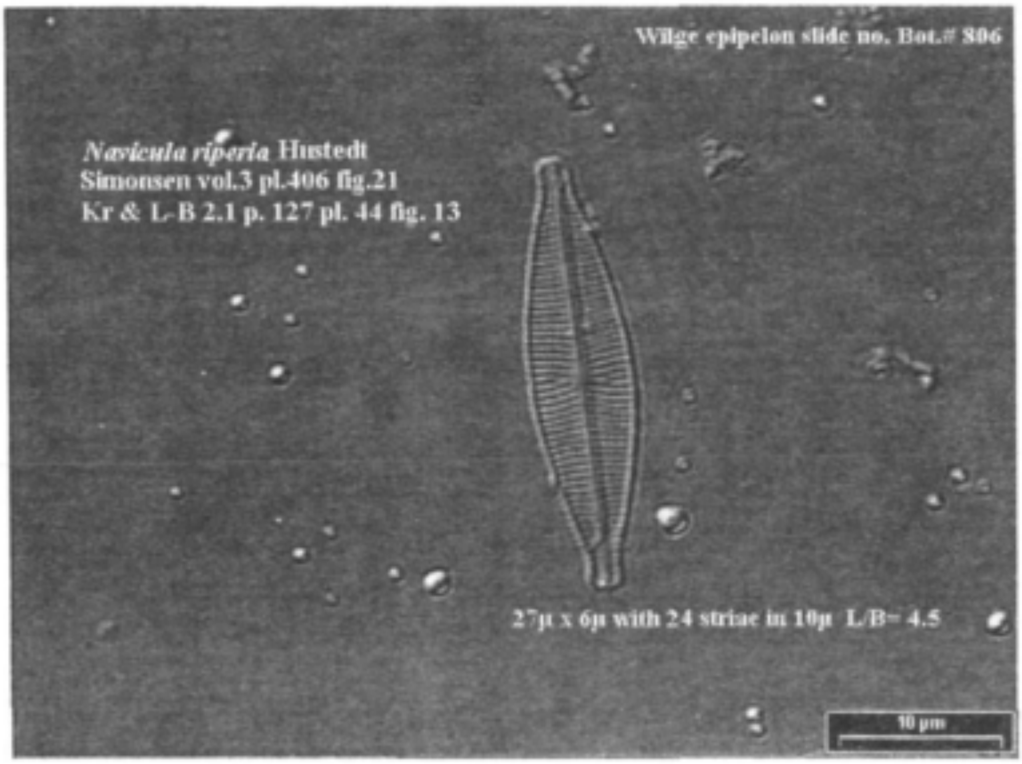
NAVIPHYL *Navicula phyllepta* Kutzing



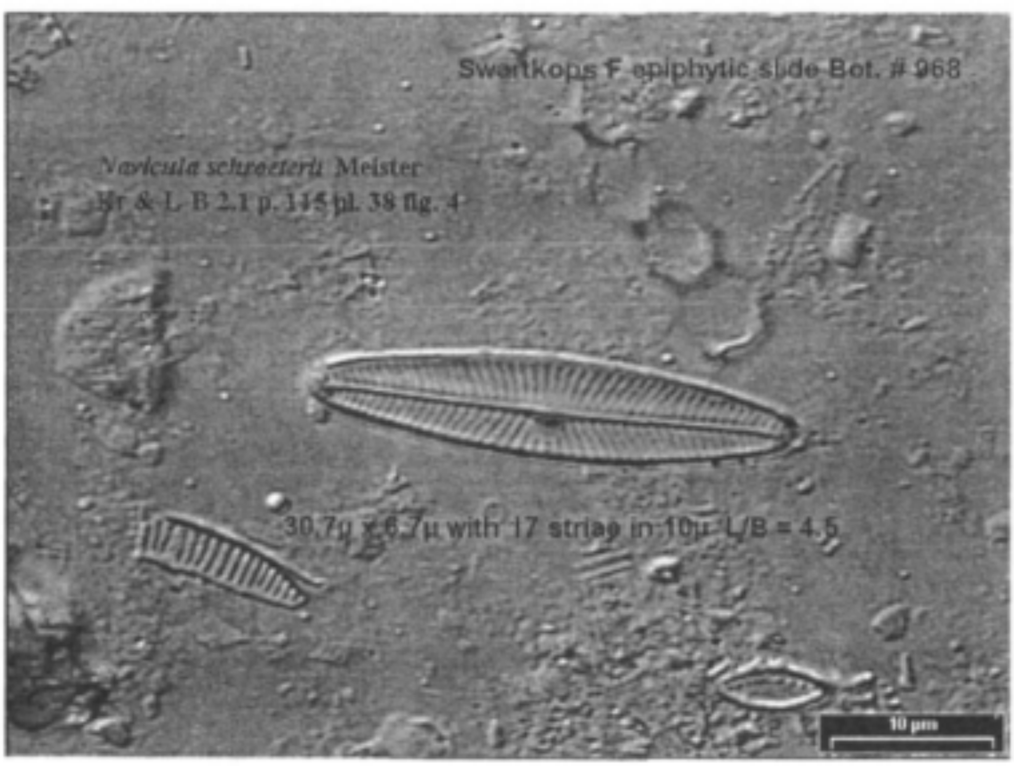
NAVIPSHA *Navicula pseudohalophila* Cholnoky



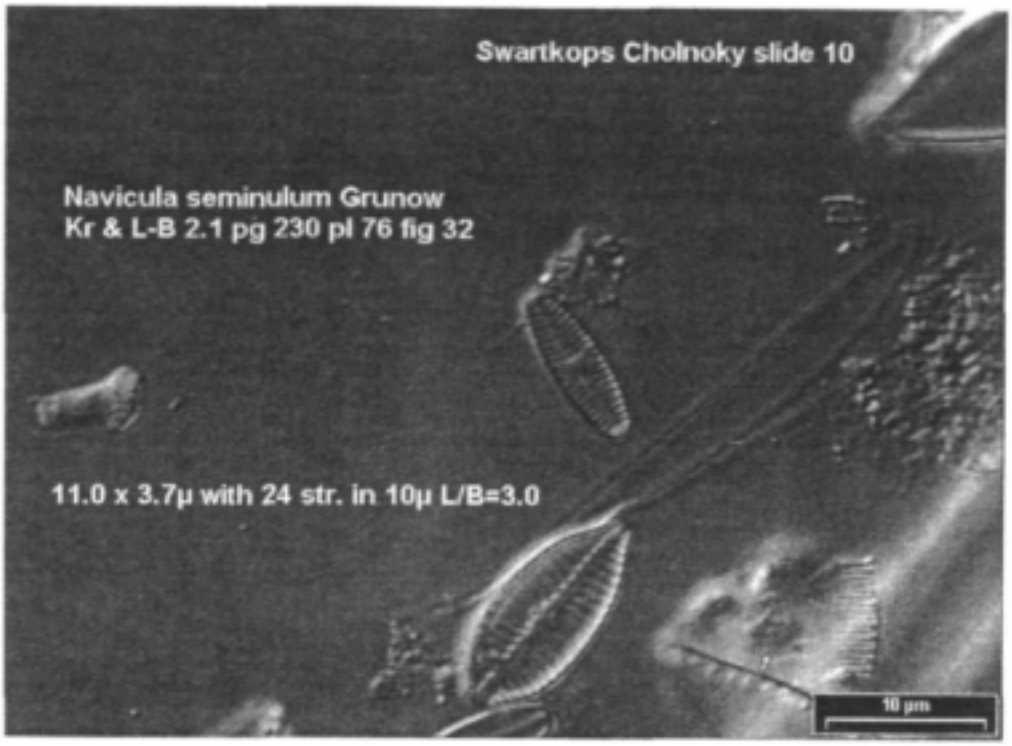
NAVIPUpu *Navicula pupula* var. *pupula* Kutzing (Now Sellaphora pupula var pupula)



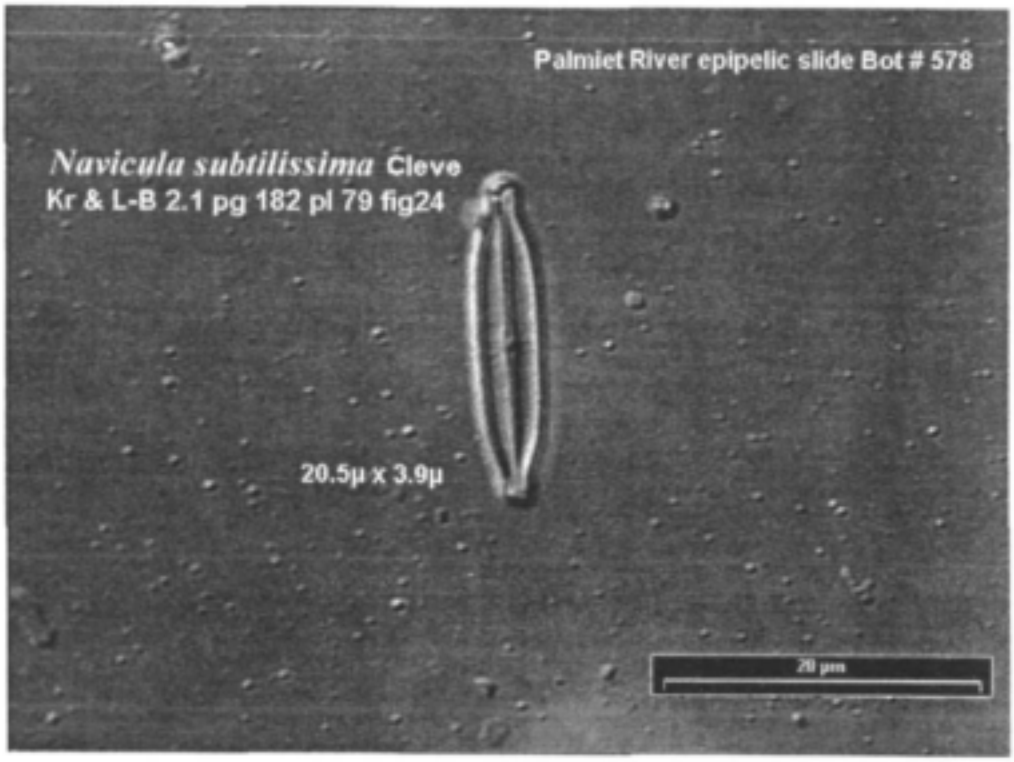
NAVIRIPA ***Navicula riparia*** **Hustedt**



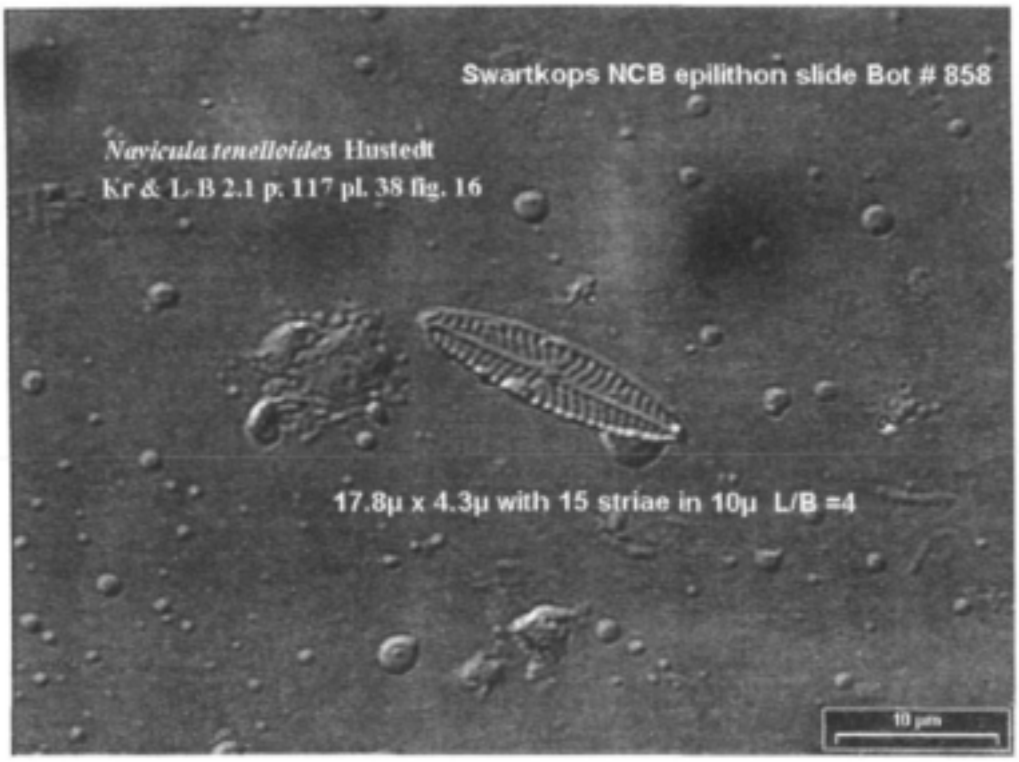
NAVISCHR ***Navicula schroeterii*** **Meister**



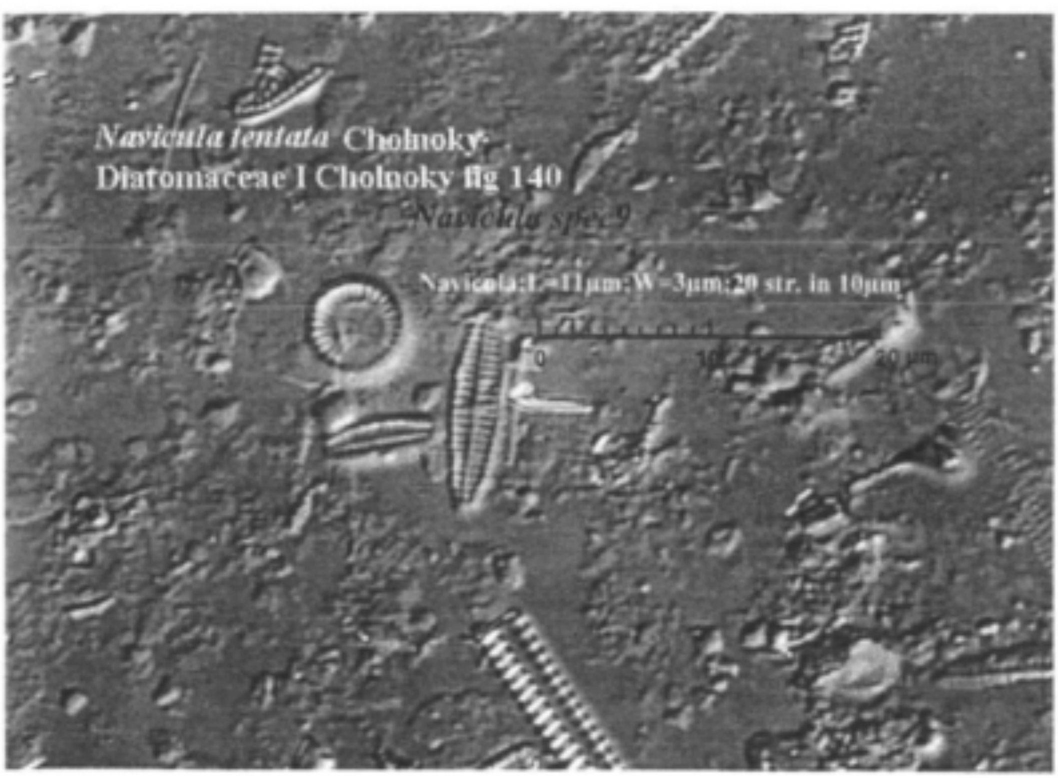
NAVISELU *Navicula seminulum* Grunow



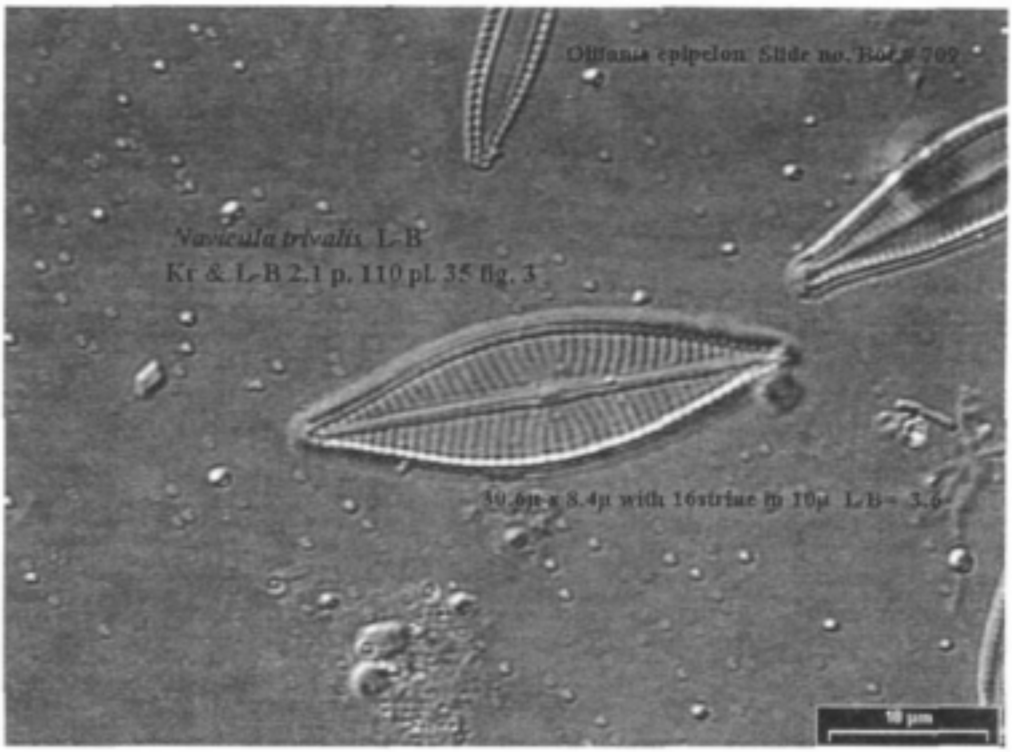
NAVISUTI *Navicula subtilissima* Cleve



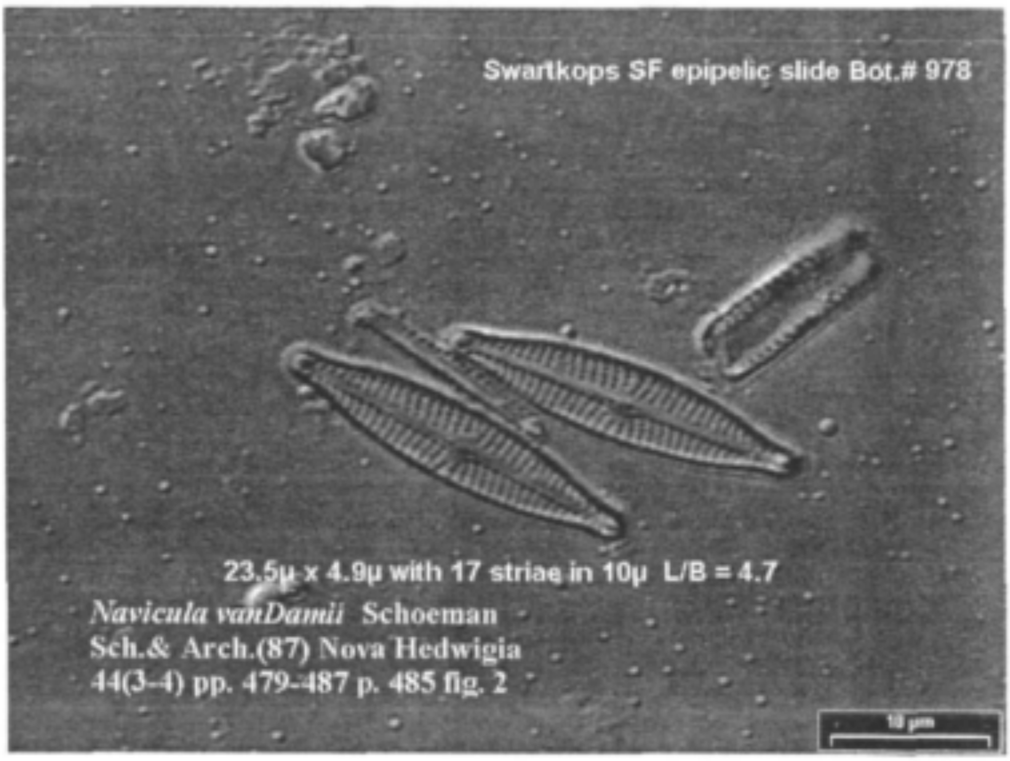
NAVITELO ***Navicula tenelloides*** **Hustedt**



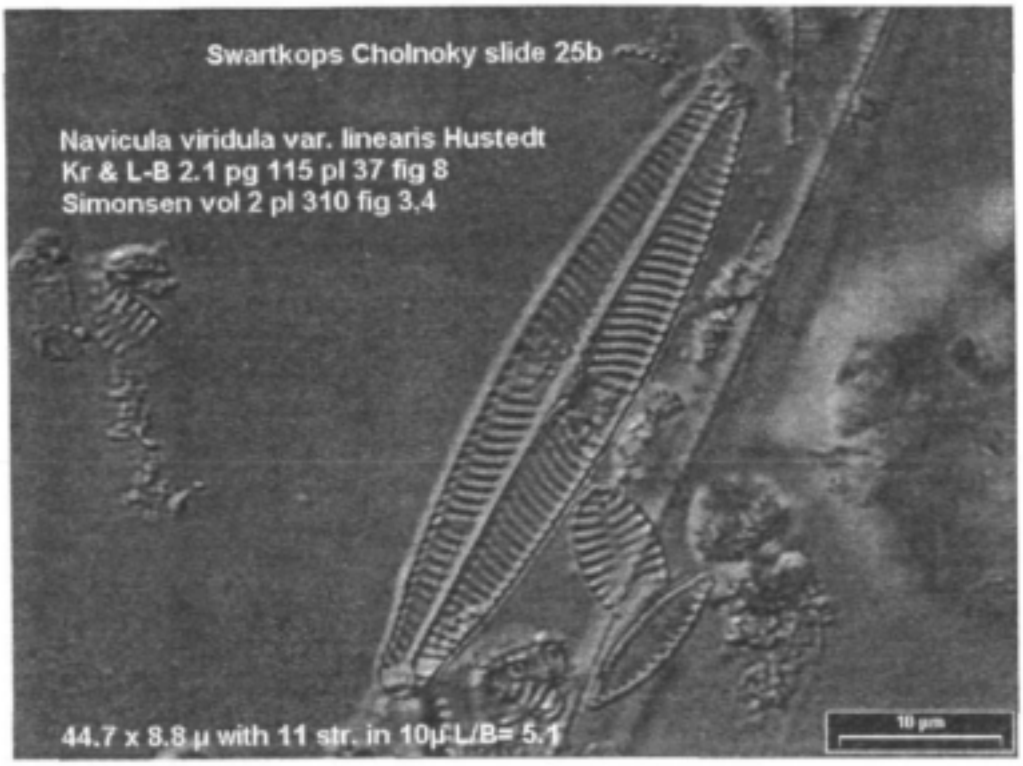
NAVITENT ***Navicula tentata*** **Cholnoky**



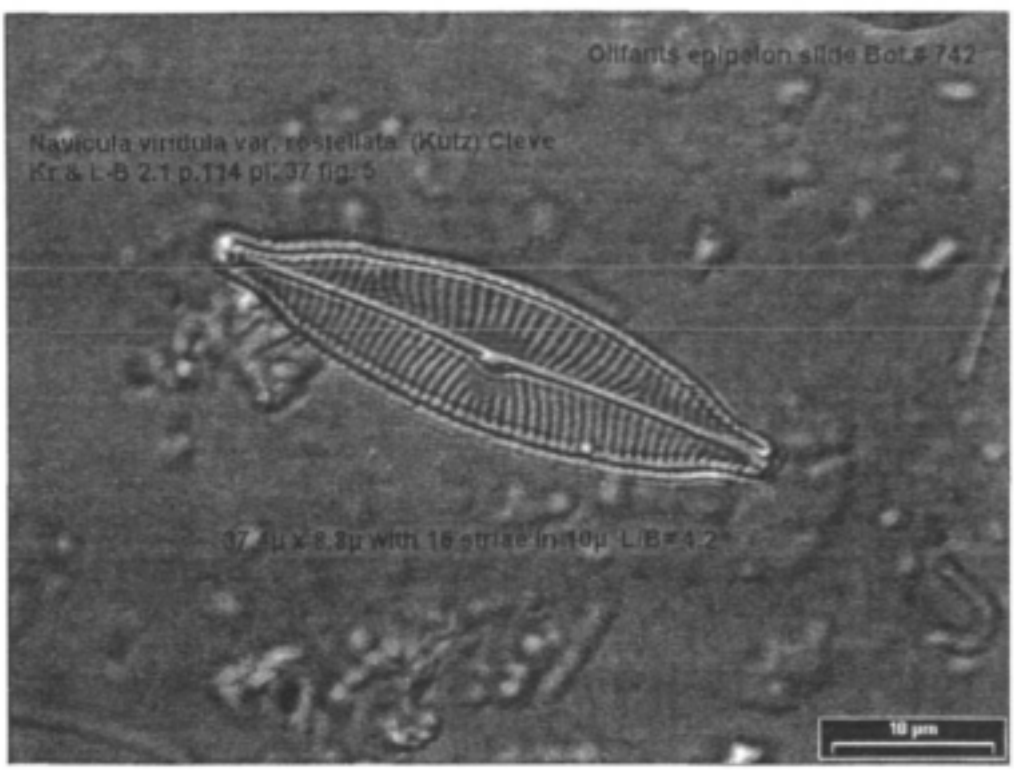
NAVITRIV *Navicula trivialis* Lange-Ber.



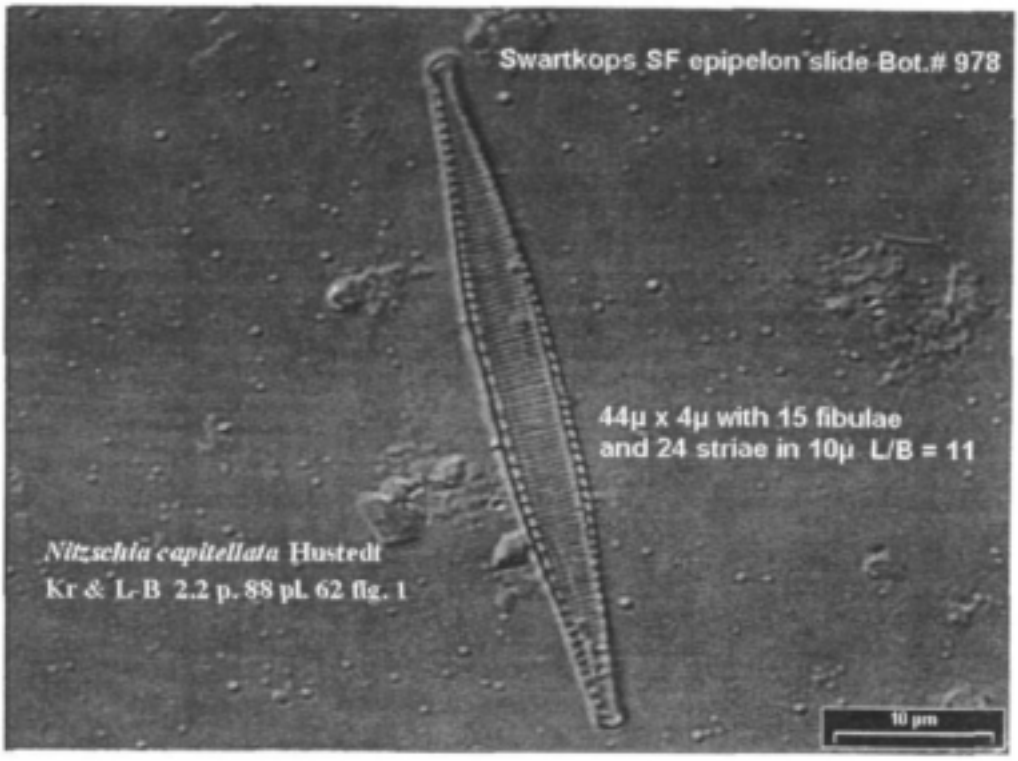
NAVIVAND *Navicula vandamii* Schoeman



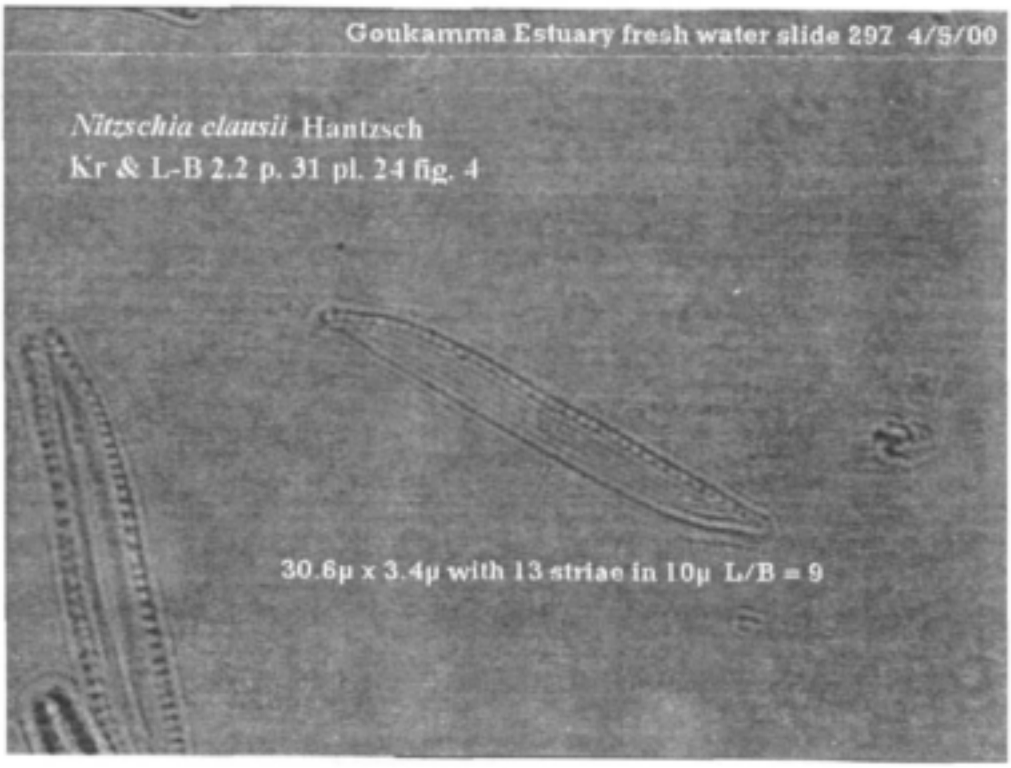
NAVIVIli ***Navicula virudula*** **var** ***linearis*** **Hustedt**



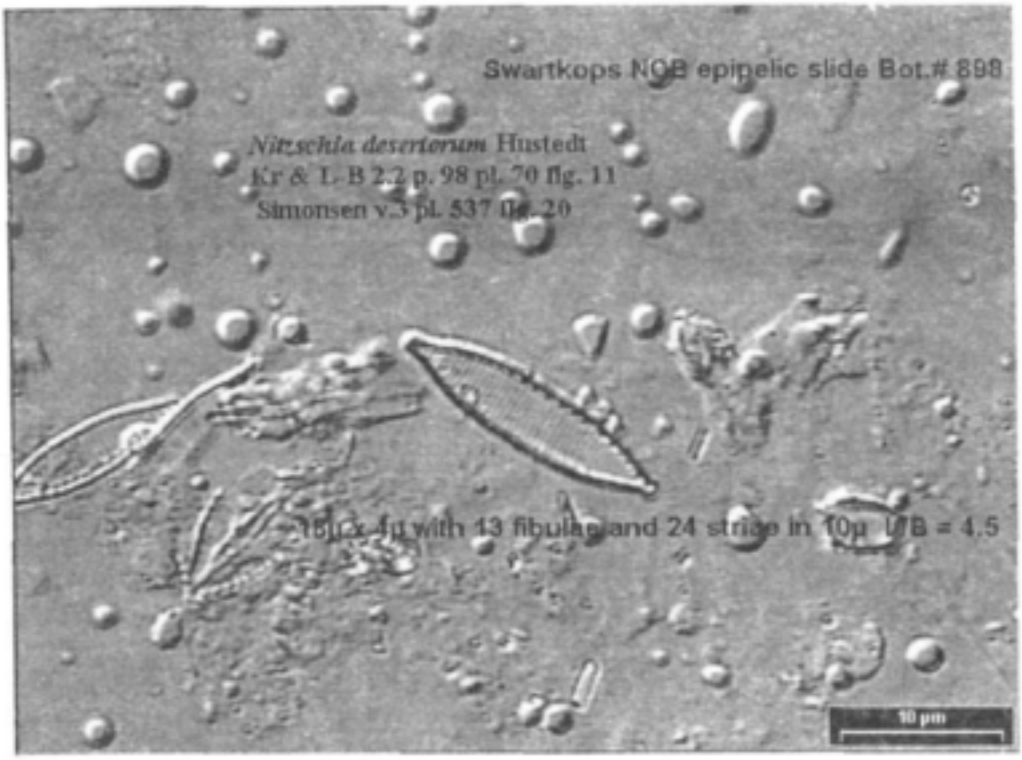
NAVIVIro ***Navicula virudula*** **var** ***rostellata*** **(Kutz) Cleve**



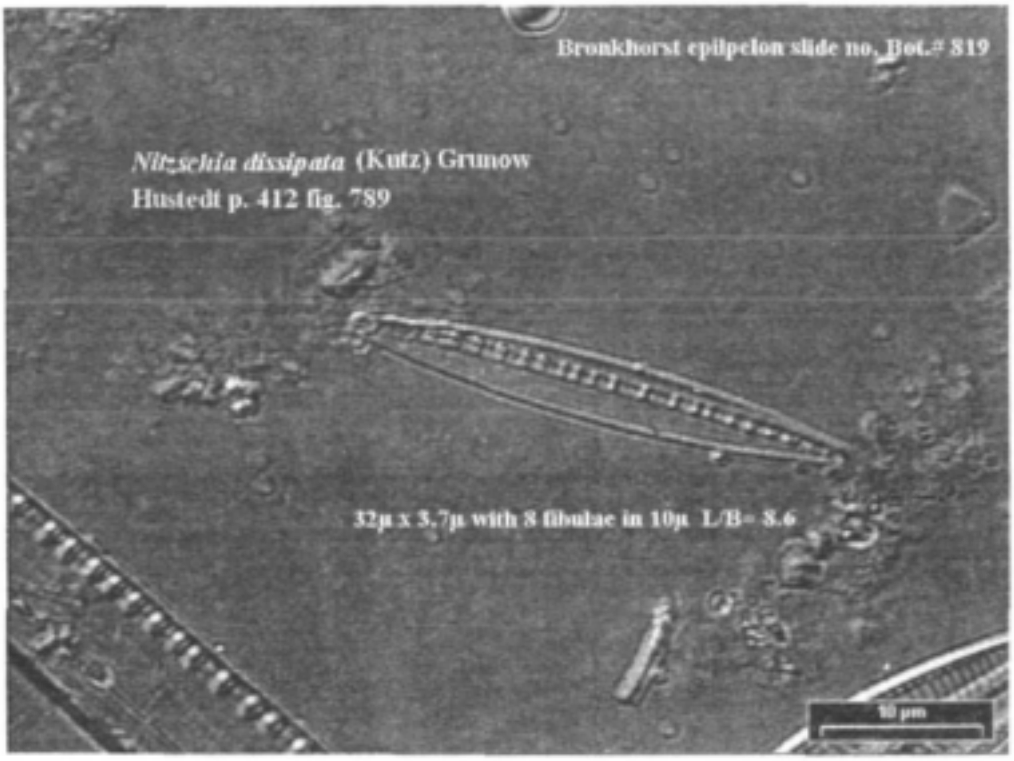
NITZCAPI *Nitzschia capitellata* Hustedt



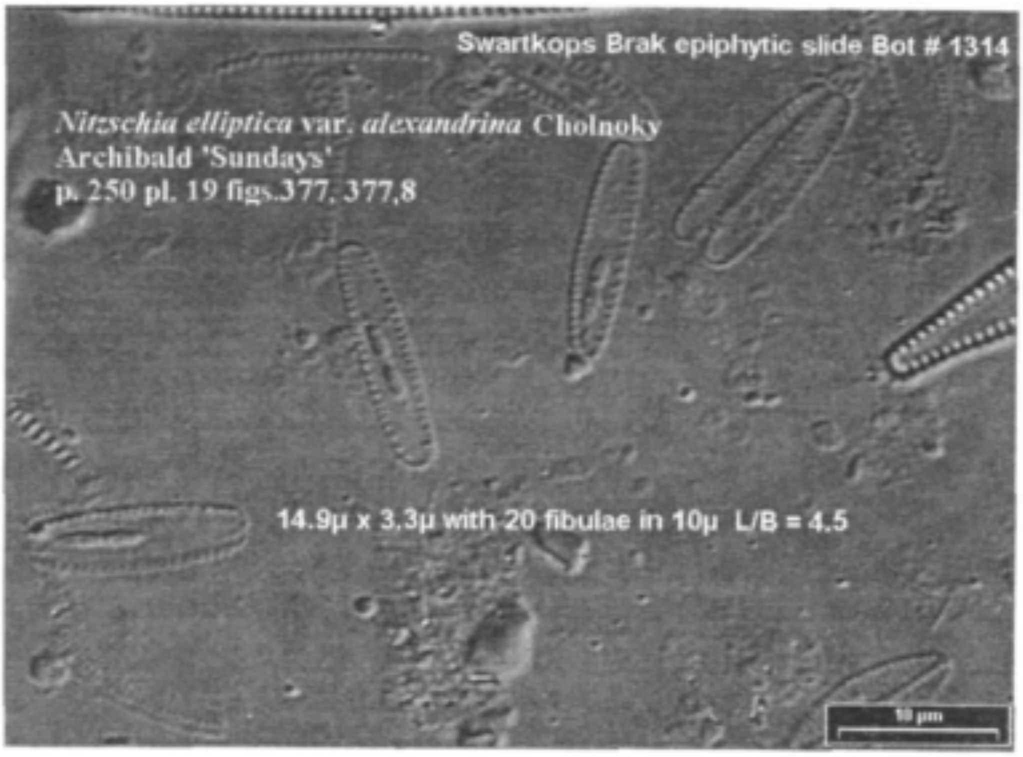
NITZCLAU *Nitzschia clausii* Hantzsch



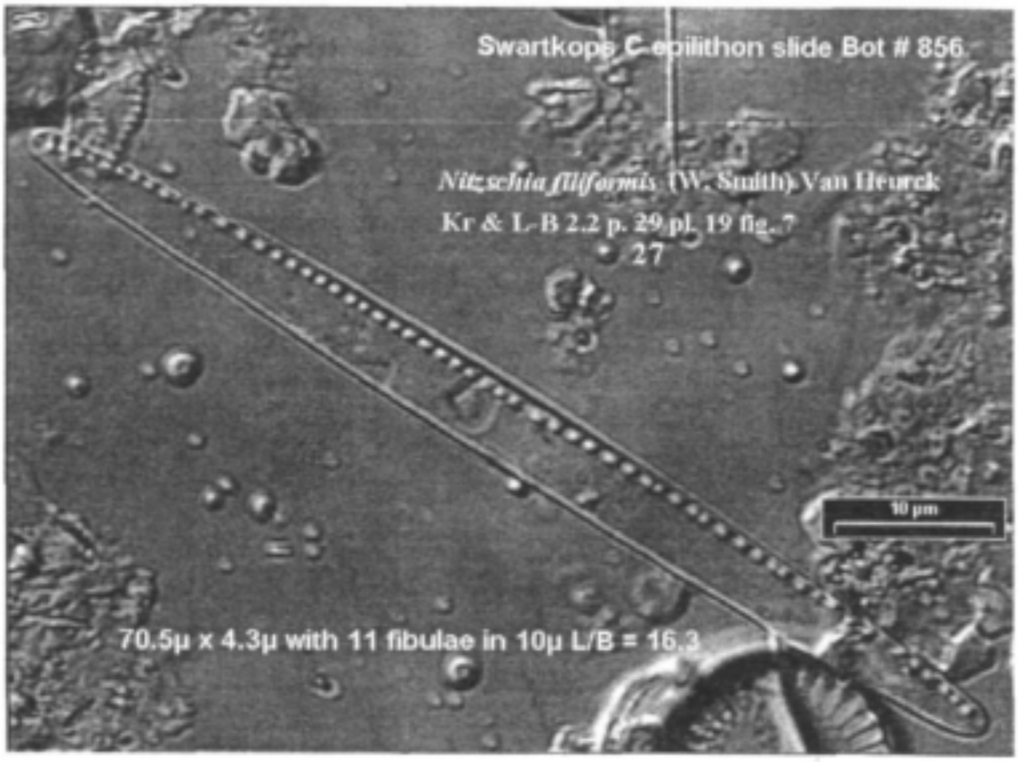
NITZDESE ***Nitzschia desertorum*** **Hustedt**



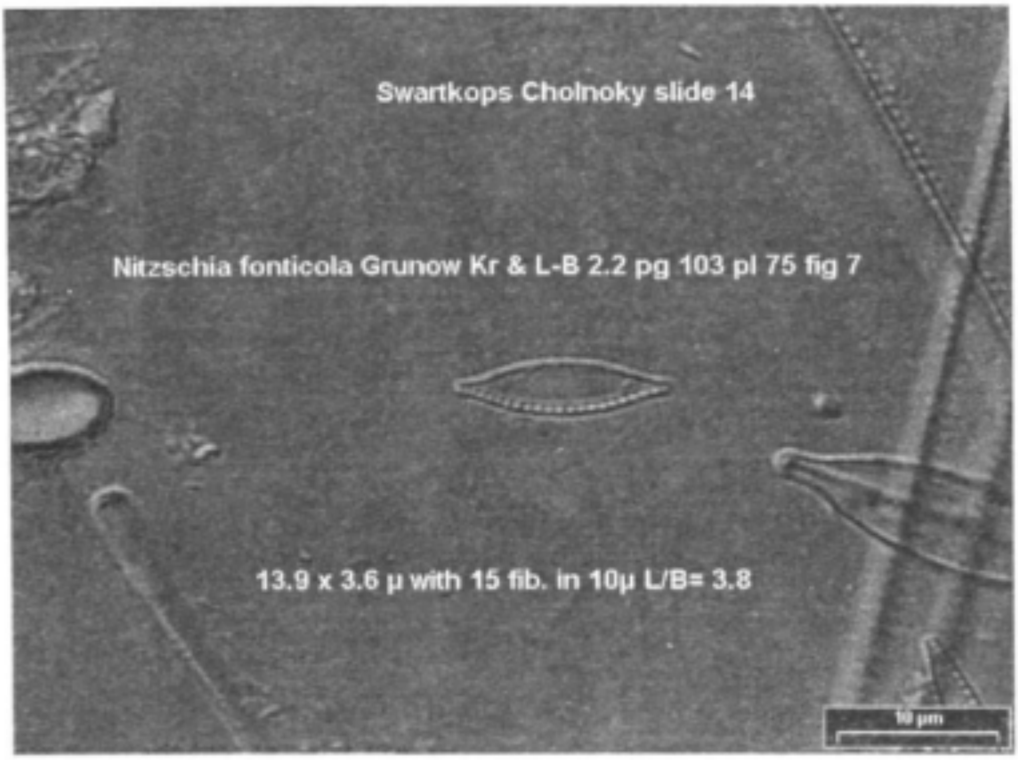
NITZDISS ***Nitzschia dissipata*** **(Kutz) Grunow**



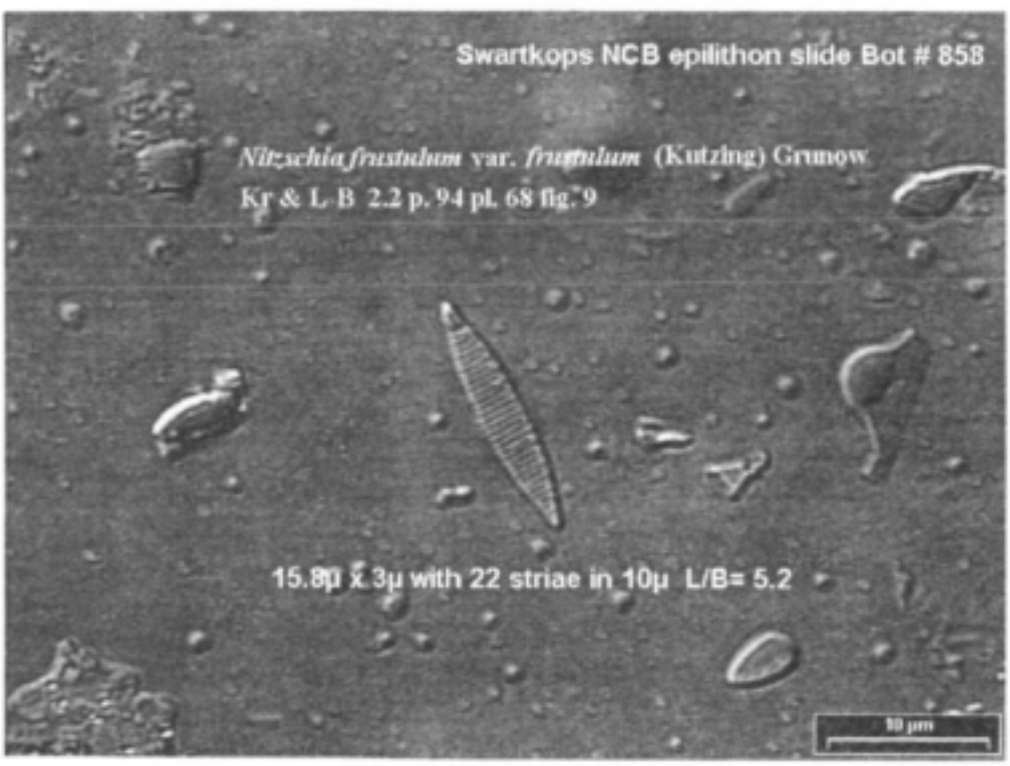
NITZELal *Nitzschia elliptica* var. *alexandrina* Cholnoky



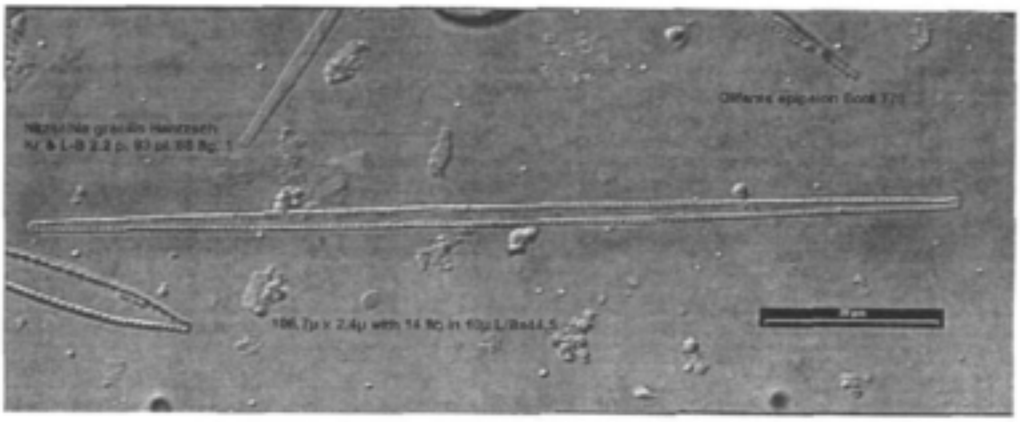
NITZFILI *Nitzschia filiformis* (W Smith) VanHeurck



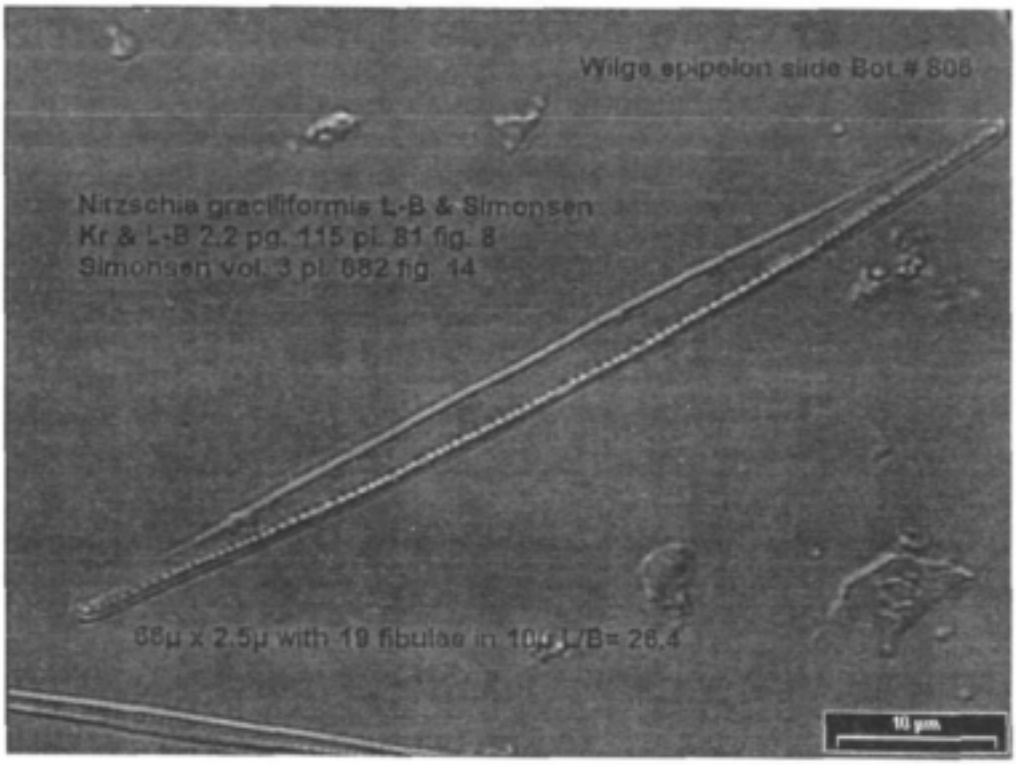
NITZFONT *Nitzschia fonticola* Grunow



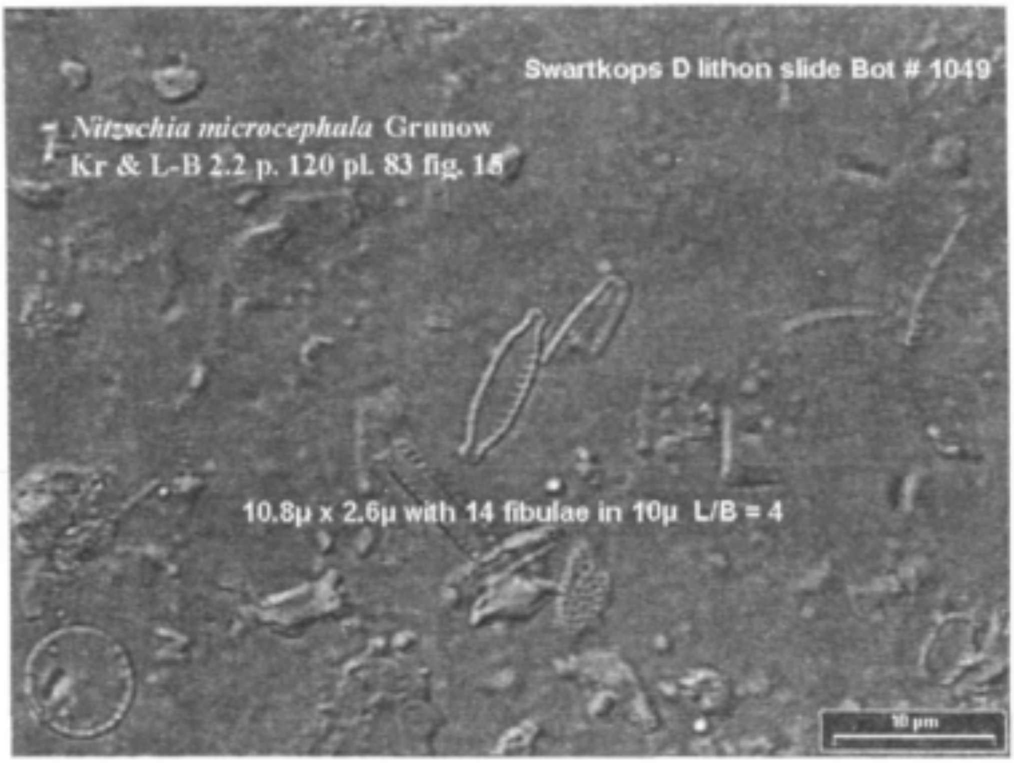
NITZFRUS *Nitzschia frustulum* var. *frustulum* (Kutzing) Grunow



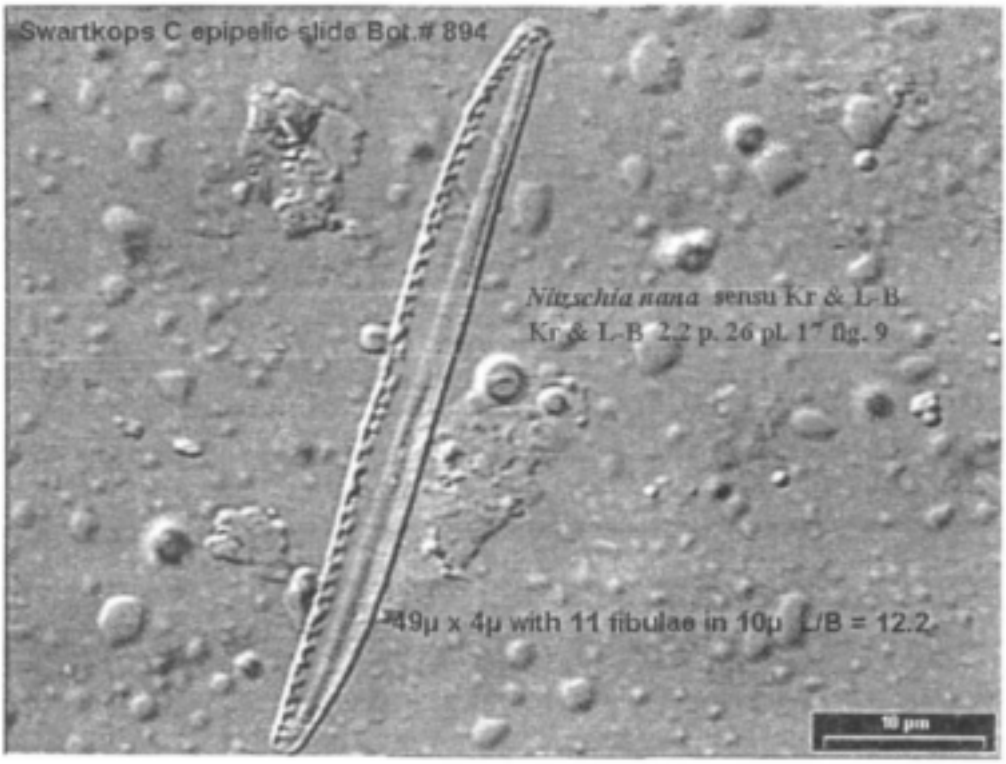
NITZGRAC *Nitzschia gracilis* Hantzsch



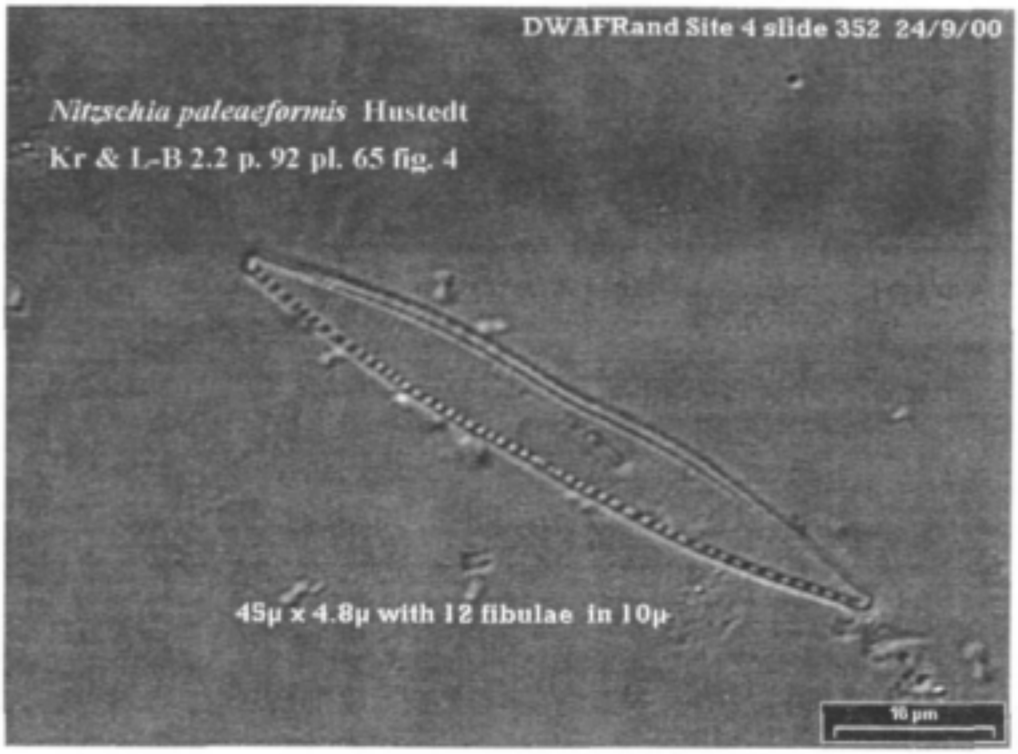
NITZGRAF *Nitzschia graciliformis* L-B & Simonsen



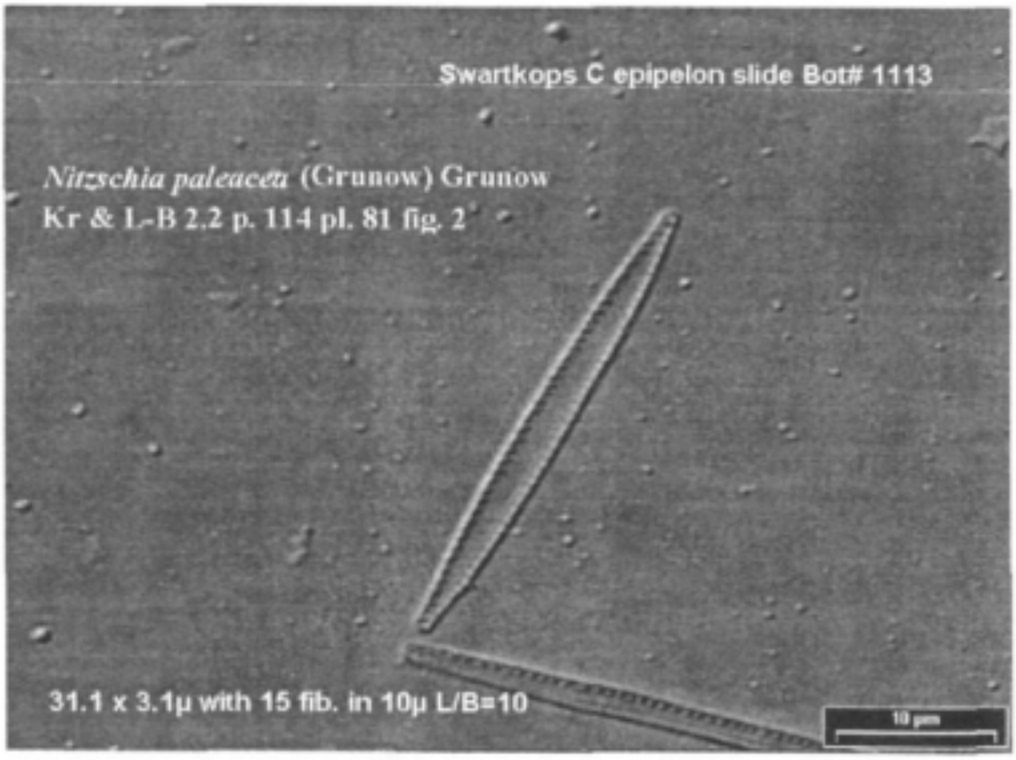
NITZMICE *Nitzschia microcephala* Grunow



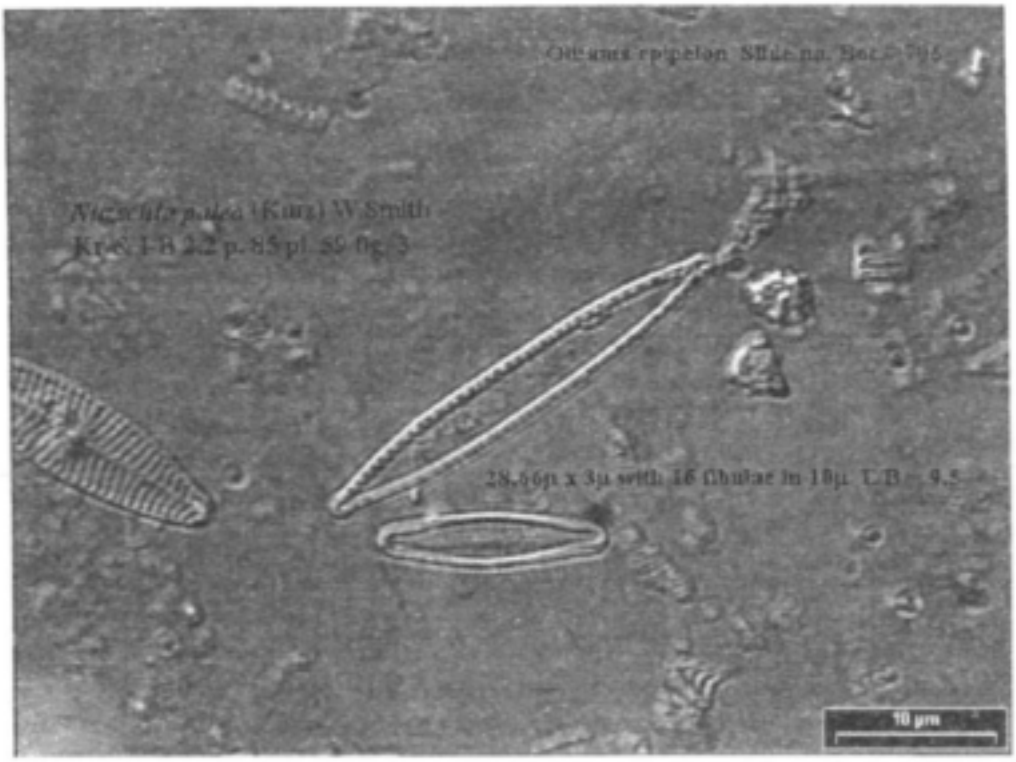
NITZNANA *Nitzschia nana* Grunow (sensu Kr & L-B)



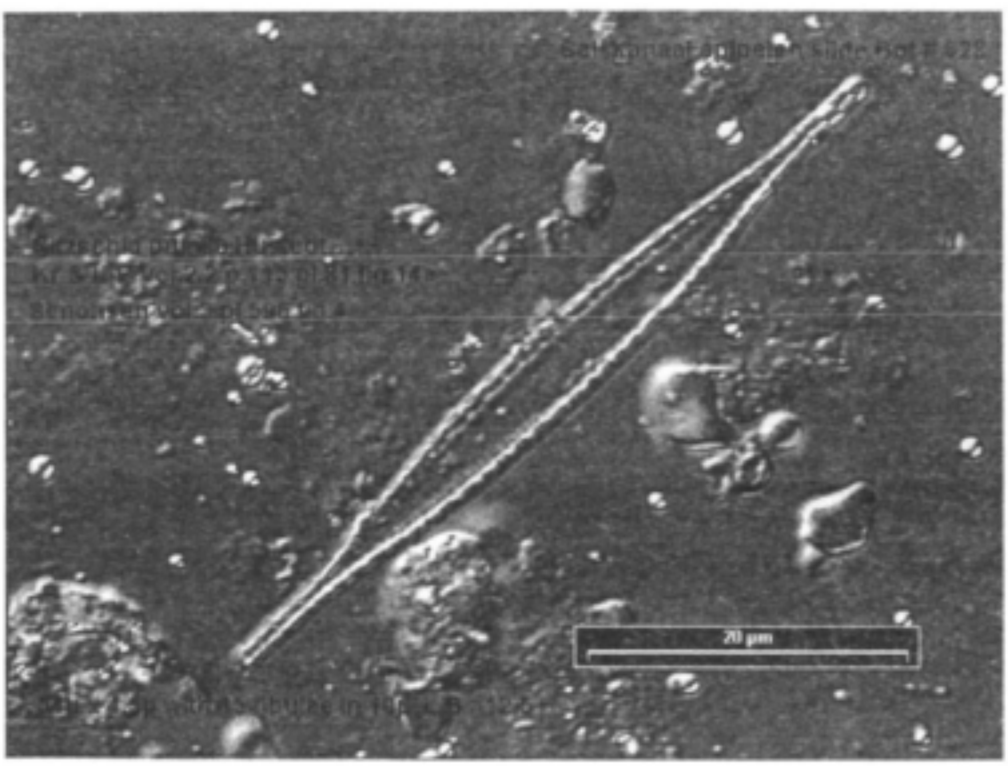
NITZPAAE *Nitzschia paleaeformis* Hustedt



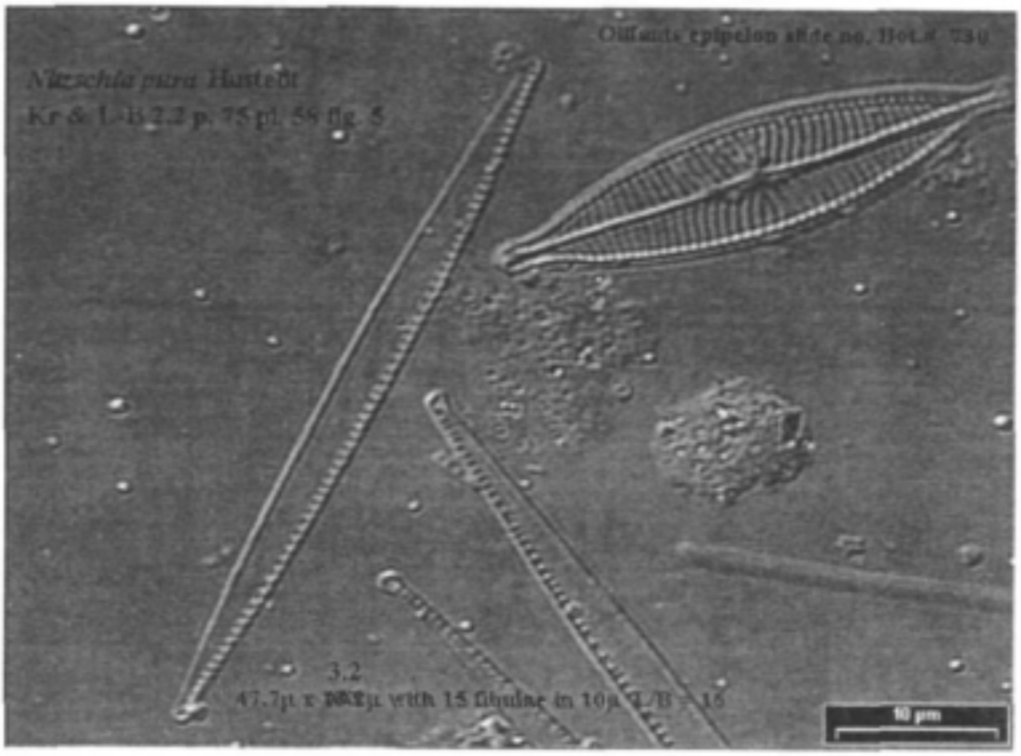
NITZPACE *Nitzschia paleacea* (Grunow) Grunow



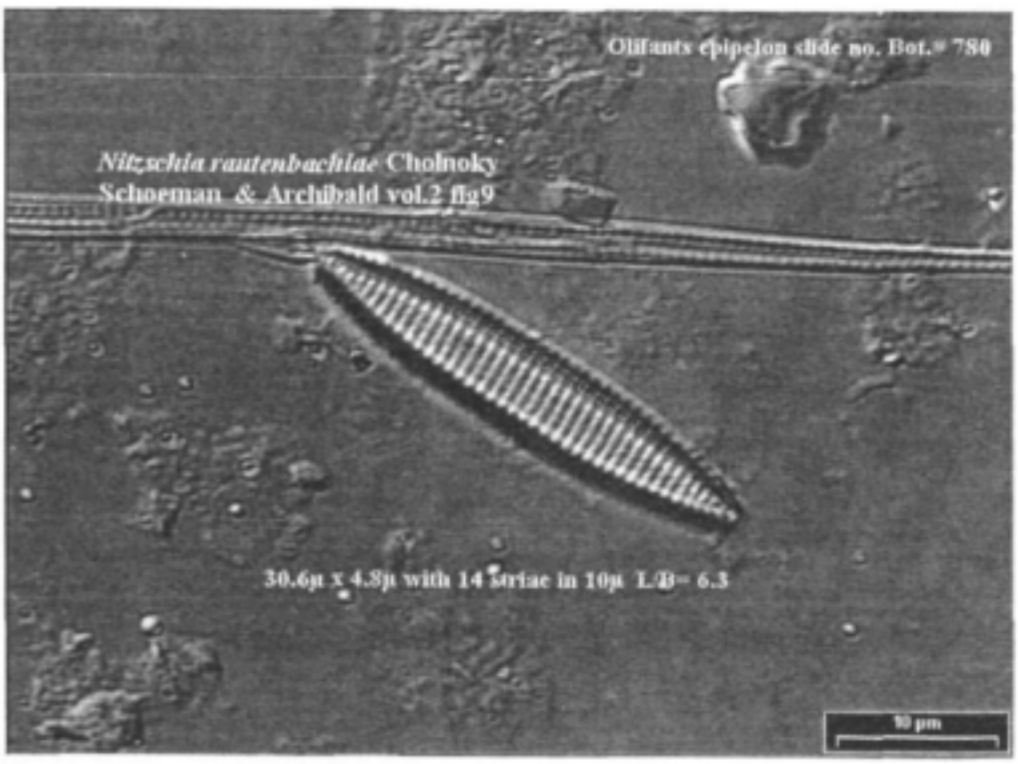
NITZPALE *Nitzschia palea* (Kutzing) W. Smith



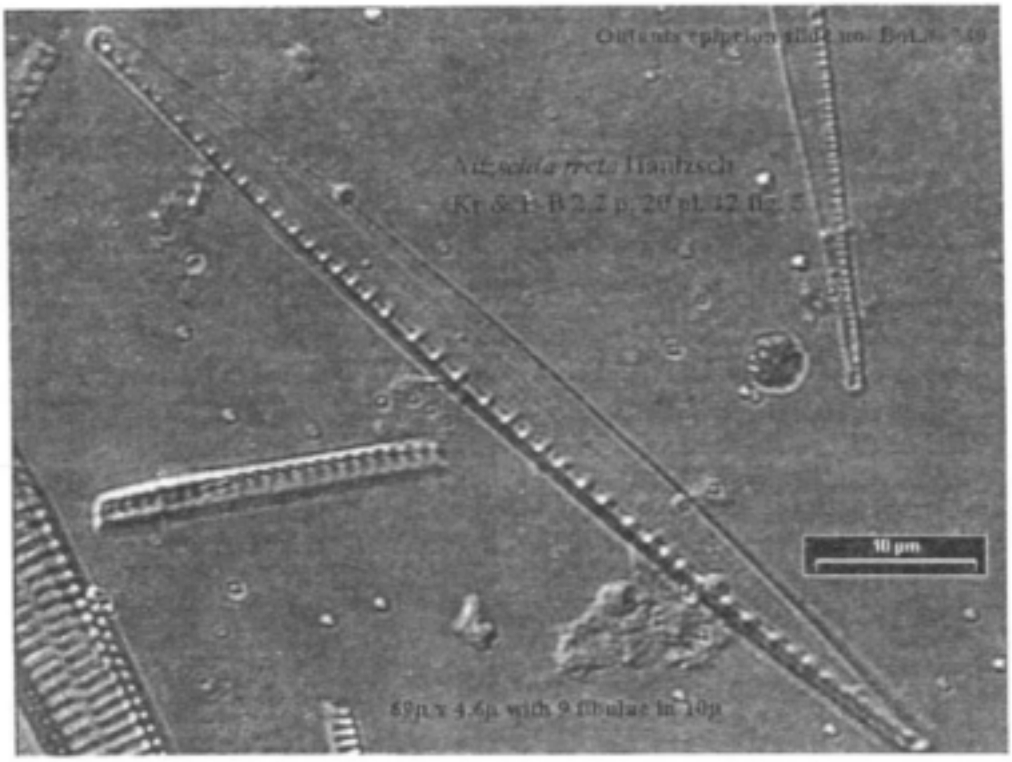
NITZPUMI *Nitzschia pumila* Hustedt



NITZPURA ***Nitzschia pura*** **Hustedt**

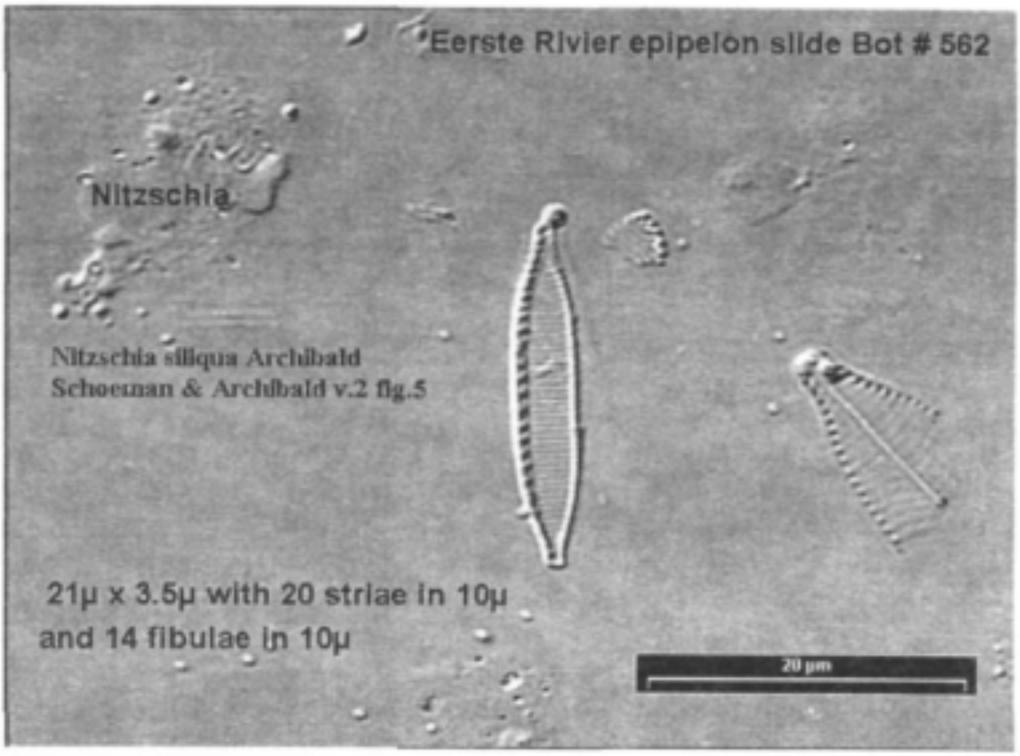


NITZRAUT ***Nitzschia rautenbachii*** **Cholnoky**

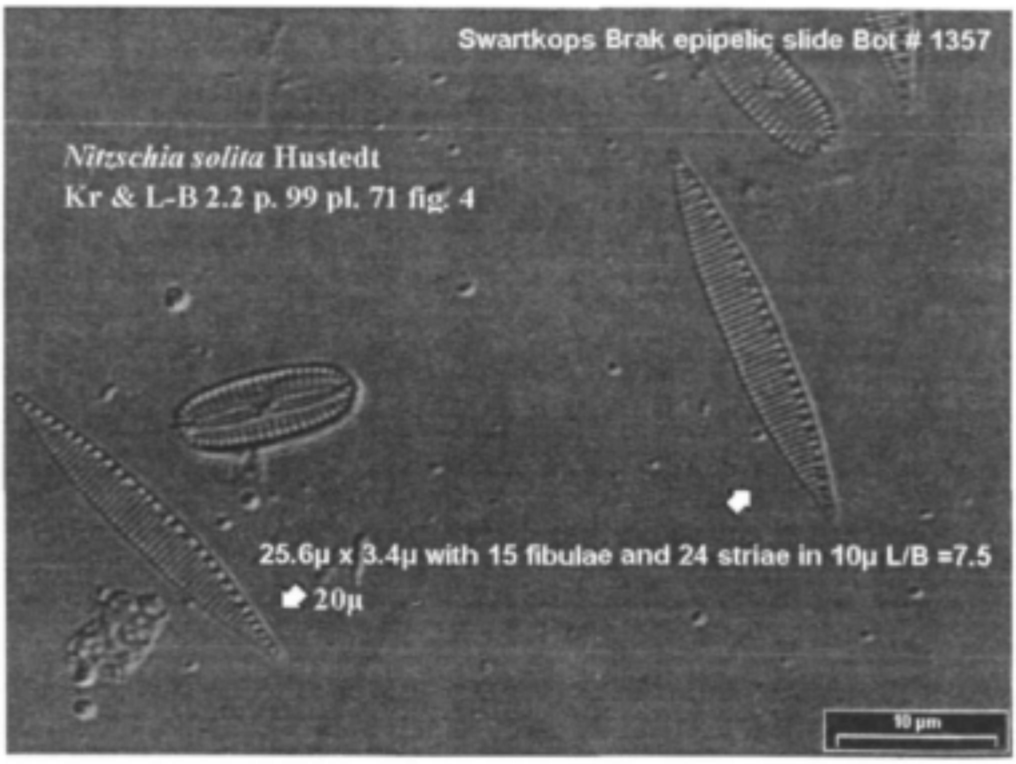


NITZRECT *Nitzschia recta* Hantzsch

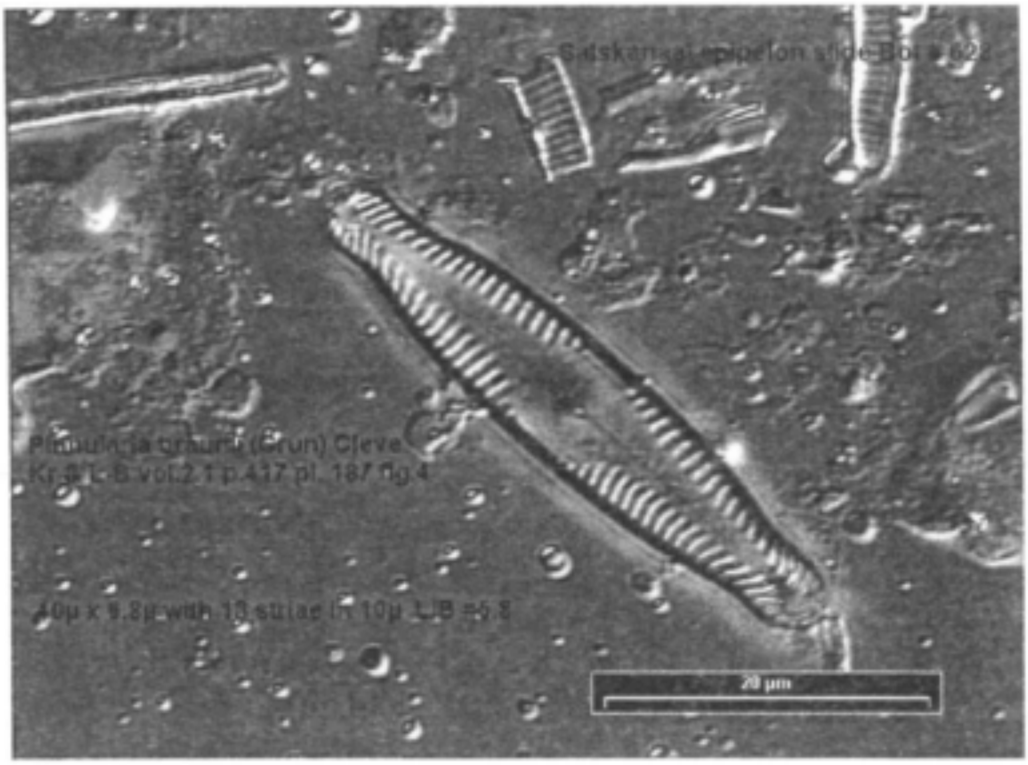
NITZSIGM *Nitzschia sigma* (kutzing) W. Smith



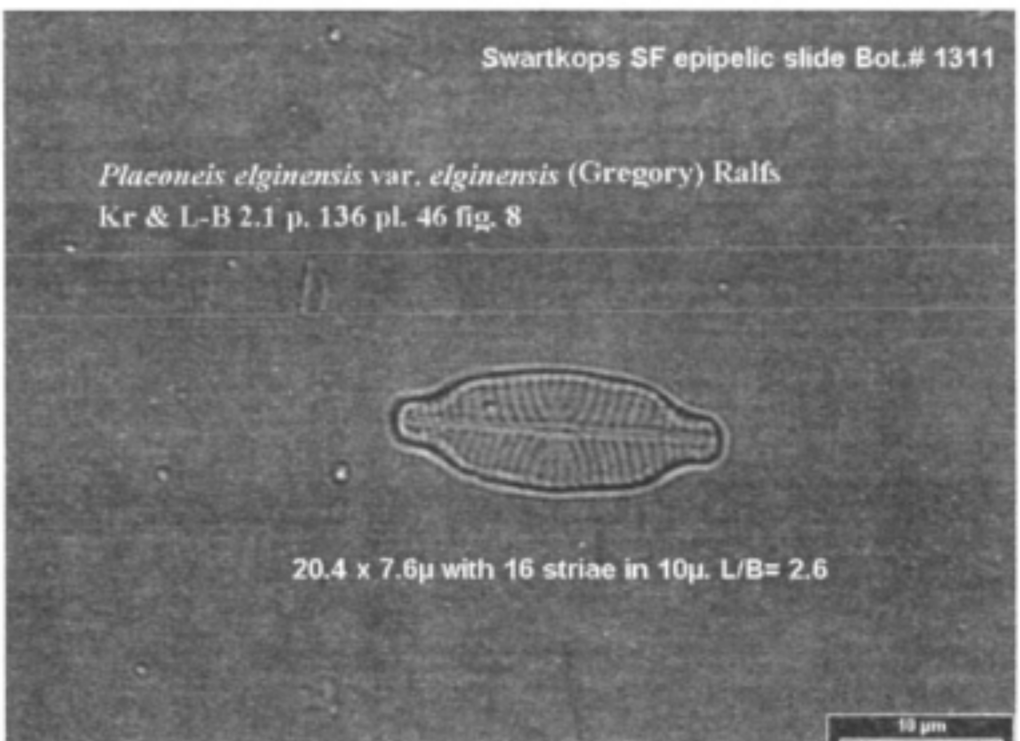
NITZSILI *Nitzschia siliqua* Archibald



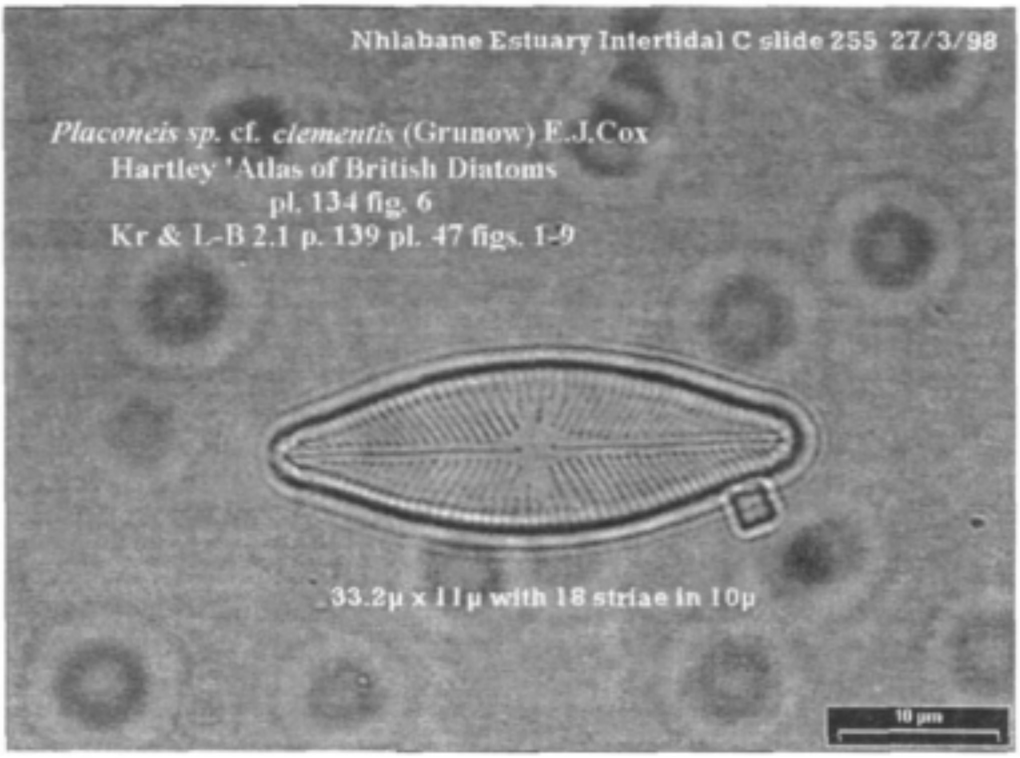
NITZSOLI *Nitzschia solita* Hustedt



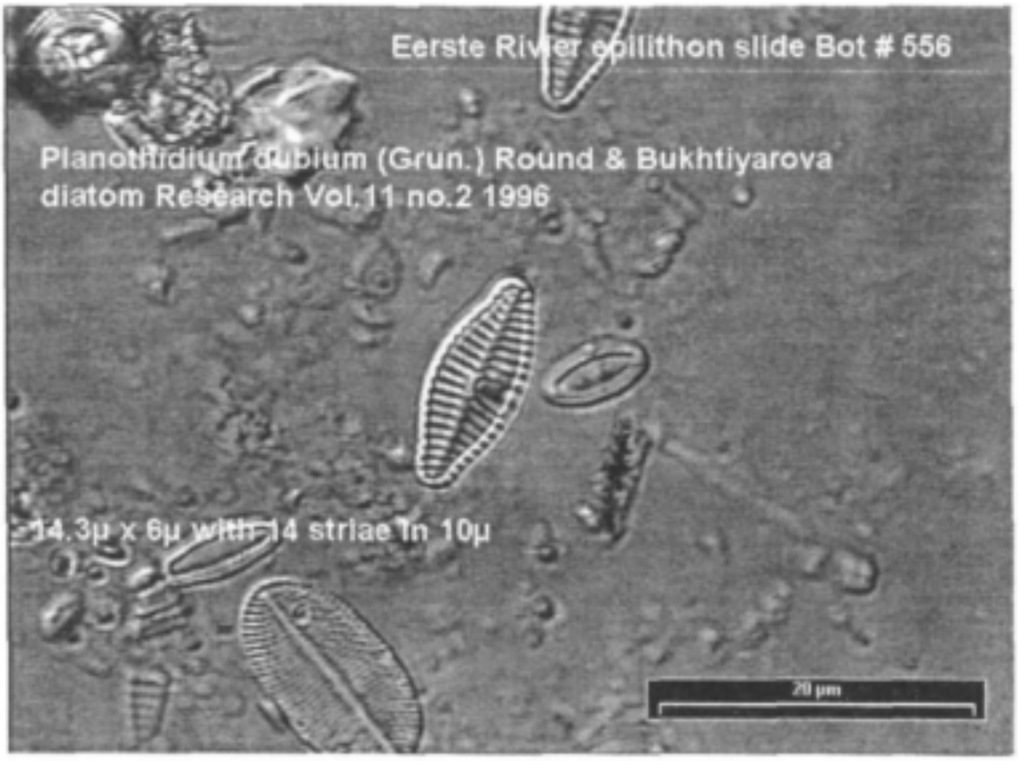
PINNBRAU ***Pinnularia braunii*** **(Grun) Cleve**



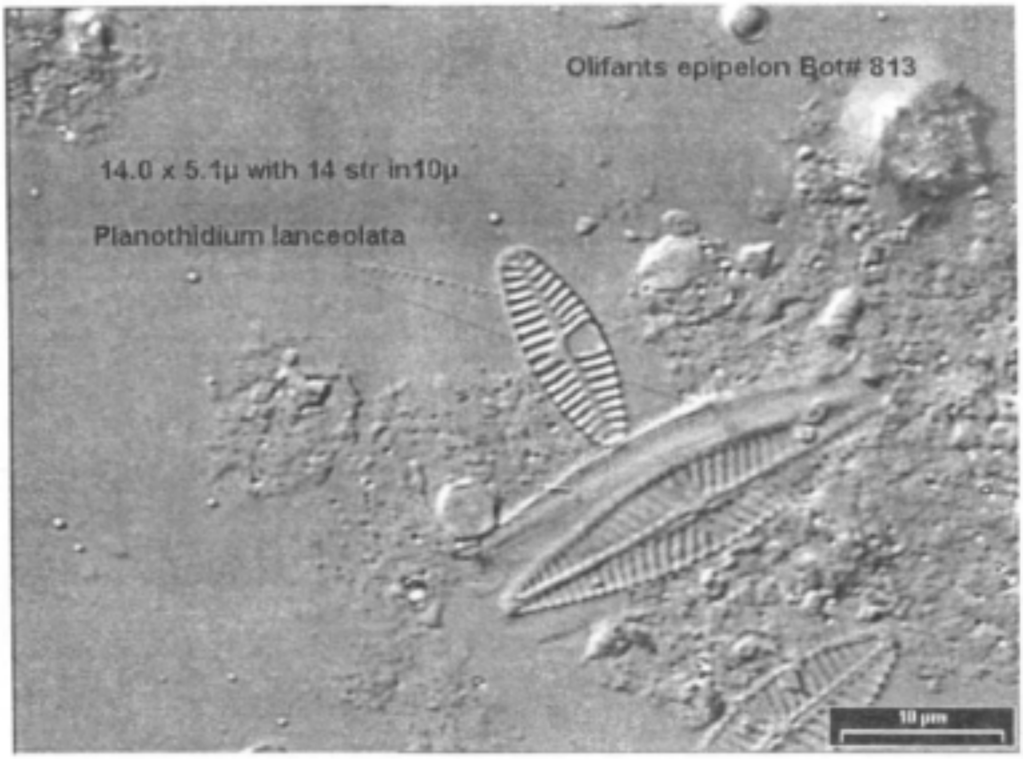
PLACELGI ***Placoneis elginensis*** **var.** ***elginensis*** **(Gregory) Mereschkowsky**



PLACSP01 ***Placoneis*** **spec1**

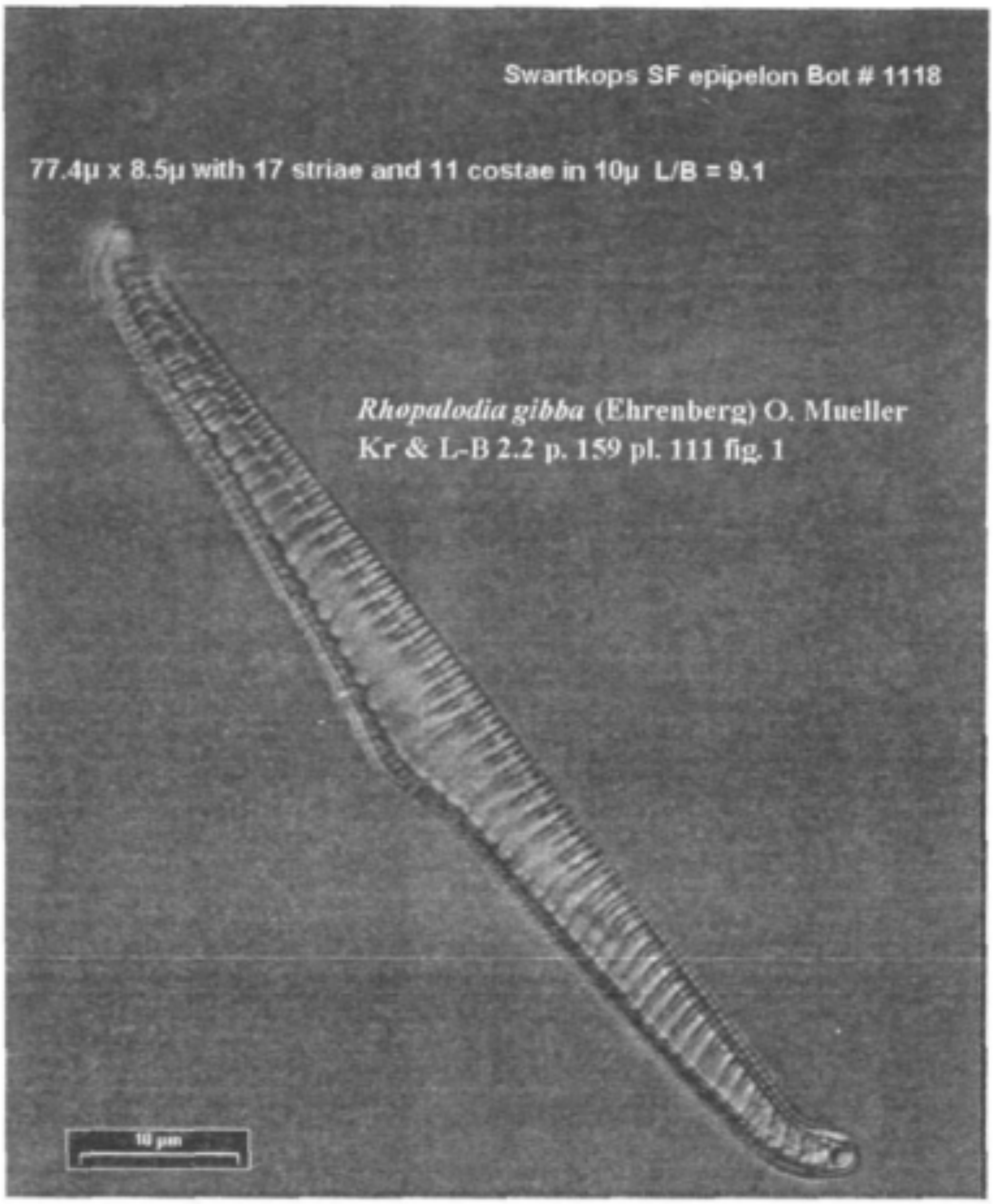


PLANDUBI ***Planothidium dubium*****(Grun) Round & Bukh.**

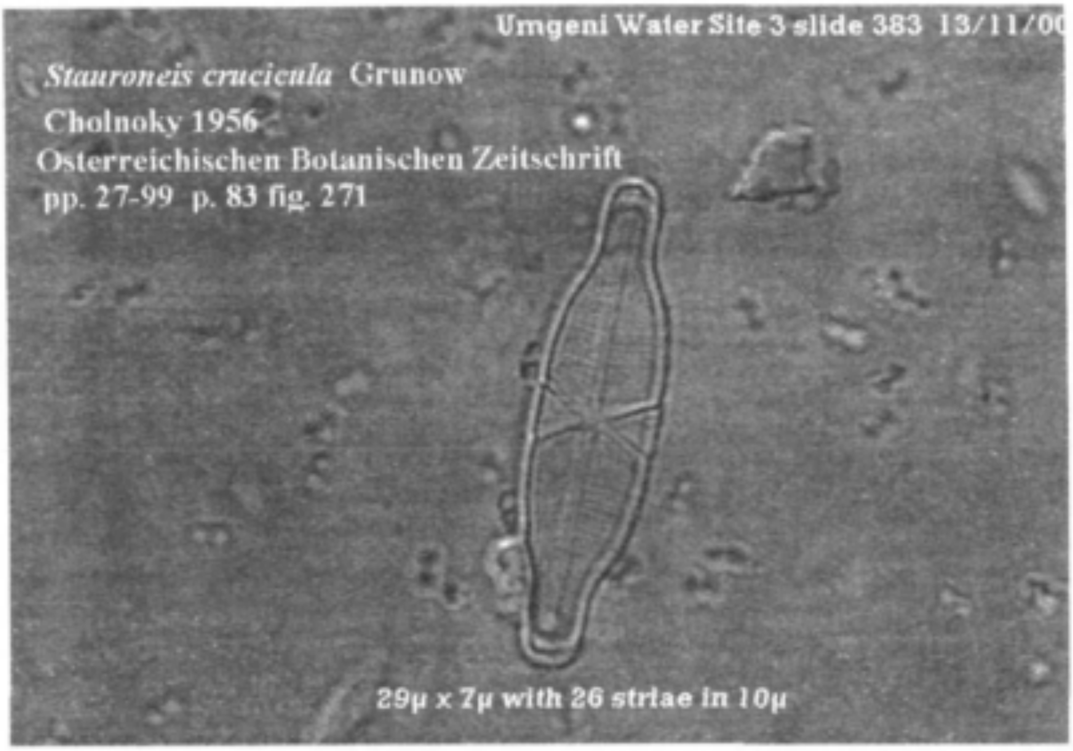


PLANLANC ***Planothidium lanceolatum*** **(Breb) Round & Bukh.**

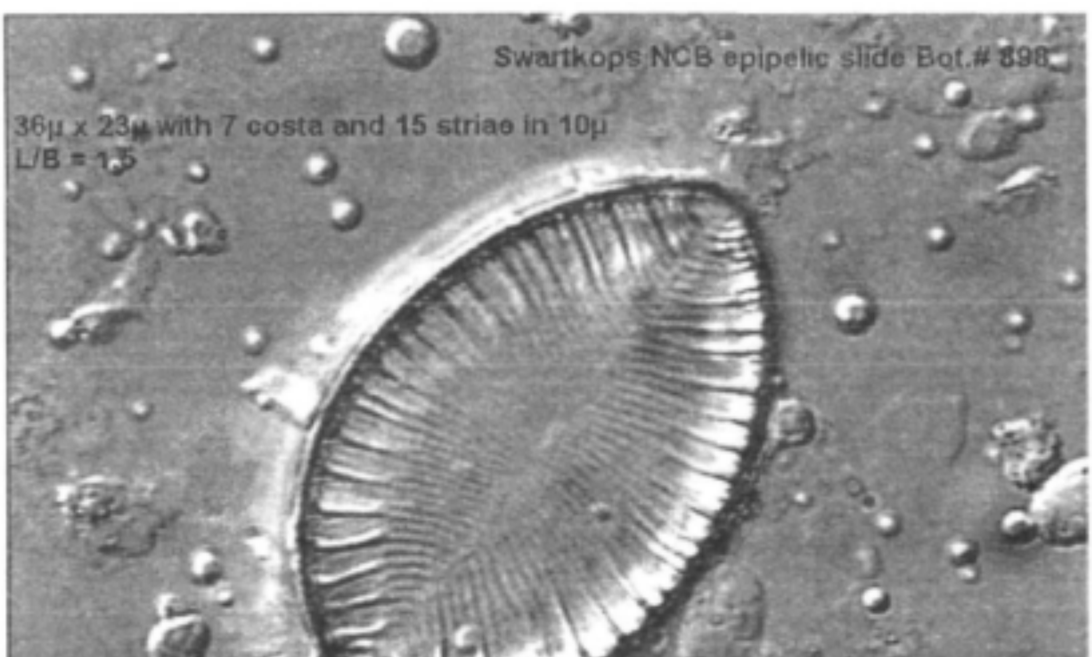
PLMAACUM ***Pleurosigma acuminatum*** **(Kutz) Raben.**



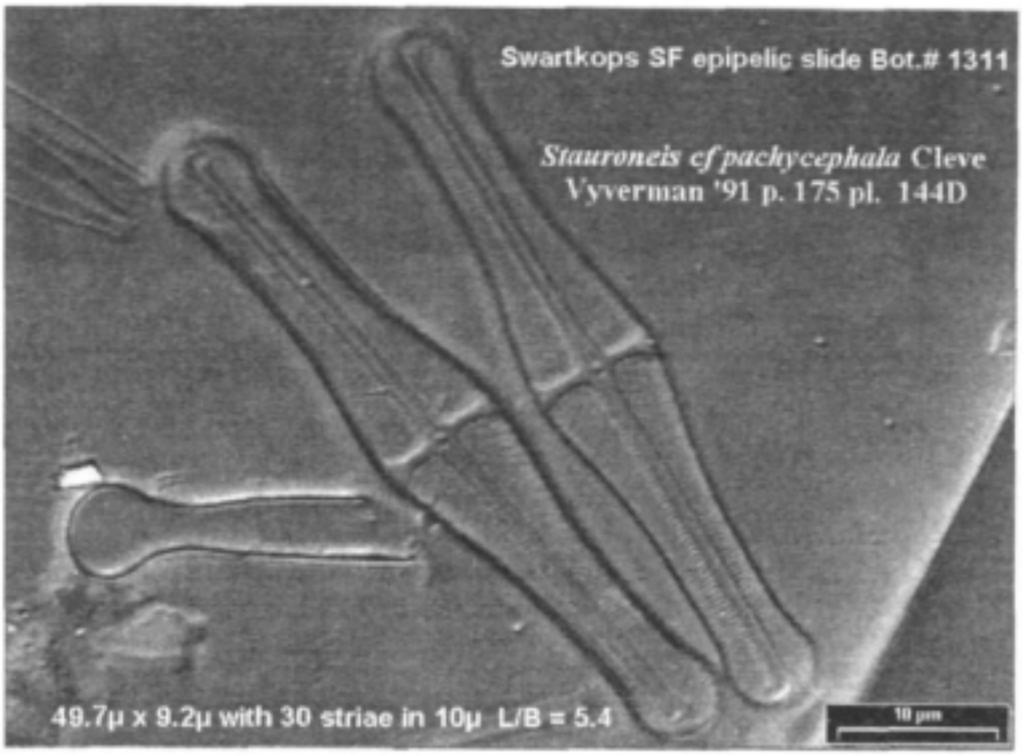
RHOPGIBA *Rhopalodia gibba* (Ehrenberg) O. Mueller



STNESP01 ***Stauroneis*** **Ehrenberg Spec 1 (West Cape).** Probably *S. crucicula* **Grunow**



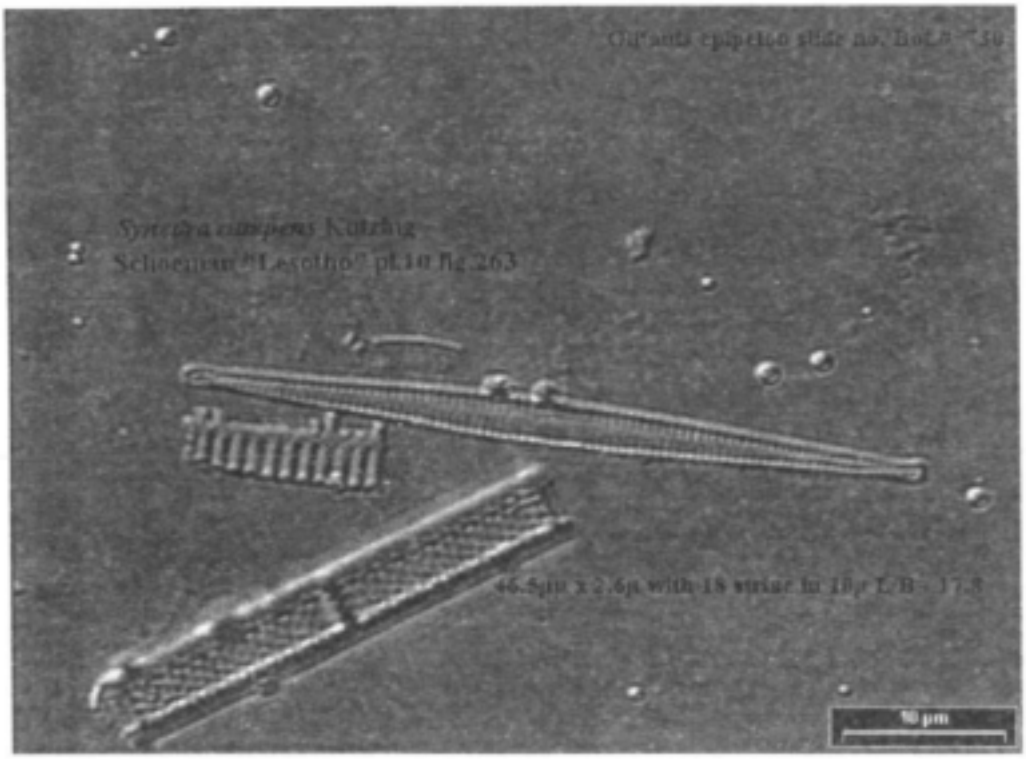
SURIBREB ***Surirella brebissonii*** **Kramer and Lange-Bertalot**



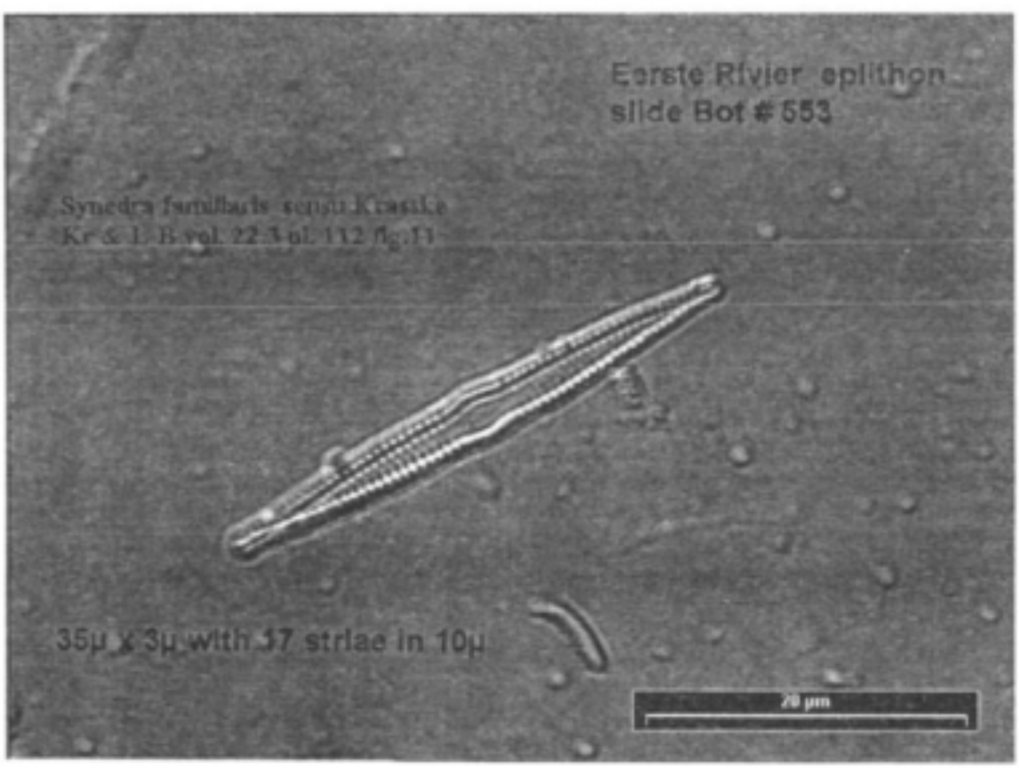
STNEPACH ***Stauroneis pachycephala*** **Cleve**

No image available

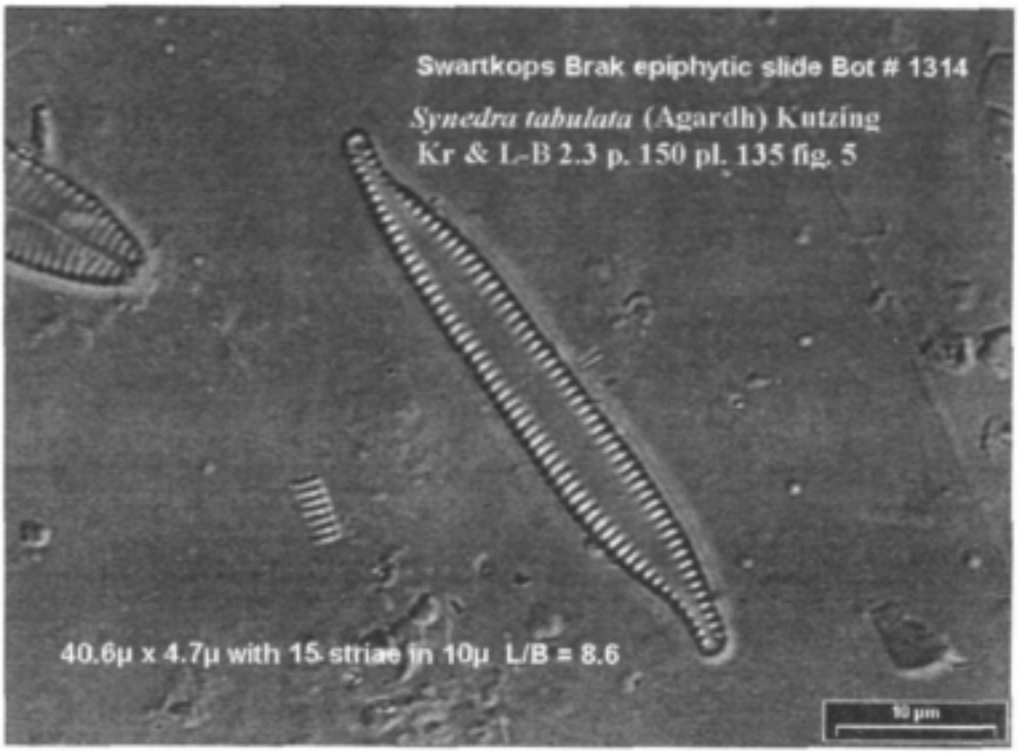
STNESPIC ***Stauroneis spicula*** **Hickie ex Grunow**



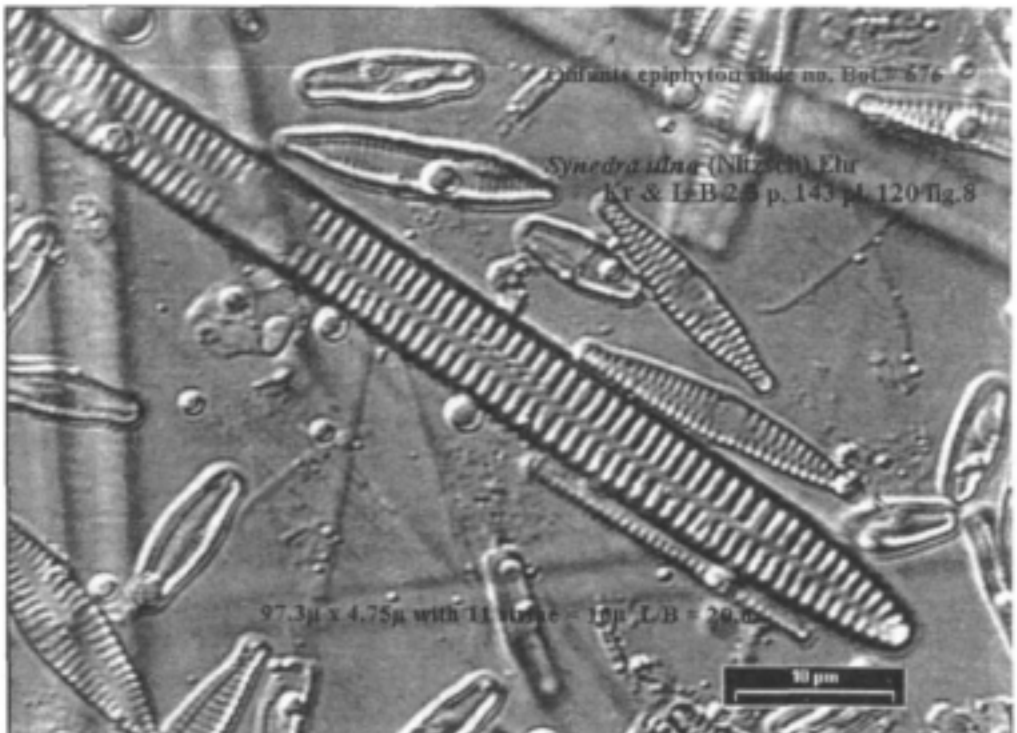
SYNEFAMI ***Synedra familiaris*** **sensu Krasske**



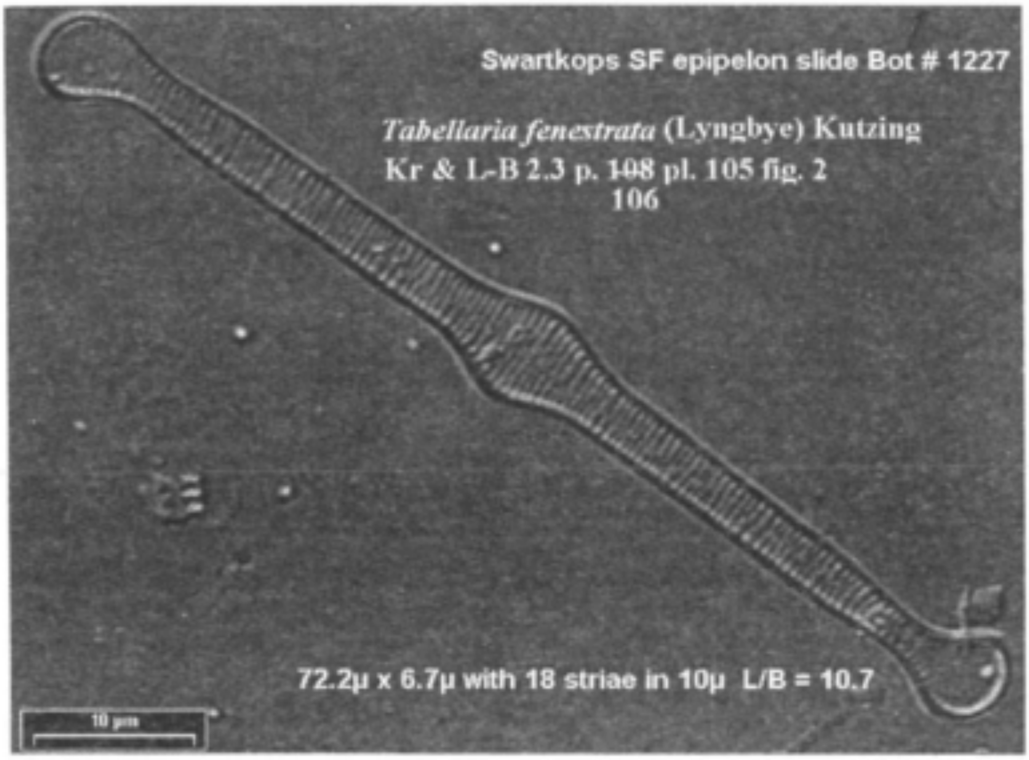
SYNERUMP ***Synedra rumpens*** **Kutzing**



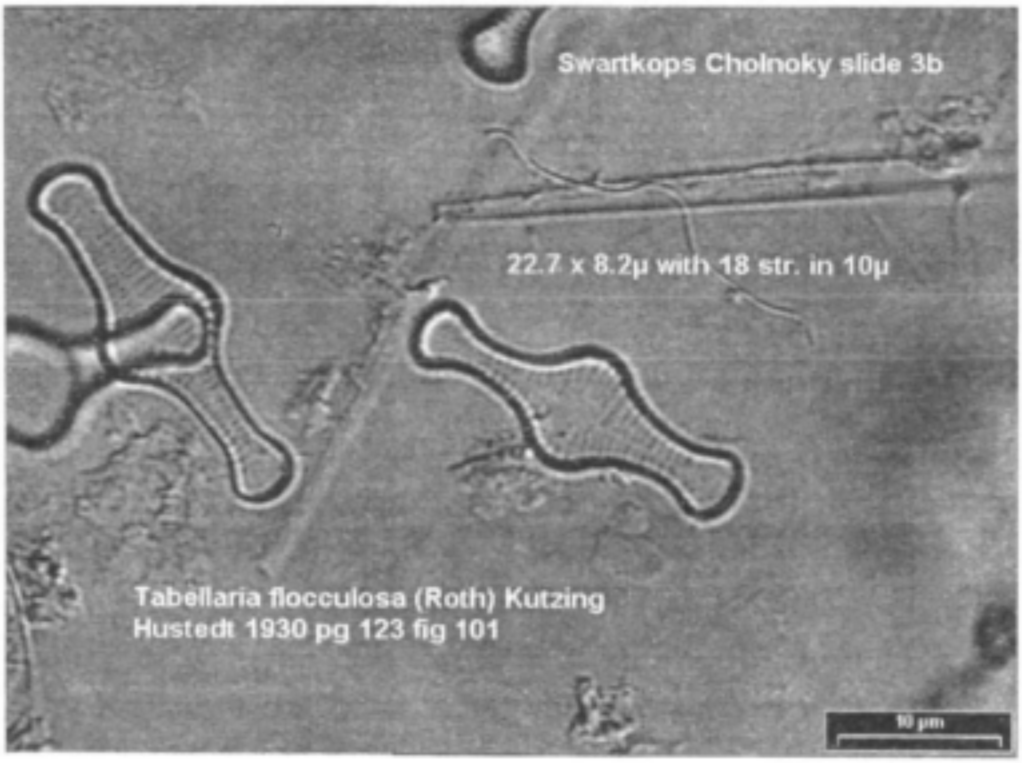
SYNETABU *Synedra tabulata* (Agardh) Kutzing



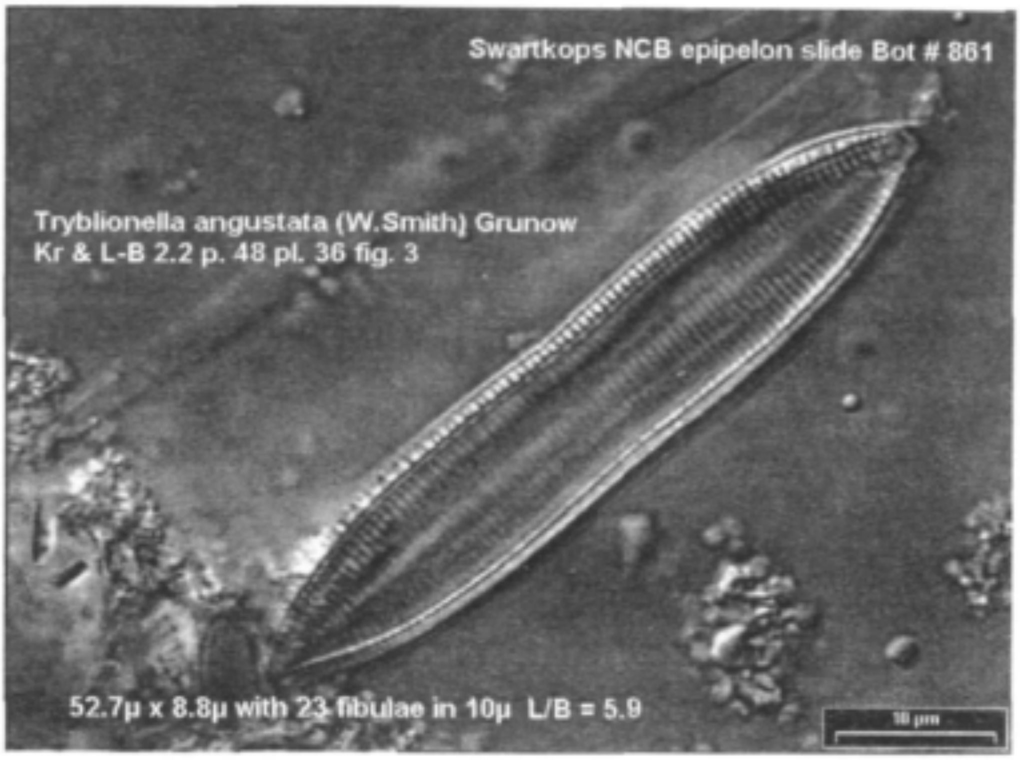
SYNEULNA *Synedra ulna* (Nitzsch) Ehrenberg



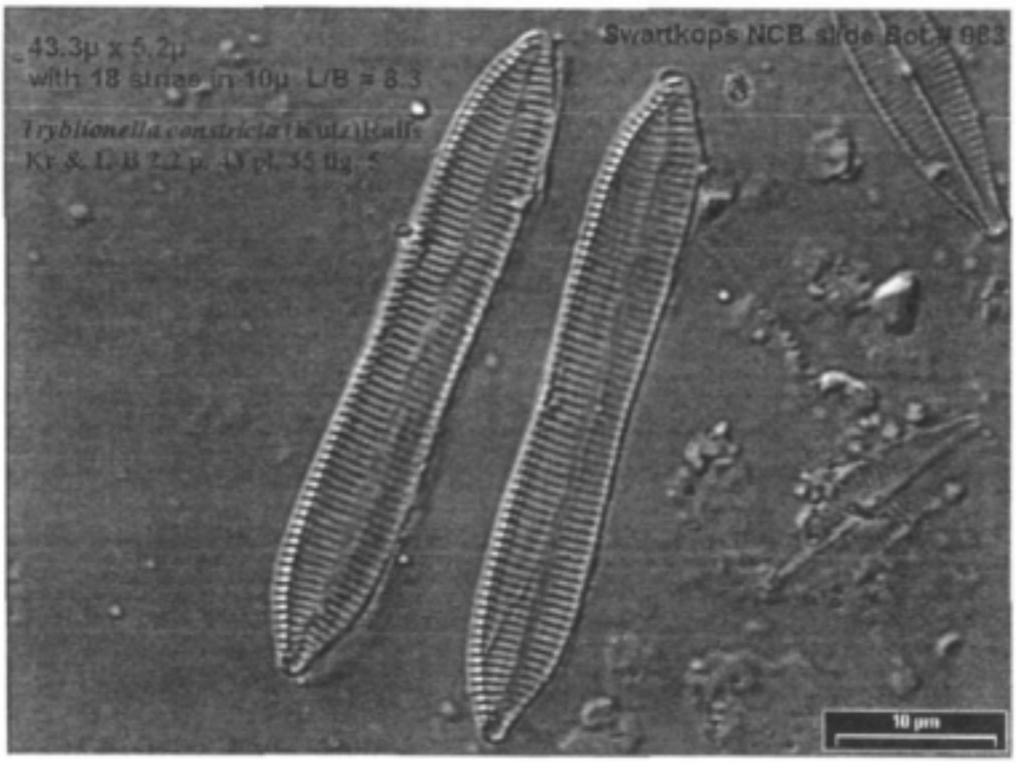
TABEFENE *Tabellaria fenestrata* (Lyngbye) Kutzing



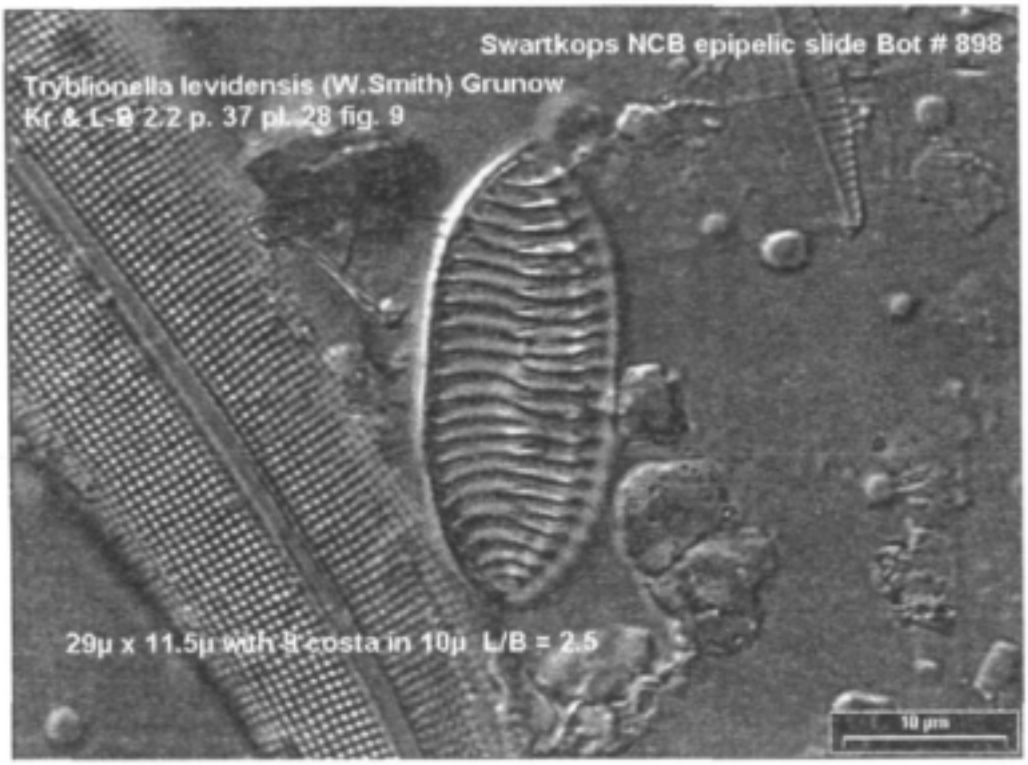
TABEFLOC *Tabellaria flocculosa* (Roth) Kutzing



TRYBANGU *Tryblionella angustata* (W.Smith) Grunow



TRYBCONS *Tryblionella constricta* (Kutzing) Ralfs



TRYBLEVI *Tryblionella levidensis* (W.Smith) Grunow

APPENDIX D

SPREADSHEET OF THE GENUS IDENTIFICATION DATABASE

(These data are contained in the MS Access database for the identification of the diatom genera. The data can be updated to suit the user and to keep up with changes in diatom taxonomy. The data relate specifically to the text "***The Diatoms***" by Round et al. 1990 – see reference at the end of the main report. The pages should be used as indicated in the following diagram. The whole database is available as MS Access in the accompanying CD – APPENDIX E).

Page 1	Page 2	Page 3	Page 4
Page 5	etc		
			Page n

GENUS	ROUN	ARAPHID	RAPHE	CIRCLE	SPOKE	LINEA	LANCEOLAT	SQUARE	ELLIPTI	PANDURIFO	RENEFOR	CRUCIFOR
Achnanthes	502	1	1			1	1			1	1	
Actinocyclus	194	1		1					1			
Amphipleura	536		1			1	1					
Amphora	600		1				1		1			
Anaulus	286	1						1				
Asterionella	350	1				1						
Asterolampra	210	1		1	1							
Attheya	340	1						1	1			
Aulacodiscus	188	1		1								
Aulacoseira	170	1		1								
Auricula	634		1									
Bacillaria	608		1			1	1					
Bacteriastrum	336	1		1	1							
Biddulphia	246	1					1		1			
Biddulphiopsis	248	1					1					
Brightwellia	182	1										
Camplyoneis	506	1	1	1								
Campylodiscus	646		1	1								
Campylosira	298	1										
Centronella	348	1										
Cerataulus	234	1		1					1			
Cerataulina	266	1		1		1						
Chaetoceros	332											
Climacosphenia	442	1										
Coscinodiscus	176	1		1								
Ctenophora	372	1				1	1					
Cylindrotheca	626		1			1						
Cyclostephanos	146	1		1								
Actinoptychus	200	1		1								
Cyclotella	144	1		1								
Cymatosira	296	1					1					
Cymatopleura	648		1			1			1	1		

OBLONG	OVATE	CUNEAT	OVAL	RECTANGL	TRIANGULA	UNDULAT	ARCUAT	COLONIA	FW	BRAK	SPINES	PLANKTON	MARIN	EPILITHI
						1	1		1		1		1	
					1							1	1	
									1					
							1		1				1	1
1	1											1	1	
								1	1			1		
												1	1	
1											1		1	
													1	
									1		1	1		
						1							1	
								1	1	1		1	1	
											1	1	1	
				1		1					1	1	1	
	1			1									1	
	1		1										1	
							1		1	1			1	
				1			1				1		1	
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							1		1			1	1	
									1			1	1	
						1							1	
									1			1	1	
				1							1	1	1	
						1			1					

EPIPSAMMI	EPIPELI	EPIPHY	H_POLAR	CAPITAT	CENTRE	STELLAT	EUTROPHI	STERNUM	ZIG_ZAG_FI	FILAMENT	RIBS	PROCESSES
											1	
	1	1									1	
	1	1		1								
	1										1	
				1		1						
											1	
1												
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										1		
	1										1	
	1			1						1	1	
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										1		
		1	1	1							1	
				1	1						1	
	1			1								
1	1									1		
	1										1	

COMMENTS	SIGMOI	SEMICIRCL	CONVEX	H_SHAPE	RAPHE_OF	RAPHE_CEN	H_VALVAR	ASYMMETRI	APICAL_P_F
					1	1			1
"H"-shaped chloroplast				1		1			
Truncate ends					1			1	
									1
Interlocking spines und									
Raphe biarcuate					1			1	
High conductivity fresh						1			
Common inshore plankt									
Fossil									
Coccineis - like						1			
Raphe raised on keel ar					1				
Processes pointing in o									
Wings support the spine									
Each valve with two lon									
A common tropical diat									
									1
Twisted in SEM						1			
Marginal chambers inte									
Inner circle, marginal c									
Heterovalvar centric.							1		1
High conductivity water					1				

GENUS	ROUN	ARAPHID	RAPHE	CIRCLE	SPOKE	LINEA	LANCEOLAT	SQUARE	ELLIPTI	PANDURIFO	RENEFOR	CRUCIFOR
Cymbella	486		1			1	1		1			
Denticula	622		1			1	1					
Diatoma	364	1					1	1	1			
Ditylum	292	1										
Ellerbeckia	168	1		1	1							
Entomoneis	632		1			1	1					
Eucampia	262	1				1			1			
Eunotogramma	288	1										
Fragillaria	346	1				1			1			
Fragilariforma	360	1				1	1		1			
Fragilariopsis	624		1			1	1		1			
Frickea	534		1			1						
Gomphoneis	498		1			1	1					
Grammatophora	436	1						1				
Guinardia	326	1		1								
Hannaea	366	1				1						
Hantzschia	610		1							1		
Hemiaulus	260	1							1			
Hemidiscus	192	1					1					
Hydrosera	250	1										
Lauderia	150	1		1								
Leptocylindrus	342	1		1		1						
Licmosphenia	404											
Lyrella	460		1			1	1		1			
Martyana	362	1							1			
Melosira	154	1		1								
Meridion	368	1										
Navicula	566		1			1	1					
Nitzschia	620		1			1	1		1	1		
Odontella	220	1					1		1			
Orthoseira	174	1		1								
Oxyneis	402	1							1	1		

OBLONG	OVATE	CUNEAT	OVAL	RECTANGL	TRIANGULA	UNDULAT	ARCUAT	COLONIA	FW	BRAK	SPINES	PLANKTON	MARIN	EPILITHI
							1	1	1					1
									1	1			1	
1									1	1		1		
				1	1						1	1	1	
									1					
						1			1	1			1	
												1	1	
				1			1						1	
								1	1		1	1		1
									1		1			
				1								1	1	
										1				
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									1			1	1	
		1						1	1					1
									1	1			1	
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											1	1	1	
									1		1			
1						1			1		1			

EPIPSAMMI	EPIPELI	EPIPHY	H_POLAR	CAPITAT	CENTRE	STELLAT	EUTROPHI	STERNUM	ZIG_ZAG_FI	FILAMENT	RIBS	PROCESSES
	1	1		1						1		
	1									1	1	
				1		1			1		1	
										1	1	
	1											
												1
1										1	1	
	1			1						1		
				1					1	1		
	1		1								1	
	1	1	1	1						1		
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		1	1	1							1	
	1			1							1	
	1			1		1				1	1	
		1								1		1
					1					1		
									1	1		

COMMENTS	SIGMOI	SEMICIRCL	CONVEX	H_SHAPE	RAPHE_OF	RAPHE_CEN	H_VALVAR	ASYMMETRI	APICAL_P_F
		1		1	1	1		1	1
					1	1			
Distinct bars									1
Central tube.									
Curved chain of large c									
Bilobed					1			1	
				1					
Assymetrical.								1	
									1
									1
Antarctica					1				1
One genus F. lewisiana						1			
USA and Russia mainly						1			1
Marine littoral spp.									1
DIC frustules paper thin									
=Cerayoneis Found in									1
Inter-tidal sand	1				1			1	
Processes link apical sp									
Sub-lanceolate.									
Brakish estuarine- Trian									1
Rib in the form of an "				1		1			
Held on stalks to sand g									1
Chains of barrels.									
Ribs. Flowing water. Fa									
Striae apically elongate						1			
Raphe strongly eccentri	1				1			1	
Compare with Biddulph									
Group of 3 to 5 dots in t									
Indicates acidic waters									1

GENUS	ROUN	ARAPHID	RAPHE	CIRCLE	SPOKE	LINEA	LANCEOLAT	SQUARE	ELLIPTI	PANDURIFO	RENEFOR	CRUCIFOR
Peronia	458	1	1			1						
Petroneis	462		1			1			1	1		
Placoneis	484		1			1	1					
Plagiogramma	238	1					1		1			
Plagiogrammopsis	300	1					1					
Plagiotropis	588		1				1					
Planktoniella	134	1		1	1							
Pleurosigma	580		1			1	1					
Pleurosira	230	1		1								
Psammodiction	612	1	1							1		
Pseudogomphonem	570		1			1	1					
Punctastriata	358	1				1	1		1			
Rhabdonema	430	1				1	1					
Rhizosolenia	318					1	1					
Rhoicosigma	580		1			1	1					
Skeletonema	140	1		1								
Stauroneis	592		1				1		1			
Staurosira	354	1							1			1
Stephanodiscus	148	1		1								
Stephanopyxis	158	1		1								
Surirella	644	1	1			1			1	1		
Tabellaria	398	1						1				1
Terpsinoe	256	1				1						
Thalassiosira	132	1		1								
Thalassionema	424	1				1						
Thalassiothrix	426	1				1						
Triceratium	218	1										
Undatella	604		1							1		
Urosolena	324					1						
Porosira	136	1		1								
Minidiscus	138	1		1								
Detonula	142	1		1	1							

OBLONG	OVATE	CUNEAT	OVAL	RECTANGL	TRIANGULA	UNDULAT	ARCUAT	COLONIA	FW	BRAK	SPINES	PLANKTON	MARIN	EPILITHI
		1							1		1			
						1							1	
									1				1	
													1	
				1							1		1	
						1				1			1	
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									1	1		1	1	
										1				
						1							1	
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						1			1		1			
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				1				1	1					
			1		1				1		1			1
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	1					1			1	1			1	
				1		1			1		1			1
						1			1	1				1
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					1					1	1		1	1
						1	1						1	
									1		1			
												1	1	
								1				1	1	
				1								1	1	

EPIPSAMMI	EPIPELI	EPIPHY	H_POLAR	CAPITAT	CENTRE	STELLAT	EUTROPHI	STERNUM	ZIG_ZAG_FI	FILAMENT	RIBS	PROCESSES
		1	1	1								
1	1			1	1					1		
	1			1	1							
1	1										1	
1	1			1						1	1	1
	1											
	1			1	1							
									1	1		1
1	1											
		1	1		1						1	
			1							1	1	
		1							1	1	1	
										1		
1	1											
										1		1
	1			1	1					1	1	
	1			1					1	1		
										1		1
	1		1								1	
		1		1		1			1			
				1					1	1	1	
						1						
			1			1						
		1										1
	1											
										1		
					1					1		1

COMMENTS_	SIGMOI	SEMICIRCL	CONVEX	H_SHAPE	RAPHE_OF	RAPHE_CEN	H_VALVAR	ASYMMETRI	APICAL_P_F
Short margilal spines						1			
Faintly panduriform or						1			
Naviculoid						1			
Obvious 'holes' middle									1
Single internal rib in ce							1		
Looks a very difficult g						1			
What appears to be a wi									
If fresh water then high	1					1			
Two marginal oscelli - z									
Raphe not obvious. Loo					1				
Mainly polar seas						1			
Raised ribs									
									1
Single spine is the clue								1	
Probably Rhoicosigma.	1					1			
						1			
External ring of spines -									
Chain of round balls co									
Very heavy ribs give it a					1				
									1
Strongly triundulate - zi									1
Centre thread under LM									
Stellate colonies									
Very long cells.									
					1			1	
Valves conical with lon									
Like watch-glasses. Lik									
Very small. Usually < 1									
Central fultoportula. Fo									

GENUS	ROUN	ARAPHID	RAPHE	CIRCLE	SPOKE	LINEA	LANCEOLAT	SQUARE	ELLIPTI	PANDURIFO	RENEFOR	CRUCIFOR
Chrysanthemodiscu	152	1		1					1			
Druridgia	156	1							1			
Endictya	160	1		1								
Hyalodiscus	162	1		1								
Podosira	164	1		1								
Paralia	166	1		1								
Palmeria	178	1										
Stellarima	180	1		1								
Gossleriella	190	1		1	1							
Azpetia	196	1		1								
Roperia	198	1		1								
Ethmodiscus	206	1		1								
Strictocyclus	208	1		1	1							
Asteromphalus	212	1		1	1							
Arachnoidiscus	214	1		1	1							
Sheshukovia	224	1						1				
Eupodiscus	228	1		1								
Amphitetras	232	1						1				
Auliscus	236	1		1								
Glyphodesmis	240	1					1		1			
Dimerogramma	242	1				1	1					
Dimeregrammopsis	244	1					1					
Isthmia	252	1							1			
Trigonium	254	1						1				
Pseudotriceratum	258	1										
Climacodium	264	1										
Bellerochea	280	1										
Subsilicea	282	1				1			1			
Streptotheca	284	1				1			1			
Lithodesmium	290	1										
Corethron	294	1		1		1						
Brockmanniella	302	1				1	1		1			

OBLONG	OVATE	CUNEAT	OVAL	RECTANGL	TRIANGULA	UNDULAT	ARCUAT	COLONIA	FW	BRAK	SPINES	PLANKTON	MARIN	EPILITHI
													1	
			1											
													1	
													1	
													1	
												1	1	
												1	1	
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				1	1							1	1	
											1	1	1	
			1	1		1					1	1	1	

EPIPSAMMI	EPIPELI	EPIPHY	H_POLAR	CAPITAT	CENTRE	STELLAT	EUTROPHI	STERNUM	ZIG_ZAG_FI	FILAMENT	RIBS	PROCESSES
		1			1							
1	1											
	1											
	1	1			1					1		
		1										
	1				1					1		1
					1							
		1			1						1	
					1							
		1			1						1	
		1			1				1		1	1
	1	1										1
		1			1				1			1
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	1				1							1
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		1	1									
		1							1			1
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	1									1	1	
					1					1		
					1					1		
										1		
	1				1					1		

COMMENTS_	SIGMOI	SEMICIRCL	CONVEX	H_SHAPE	RAPHE_OF	RAPHE_CEN	H_VALVAR	ASYMMETRI	APICAL_P_F
Cells in pairs.									
Shaped like a watch gla			1						
Cells spherical or sub-s			1						
		1							
Not Coscinodiscus.			1						
Not Coscinodiscus.									
Only 1 genus. R. tessell									
Very easily broken. Ver									
Looks like a petri dish.									
Odd-shaped.									
									1
	1								1
Only one genus D. furci									1
				1					
Common in Antarctica									
									1

GENUS	ROUN	ARAPHID	RAPHE	CIRCLE	SPOKE	LINEA	LANCEOLAT	SQUARE	ELLIPTI	PANDURIFO	RENEFOR	CRUCIFOR
Minutocellus	304	1					1		1			
Leyonella	306	1					1		1			
Arcocellus	308	1				1						
Papilliocellus	310	1					1		1			
Extubocellus	312	1		1								
Proboscia	320	1				1						
Pseudosolena	322	1				1						
Urosolena	324	1				1						
Dactyliosolen	328	1		1								
Gonioceros	334	1					1		1			
Acanthoceros	338	1				1						
Trachysphenia	384	1					1					
Thalassioneis	386	1				1						
Falcula	388	1				1						
Sceptroneis	416	1				1						
Psammodiscus	418	1		1					1			
Ardissonia	420	1				1						
Toxarium	422	1				1						
Microtabella	434	1						1				
Eunotia	452		1									
Actinella	454		1			1						
Semiorbis	456		1									
Gomphocymbella	492		1				1					
Parlibellus	516		1			1	1					
Climaconeis	520		1			1	1					
Cosmoneis	526		1				1		1			
Frickea	534		1			1						
Toxonidea	582		1				1					
Donkinia	584		1			1	1					
Catenula	598		1									
Thalassiophysa	606		1							1		
Trybionella	614		1			1			1	1		

OBLONG	OVATE	CUNEAT	OVAL	RECTANGL	TRIANGULA	UNDULAT	ARCUAT	COLONIA	FW	BRAK	SPINES	PLANKTON	MARIN	EPILITHI
											1	1	1	
							1				1		1	
			1	1		1	1				1	1	1	
				1								1	1	
			1	1									1	
												1		
											1	1	1	
									1		1	11		
							1					1	1	
				1				1			1	1	1	
				1							1	1		
				1									1	
						1								
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						1	1						1	
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				1			1	1				11	1	
						1								
						1			1	1			1	

EPIPSAMMI	EPIPELI	EPIPHY	H_POLAR	CAPITAT	CENTRE	STELLAT	EUTROPHI	STERNUM	ZIG_ZAG_FI	FILAMENT	RIBS	PROCESSES
	1									1		
	1			1						1		
										1	1	
										1		
										1	1	
										1		
		1	1									
				1								
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		1	1	1								
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		1			1							
	1			1							1	
				1	1							
	1			1								
	1											
	1									1		
											1	
	1										1	

COMMENTS_	SIGMOI	SEMICIRCL	CONVEX	H_SHAPE	RAPHE_OF	RAPHE_CEN	H_VALVAR	ASYMMETRI	APICAL_P_F
			1				1		1
			1						
Very small < 4um.									1
Surf-zone diatom									
									1
Antarctica									1
Epizoic									1
									1
Not Coscinodiscus									
(Long - up to 0.75 mm)									
Long - up to 1 mm long									
Elongate									1
Oligotrophic water					1			1	
Very acid humic water					1			1	
Mountain habitats					1				
					1	1		1	
						1			
						1			
Calcareous water						1			
Only 1 species - F. lewi						1			
Raphe bi-arcuate		1			1			1	
Raphe sigmoid	1				1				
		1			1			1	
Raphe bi-arcuate					1			1	
High conductivity water					1				

GENUS	ROUN	ARAPHID	RAPHE	CIRCLE	SPOKE	LINEA	LANCEOLAT	SQUARE	ELLIPTI	PANDURIFO	RENEFOR	CRUCIFOR
Cymbellonitzschia	616		1									
Raphalodia	630		1			1						
Hydrosilicon	636		1			1			1	1		
Petrodictyon	638		1						1			
Plagiodiscus	640		1								1	
Stenopterobia	642		1			1						
Cuneolus	474		1				1					
Gomphonemopsis	478		1			1	1					
Anomoeneis	480		1				1					
Staurophora	482		1			1	1					
Synedrosphenia	444											
Asterionelliopsis	392	1										
Brachysira	540		1			1	1					
Cocconeis	504	1	1	1					1			
Craticula	594		1				1					
Delphineis	410	1							1			
Diploneis	562		1			1			1	1		
Frustulia	538		1			1	1					
Gomphonema	494		1									
Gyrosigma	586		1			1	1					
Haslea	576		1				1					
Licmorphora	404											
Mastogloia	466		1			1			1			
Neidium	542		1			1	1					
Opephora	382							1				
Phaeodactylum	560		1			1			1			
Pinnularia	556		1			1	1		1			
Pseudostaurosira	356	1				1			1			1
Rhaphoneis	406	1				1						
Rhoicosphenia	470		1			1	1					
Sellaphora	552		1			1	1		1			
Staurosirella	352	1				1		1	1			1

OBLONG	OVATE	CUNEAT	OVAL	RECTANGL	TRIANGULA	UNDULAT	ARCUAT	COLONIA	FW	BRAK	SPINES	PLANKTON	MARIN	EPILITHI
				1			1		1	1				
						1	1		1	1			1	
						1							1	
			1			1				1			1	
						1							1	
						1			1					
		1											1	
													1	
									1					
										1			1	
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EPIPSAMMI	EPIPELI	EPIPHY	H_POLAR	CAPITAT	CENTRE	STELLAT	EUTROPHI	STERNUM	ZIG_ZAG_FI	FILAMENT	RIBS	PROCESSES
										1	1	
	1	1		1							1	
	1										1	
	1		1								1	
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		1	1					1			1	
	1			1	1			1			1	
1	1							1	1	1		

COMMENTS_	SIGMOI	SEMICIRCL	CONVEX	H_SHAPE	RAPHE_OF	RAPHE_CEN	H_VALVAR	ASYMMETRI	APICAL_P_F
		1			1				
					1			1	
					11				
					1				
					1				
Acid oligotrophic lakes	1				1				
Raphe slits unequal in l						1			
						1			
High conductivity water						1			
						1			
									1
Oligotrophic lakes & bo						1			
Heterovalvar.						1	1		
Naviculoid.						1			
Two small pores at the									
Recognised by longitud						1			
H-shaped plastid.				1		1			
						1			
Striae at right angles	1					1			
Valves with acute poles						1			
Fan-shaped.									
Thickened ribs on edge.						1			
						1			
Stellate colonies.									1
Only P.tricornutum						1			
					1	1			
									1
									1
Curved fan shape						1			
H-shaped chloroplast.				1		1			
									1

GENUS	ROUN	ARAPHID	RAPHE	CIRCLE	SPOKE	LINEA	LANCEOLAT	SQUARE	ELLIPTI	PANDURIFO	RENEFOR	CRUCIFOR
Striatella	432	1					1					
Synedra	370	1				1						
Tabularia	376	1				1	1					
Tetracyclus	400	1							1			
Neosynedra	374	1				1						
Catacombas	378	1				1						
Hyalosynedra	380	1				1						
Pteroncola	390	1				1		1	1			
Bleakeleya	394	1				1						
Podocystis	396	1										
Diplomenora	408	1		1					1			
Neodelphenis	412	1				1	1		1			
Perissonoe	414	1						1				
Trichotoxon	428	1				1						
Cyclophora	439	1				1		1				
Gephyria	440	1				1						
Pseudohimantium	446	1										
Aneumastis	464		1				1		1			
Dictyoneis	468		1							1		
Campylopyxis	472		1			1	1					
Brebissonia	488		1				1					
Encyonema	490		1									
Didymosphenia	496		1									
Reimeria	500		1			1	1					
Anorthoneis	510	1	1	1					1			
Acanthidium	512	1	1			1	1		1			
Psammothidium	512	1	1			1	1		1			
Eucocconeis	514	1	1	1		1	1		1			
Berkeleya	518		1			1	1		1			
Stenoneis	522		1			1						
Cavinula	524		1			1	1		1			
Scolioneis	528		1			1	1					

OBLONG	OVATE	CUNEAT	OVAL	RECTANGL	TRIANGULA	UNDULAT	ARCUAT	COLONIA	FW	BRAK	SPINES	PLANKTON	MARIN	EPILITHI
				1									1	
						1		1	1			1		
				1			1	1	1	1			1	1
						1			1					
						1							1	
													1	
													1	
								1					1	
						1		1			1	1	1	
	1	1											1	
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								1			1	1	1	
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									1					
										1	1			

EPIPSAMMI	EPIPELI	EPIPHY	H_POLAR	CAPITAT	CENTRE	STELLAT	EUTROPHI	STERNUM	ZIG_ZAG_FI	FILAMENT	RIBS	PROCESSES
		1						1				
		1		1				1			1	
		1		1				1			1	
	1	1		1				1	1		1	
		1		1				1				
		1						1				
		1		1				1				
		1						1	1			
		1	1	1				1				
		1	1					1			1	
1								1				
				1				1	1		1	
				1		1		1				
								1				
				1	1			1				
		1						1				
								1				
	1			1	1			1				
	1							1				
		1			1			1				
	1							1			1	
		1						1			1	
		1	1	1				1			1	
	1							1			1	
1	1							1				
	1			1				1		1	1	
	1			1				1		1		
					1			1				
		1		1				1				
	1							1				
	1							1			1	
	1							1				

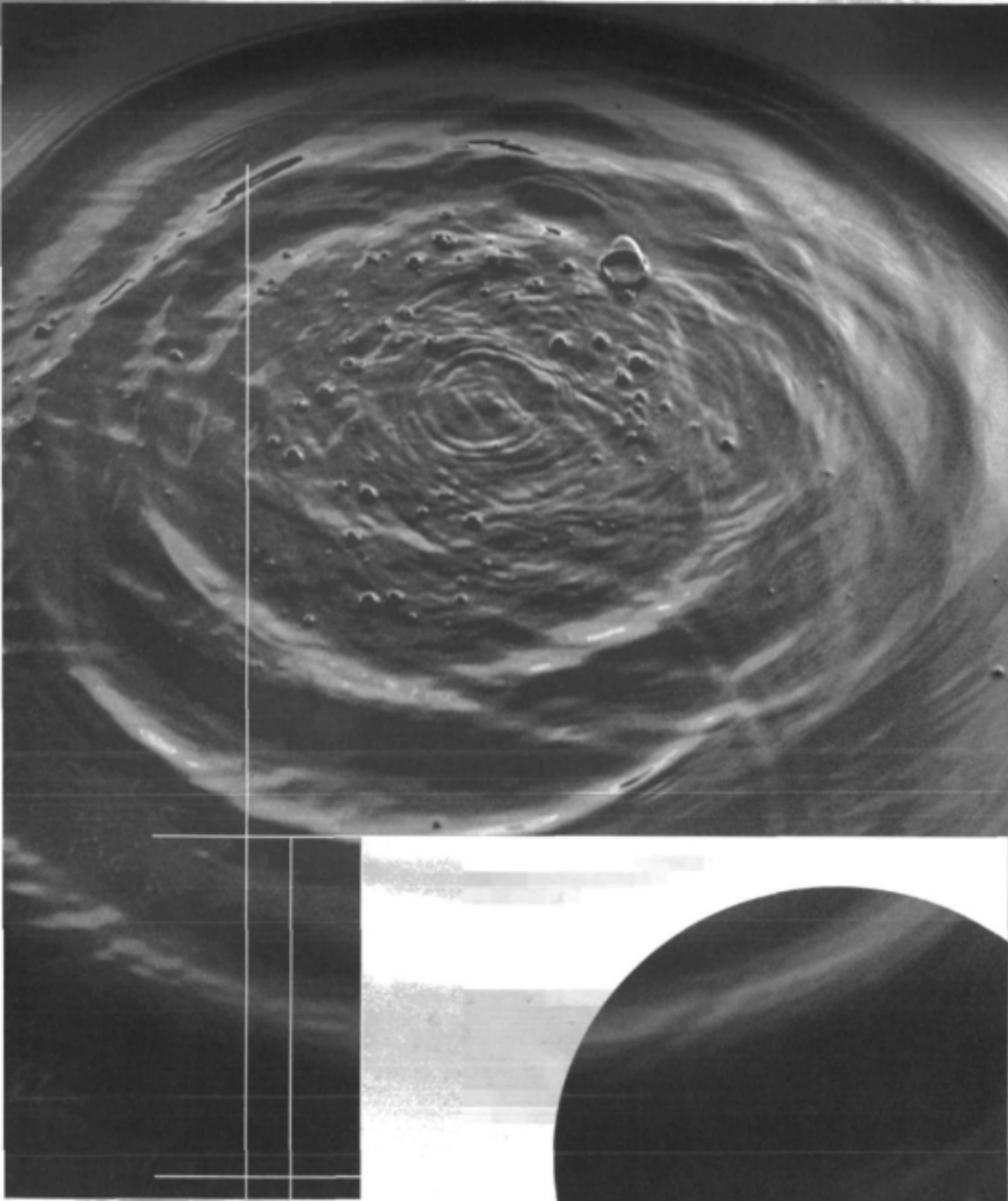
COMMENTS	SIGMOI	SEMICIRCL	CONVEX	H_SHAPE	RAPHE_OF	RAPHE_CEN	H_VALVAR	ASYMMETRI	APICAL_P_F
Looks like a raphe but it									1
Needle-like									1
Only FW!									1
Low pH									
									1
									1
									1
Sternum in TEM only									1
									1
									1
Coastal waters									
Crossed sternum									
Wide sternum									
Cup-like internal thicke							1		1
									1
Epizoic on copipods		1						1	
Raphe fissure sinuous						1			
						1			
						1			
Apical pore plate						1			1
Raphe sinuous		1			1			1	
						1			1
Raphe sinuous						1		1	1
					1				
Heterovalvar						1	1		
Heterovalvar						1	1		
Oligotrophic water						1	1		
Raphe slits short						1			
One species						1			
H-shaped plastids				1		1			
H-shaped plastids	1			1		1			

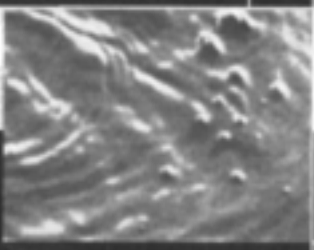
GENUS	ROUN	ARAPHID	RAPHE	CIRCLE	SPOKE	LINEA	LANCEOLAT	SQUARE	ELLIPTI	PANDURIFO	RENEFOR	CRUCIFOR
Diadesmis	530		1			1	1					
Luticola	532		1			1	1		1			
Scoliopleura	544		1			1			1			
Scoliotropis	546		1			1						
Biremis	548		1			1						
Progonia	550		1							1		
Fallacia	554		1			1	1		1			
Diatomella	558		1			1			1			
Trachyneis	568		1			1			1			
Seminavis	572		1									
Rhoikoneis	574		1			1			1			
Cymatoneis	578		1			1	1		1			
Stauropsis	590		1				1	1				
Proshkinia	596		1			1	1					
Gomphotheca	618		1			1						
Epithemia	628		1			1			1			
Gomphoseptatum	476		1			1	1					

OBLONG	OVATE	CUNEAT	OVAL	RECTANGL	TRIANGULA	UNDULAT	ARCUAT	COLONIA	FW	BRAK	SPINES	PLANKTON	MARIN	EPILITHI
						1	1	1	1		1			
									1	1	1			
										1				
										1				
													1	
						1							1	
									1				1	
				1				1	1					
													1	
							1						1	
						1							1	
				1								1	1	
												1	1	
						1		1		1			1	
						1	1		1					
													1	

EPIPSAMMI	EPIPELI	EPIPHY	H_POLAR	CAPITAT	CENTRE	STELLAT	EUTROPHI	STERNUM	ZIG_ZAG_FI	FILAMENT	RIBS	PROCESSES
				1				1		1		
	1			1				1		1		
	1							1				
	1							1				
	1							1				
								1			1	
	1							1			1	
								1	1			
1	1				1			1				
	1	1						1			1	
		1			1			1			1	
	1							1			1	
					1			1				
	1			1	1			1			1	
	1							1			1	
	1	1		1				1			1	
		1	1		1			1				

COMMENTS	SIGMOI	SEMICIRCL	CONVEX	H_SHAPE	RAPHE_OF	RAPHE_CEN	H_VALVAR	ASYMMETRI	APICAL_P_F
Damp sites						1			
						1			
Frustule twisted					1	1			
Frustule twisted	1				1	1			
					1	1			
Sternum broad						1			
H-plastids				1		1			
Mountain streams						1			
Sides of the raphe stern						1			
		1			1			1	
						1			
Open lattice structure						1			
Frustule delicate					1	1			
						1			
Very long					1	1		1	
Base-rich habitats					1			1	
						1			1





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